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COMMERCIAL TREE CROPS FOR PHOSPHATE MINED LANDS

FINAL REPORT

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COMMERCIAL TREE CROPS FOR PHOSPHATE MINED LANDS

FINAL REPORT

2001-2005

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PERSPECTIVE

A recurring question is, "Are clay settling areas wastelands or can they be put to some good use (either economic or ecological)?" Much FIPR research has been done in the past on developing techniques for growing commercial agronomic and horticultural crops on clay settling areas (CSAs). This project was aimed at forest crop production. The report provides information related to the technical and economic feasibility but also gives observations on additional ecological benefits from tree crop production with regard to cogongrass control and soil development.

The University of Florida has completed a five-year project to examine commercial production of cypress, cottonwood, eucalyptus, and slash pine hybrids on CSAs. Goals of the project were to: (1) identify and evaluate superior tree genotypes for CSAs; (2) develop appropriate management practices for commercial tree crops for energy, mulch, pulp and/or lumber; (3) document the productivity of superior genotypes; and (4) estimate their economic value. Greatest success was with eucalyptus, which was highly productive on a clay settling area. The shade of the eucalyptus tree canopy effectively suppressed cogongrass, and some native plant species were observed to become established. In addition, the eucalyptus trees had a very positive effect on soil development: increased organic carbon concentration and improved tilth (improved structure and friability). Harvest of the eucalyptus was hampered by damage from three hurricanes in the summer of 2004, followed by an unusually wet winter and spring, which hindered the operation of harvesting equipment on the clay. Poor weed control resulted in excessive competition from cogongrass, particularly during the early stages of establishment, that reduced the survival and production of cypress and cottonwood, clouding the picture of true yield potential of these species.

For additional information on potential uses of CSAs, the reader is referred to the following two publications. A wide array of agricultural and horticultural crops were grown on CSAs, including ornamental trees.

- *Polk County Mined Lands Research and Demonstration Project*. FIPR Publication No. 03-088-107.

- *The Mined Lands Agricultural Research Project: Summary of Experiments and Extension Recommendations*. FIPR Publication No. 03-093-128.

A project to be completed in 2008 examines the development of wetlands on CSAs and their possible use as mitigation wetlands.

- *Wetlands on Clay Settling Areas*. FIPR Project 03-03-149.

Steven G. Richardson
Reclamation Research Director

ABSTRACT

To further commercial forestry on underutilized phosphate mined lands in central Florida, our five-year Short Rotation Woody Crops (SRWC) project initially assessed genotypes, management practices, productivities, and/or economic potential for cypress (*Taxodium distichum*), cottonwood (*Populus deltoides*), and slash pine (*Pinus elliottii*) on clay settling areas (CSA) and overburden sites and then expanded these assessments to include the non-invasive eucalypts *Eucalyptus grandis* and *E. amplifolia*. In 15 field studies and/or commercial-scale plantings, cypress showed promise with intensive culture, slash pine performance was less than expected, and cottonwood grew well in the absence of cogongrass (*Imperata cylindrica*) but was not as productive as *E. grandis* and *E. amplifolia*. SRWCs on CSAs require herbiciding/disking, bedding, watering/packing seedlings, fertilization, high planting density, superior trees, and winter harvesting so that coppice regeneration suppresses weeds. Assuming high site preparation and planting costs (\$728 and \$486 acre^{-1}, respectively), double row growth (14.2 dry tons acre^{-1} yr^{-1}), a reasonable stumpage price (\$18.20 dry ton^{-1}), and discount rates of 10% and 4%, production of *E. amplifolia* on CSAs is profitable, with land expectation values (LEV) of \$308 and \$2,633 acre^{-1}, respectively. With a carbon sequestration benefit of \$4.55 ton^{-1}, LEVs increased to \$383 and \$2,718 acre^{-1}, respectively, while the CO_2 mitigation benefits associated with biofuels increased LEVs to \$532 and \$3,185 acre^{-1}, respectively. In addition, below-ground carbon sequestration (roots + soil organic carbon) is likely to be \$437-475 acre^{-1} or \$330-364 acre^{-1}, assuming discount rates of 4% and 7%, respectively. When land is already owned and SRWC production involves only establishment and management costs, the internal rates of return, the actual return on invested capital, are estimated to range from 4 to 32%; at a likely stumpage price of \$10/green ton or higher, rates of return on investment could exceed 12%. *E. grandis* SRWCS on CSAs are at risk of blowdown near harvest age of three to four years. SRWC cost competitiveness depends on establishment success, yield improvements, harvesting costs, markets, and incentives; public and private partnering is necessary for commercializing SRWCs on ~123,000 acres of reclaimed phosphate mined lands. *E. grandis* and *E. amplifolia* SRWCs appear to improve CSA soil characteristics, exclude cogongrass, and facilitate the establishment of native plants, and *E. grandis*- and cottonwood-dominated portions of one CSA had much more favorable soil than cogongrass-dominated areas, as, e.g., ten- and four-fold increases in soil nitrogen and carbon, respectively, were noted in the *E. grandis* commercial planting. SRWCs may serve as “bridge crops” to restore cogongrass infested CSAs to native forest or productive agricultural lands while maintaining or even augmenting forestry’s current \$685 million annual value and 6,800 jobs in Polk County. These results also emphasize both the potential for SRWCs on CSAs to mitigate atmospheric CO_2 and for CO_2 mitigation incentives to contribute to SRWC profitability.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (CONT.)

Figure **Page**

LIST OF TABLES

Table **Page**

LIST OF TABLES (CONT.)

Table **Page**

LIST OF TABLES (CONT.)

Table **Page**

LIST OF TABLES (CONT.)

Table **Page**

EXECUTIVE SUMMARY

To support development of Short Rotation Woody Crops (SRWC) on underutilized reclaimed phosphate mined lands in central Florida, our five-year project initially identified, developed, and/or documented (1) superior cypress (*Taxodium distichum*), cottonwood (*Populus deltoides*), and slash pine (*Pinus elliottii*) genotypes; (2) appropriate management practices for these SRWCs; (3) their productivities; and (4) their economic value on clay settling areas (CSA) and overburden sites. Project activities through 2005 included establishment, maintenance, and measurement of 15 field studies involving more than 20,000 trees (primarily at the 125 acre Kent CSA near Lakeland), selection and propagation of over 300 genotypes, and establishment of seed orchards and a clonal nursery to produce commercial planting stock. Supplemental studies in commercial-scale plantings of over 250,000 trees provided "real-world" estimates of productivity, management, and costs. Cypress showed promise with intensive culture, slash pine performance was less than expected, and cottonwood grew well in the absence of cogongrass (*Imperata cylindrica*) but was not as productive as the non-native but non-invasive eucalypts *Eucalyptus grandis* and *E. amplifolia*.

To apply, extend, and demonstrate Kent results through 2004, a two-acre species-culture study (SRWC-107) was installed on a rolling, sandy at the top, clayey at the bottom, previously cogongrass infested CSA at the IMC Agrico Peace River Park (PRP) at Homeland, FL, in the first half of 2005. In SRWC-107, superior genotypes of cottonwood, slash pine, cypress, *E. amplifolia*, and *E. grandis* were planted in paired rows 2.6' apart) separated by up to 9.8' from adjacent pairs within five treatments: (1) herbicide, (2) mulch, (3) interplanted native trees, (4) interplanted native shrubs, and (5) a control. This study, which, after one year, demonstrated cottonwood productivity and mulching effectiveness, further documents SRWC potential for restoring mined lands by improving soil conditions, controlling invasive species, sequestering carbon, and providing a transition to native species.

Overall, our cypress research (1) assessed genotypes for phosphate mined lands; (2) established seed orchards; (3) defined management practices; and (4) estimated yield of commercial plantations. Genetic improvement can increase productivity when genetically inferior trees, based on progeny performance, are rogued from the orchard and all trees are flowering. Silvicultural enhancements, notably good site preparation, vegetation control, and amendments, on good quality sites are essential. Bedding of CSAs is necessary for successful establishment and initial weed control, and watering at planting is critical in dry planting seasons. On overburden sites, ripping alone did not result in suitable survival and rapid early growth. Planting of bareroot seedlings should be completed before March. Post planting weed control for at least the first growing season is helpful. Cypress was up to 17.1' tall in four years, and after 90 months, averaged 26.6' in height and 5.4" in DBH. Three cypress plantations grew rapidly for the first five years but averaged only ~$60 ft^3 acre^{-1} yr^{-1}$ through 15 years. Collective results suggest potential for commercial cypress plantations using genetically superior bareroot or containerized seedlings.

Our cottonwood research (1) identified productive clones; (2) established clonal nurseries; (3) evaluated management practices; and (4) estimated yield and market potential. Several commercially available clones are not suitable for CSAs and survived poorly at the Kent CSA compared to *E. amplifolia* and *E. grandis*. Height of surviving cottonwood exceeded 8.2' in less than five months. In general, because of cogongrass resurgence, cottonwood coppicing appears less reliable and vigorous than *E. amplifolia* coppicing, which is also better than that of *E. grandis*. In SRWC-107, cottonwood grew much better although survival was affected by dry post-planting conditions; tree size was moderately influenced by cultural treatment as average 11-month heights ranged from 9.2 to 13.4'. Hurricane resistance of cottonwood was evidenced as 3- to 4-year-old trees at Kent suffered minimal damage while similar aged and older *E. grandis* incurred major stem breakage and blowdown and as 10-month-old cottonwood in SRWC-107 were undamaged while younger *E. amplifolia* and *E. grandis* suffered minor twisting and lodging. Management guidelines are thorough site preparation through herbiciding, chopping\disking, and bedding by the end of December, planting and immediate watering and packing of fresh unrooted cuttings of tested superior clones at close spacing (~2,000 trees $acre^{-1}$) from January through February, and post-planting weed control. Cottonwood harvesting appears best done in the winter by the end of February, so that coppice regeneration suppresses weeds. Cottonwood currently has no commercial value in central Florida but may be profitable for energywood or other biofuels.

Our slash pine research (1) evaluated taxa and genotypes and (2) developed recommendations for use of the best taxa. Taxa differences were minor on overburden but large when containerized trees were planted on difficult CSAs. Tree growth on overburden was impacted by the compacted soil, and on CSAs, weed competition greatly reduced survival and growth. After nearly 4 years on the overburden site at Bowling Green, F_1 and F_2 hybrids were significantly taller than local taxa. On unmined flatwoods at Avon Park, taxa differences were not evident after one year. slash pine management guidelines for site preparation and establishment on CSAs are like those of cottonwood: thorough site preparation by herbiciding, chopping\disking, and bedding by the end of November, planting bareroot seedlings of the best progenies by March at close spacing using mechanical planters that apply water and pack simultaneously, post-planting weed control for at least the first two years.

While *E. grandis* and *E. amplifolia* growth potential on CSAs is quite high, SRWC cost competitiveness will depend on establishment success, yield improvements, harvesting details, and perhaps incentives (tax, mining reclamation, etc.). *E. amplifolia* can have high survival on well prepared, bedded CSAs, respond to fertilization, tolerate high stand densities, and coppice reliably.

E. grandis has the potential to be the most productive species with thorough site preparation and fertilization and properly timed harvesting. *E. grandis* is best suited for immediate commercialization because of its ample availability of seed, while seed of *E. amplifolia* is limited. *E. grandis* yields in commercial plantings on CSAs could be as low as 20 to as high as 32 green tons/acre/year. *E. grandis* SRWCS on CSAs are at risk of hurricane blowdown three to four years after planting; younger cottonwood, *E. grandis*, and *E. amplifolia* SRWCs appear much less susceptible to wind damage. Strong collaboration among public and private partners is essential for commercializing SRWCs.

Intensive site preparation and dense plantations with rapid early growth and canopy closure are necessary to control cogongrass and enhance secondary succession. *E. grandis*, *E. amplifolia*, and cottonwood all coppice, which insures rapid canopy regrowth after harvest. Eucalypts, however, are apparently superior to cottonwood in suppressing cogongrass. Though cottonwood forms dense canopy as early as *E. grandis* and *E. amplifolia*, its deciduous nature may allow cogongrass to reinvade the understory.

The most likely SRWC products on CSAs are (1) mulchwood, an existing multimillion dollar market in Polk County annually, (2) energywood for electricity generation, a prospective market with much potential for expansion if renewable energy incentives develop, and (3) biofuels. Mulchwood stumpage prices, annual production, and land requirement estimates range from \$11-14 green ton^{-1}, 25,000-260,000 green tons year^{-1}, and 1,600-17,500 acres of plantations, assuming a growth rate of 15 green tons acre^{-1} year^{-1}. The hurricane-damaged 3- to 4-year-old *E. grandis* and *E. amplifolia* at Kent sold for mulch at \$8 ton^{-1} in 2005, but cottonwood was not marketable.

A decision support system spreadsheet for SRWCs on CSAs, based on an economic optimization model, estimated the minimum stumpage prices needed to achieve the conventional forest and agricultural land expectation values (LEV) of \$500 and \$1,000 acre^{-1}, respectively, in Florida. Stumpage prices of \$15 and \$19 ton^{-1}, respectively, are required to match these LEVs, assuming \$728 acre^{-1} site preparation and \$486 acre^{-1} planting costs, an average *E. amplifolia* growth of 11.2 tons acre^{-1} yr^{-1}, and an interest rate of 5%. Under these same site prep and planting cost assumptions, double row *E. amplifolia* growth of 14.2 dry tons acre^{-1} yr^{-1}, a reasonable stumpage price of \$18.20 ton^{-1}, and interest rates of 10% and 4%, production of *E. amplifolia* on CSAs in central Florida is profitable, with LEVs ranging from \$308 and \$2,633 acre^{-1}, respectively. With the incorporation of a carbon (C) sequestration benefit of \$4.55 ton^{-1}, LEVs increase to \$383 and \$2,718 acre^{-1}, respectively, while recognizing the CO_2 mitigation benefits associated with a biofuel scenario increases LEVs to \$532 and \$3,185 acre^{-1}, respectively. In addition, the societal value of below-ground C sequestration (roots + SOC at \$4.55 ton^{-1} C) is likely to be \$437-475 acre^{-1} or \$330-364 acre^{-1}, assuming discount rates of 4% and 7%, respectively. When land is already owned and SRWC production involves only establishment and management costs, the internal rates of return, the actual return on invested capital, are estimated to range from 4 to 32%. As SRWC stumpage price is most likely to be \$10/green ton or higher, rates of return on investment are likely to exceed 12%.

This model also examined the influence of incentives for atmospheric CO_2 mitigation on LEV and optimal management. The shortest optimal initial growth stage was 2.6 years under conditions of highest stumpage price and interest rate and lowest operational costs, and the longest optimal initial growth stage with a positive LEV was 3.5 years with high operational costs, low interest rate and low stumpage price. Aboveground yields of *E. grandis* and *E. amplifolia* under five treatments increased rapidly through 3.5 years of age. Under the base scenario presented above, increasing the price of C from \$0 to 14 acre^{-1} increased LEVs from \$2,633 to \$3,223 and \$2,633 to \$6,646 acre^{-1} for mulch and biofuel scenarios, respectively. Assuming a C price of \$4.55 ton^{-1}, total estimated below-ground C benefits range from \$263 acre^{-1} for low growth and 10% interest to \$474 acre^{-1} for high growth and 4% interest. Raising the C price to \$14 and \$23 ton^{-1} increased the below ground C benefit by approximately 3 and 5 times, respectively.

E. grandis and *E. amplifolia* SRWCs appear to improve CSA soil characteristics, exclude cogongrass, and facilitate the establishment of native plants. *E. grandis*- and cottonwood-dominated portions of the Kent site had much more favorable soil than cogongrass-dominated areas (e.g., ten- and four-fold increases in soil nitrogen and carbon, respectively, were noted in the *E. grandis* commercial planting). Soil organic matter (SOM) in the operational area of the Kent CSA was as high as 6.50% in the two rows of cottonwood planted on one 11' wide bed (Double-*PD*) culture. In all Kent study treatments, SOM was higher than in mineral soil. SOM was 3.15 times higher under *E. grandis* and more than 2.3 times higher in all the cultures compared to a cogongrass-dominated area. Across species, planting densities and ages, few soil properties were significantly different in the operational area. The phosphatic clay at the Kent CSA is highly fertile and has high amounts of P, Ca, Mg and K. The PRP soils similarly had high SOM, as much as 7.7% for cottonwood in SRWC-107, favorable nitrate levels, and lower pH and bulk density, 6.6 and 0.52, respectively, for the cottonwood. Soil analyses by Wallace Laboratories also noted a desirable decrease in pH in the presence of *E. grandis*, which in turn lowered gypsum requirements and the amount of polyacrylamide needed to improve soil aeration. These collective results suggest that SRWCs can significantly improve soil properties of phosphate mined lands.

Understory species common to disturbed sites, moist habitats, and/or new plantations were observed frequently in the one row of *E. grandis* on a bed (Single-*EG*) , two rows of *E. grandis* on a bed (Double-*EG*), four rows of *E. grandis* on a 22' bed (Quadruple-*EG*), and Double-*PD* cultures at the Kent site. Of 57 herbaceous species, among the most common of 40 native species were virgin's bower (*Clematis virginiana*), Spanish needle (*Bidens alba*), creeping dayflower (*Commelina diffusa*), and southern shield fern (*Thelypteris kunthii*). Of 26 shrubs/subshrubs (19 native), Caesar's weed (*Urena lobata*) had the highest percent cover, frequency, and species composition in Single-*EG*, Double-*EG*, and Quadruple-*EG*. In Double-*PD*, saltbrush (*Baccharis halimifolia*) had the highest frequency and species composition. Similar favorable vegetative establishment was underway at the PRP one year after SRWC establishment.

SRWCs may build soils and suppress cogongrass while producing commercial products to augment forestry's \$685 million annual value and 6,800 jobs in Polk County. Cogongrass was absent in all *E. grandis* cultures with high tree survival, while over 70 native species were present in the *E. grandis* understory. Cogongrass importance value index (IVI) was negatively correlated with both *E. grandis* (r = -0.91, p < 0.0001) and *E. amplifolia* (r = -0.73, p = 0.0028) basal area. For all eucalyptus at the Kent CSA, cogongrass IVI also was negatively correlated with stand basal area (r = -0.52, p =

0.0004). If SRWCs dramatically improve environmental conditions by changing microclimate, vegetation, and soil, SRWCs may serve as "bridge crops" to restore cogongrass infested CSAs to native forest or productive agricultural lands. These results also emphasize both the potential for SRWCs on CSAs to mitigate atmospheric CO_2 and for CO_2 mitigation incentives to contribute to the profitability of SRWC production.

Project results were disseminated through 58 publications/presentations and two websites. Of 33 publications, five were theses or dissertations. The 25 presentations included four tours of the Kent site. The "Tree Crops for Phosphate Mined Lands" (http://trees.ifas.ufl.edu) and Treepower (www.treepower.org) websites provide information about the project.

INTRODUCTION

Central Florida produces 75% of the nation's and 25% of the world's phosphate supply, primarily used for fertilizer (IMC Phosphates 2002). Consequently, there are about 131,000 hectares (325,000 acres) of phosphate-mined lands in the region (Segrest 2007). Closed phosphate mined lands are the most unused and lowest value lands in central Florida.

Our project assessed the biological and economic feasibility of growing short rotation woody crops (SRWC) on ~123,000 acres of currently underutilized clay settling areas (CSAs) in central Florida. CSAs are largely left idle because of operational difficulties and economic factors. SRWCs could maintain and expand commercial forestry, which currently adds $685 million annually to the Polk County economy (Hodges and others 2005), and provide biofuels in central Florida.

CSAs, classified as clayey Haplaquents (Mislevy and others 1989) are subject to compaction and have poor physical structure, poor drainage, low soil carbon and bioavailable nitrogen (N), high levels of P, K, and micronutrients, pH of 7.0-8.3, and are commonly dominated by cogongrass (*Imperata cylindrica*), an invasive exotic in Florida. Therefore, CSA reclamation must address not only the limitation of soil properties to forest or agriculture establishment but also eliminate established exotic plants. Successful plant-based reclamation requires a system that improves the site for sustainable crop management or subsequent native plant establishment. The ideal plant management system increases soil N, enhances the physical structure of the soil through root and macrofauna activity and water use, and sequesters soil organic carbon (SOC).

Fast-growing *Populus deltoides, Eucalyptus grandis, E. amplifolia, Pinus elliottii*, and *Taxodium distichum* grown as SRWCs may also thus serve as "bridge crops" transitioning cogongrass infested CSAs to native forest or productive agricultural lands while producing commercial fiber products such as mulchwood, energywood, ethanol, timber, pallets, and composites. Mulchwood, an existing multimillion dollar market in Polk County annually, is the most likely immediate SRWC market, and energywood for electricity generation is a prospectively larger market (Rockwood and others 2005).

Through an extraordinary collaboration with public and private partners, our five-year project identified and developed (1) superior trees and (2) appropriate management practices for three native species and two non-invasive exotics, (3) documented the productivities of superior genotypes of these species, and (4) estimated their economic value on CSAs in Polk County. Addressing these objectives, this report is subsequently organized by SRWC selection and management, economics, and ecological impacts.

SRWC SELECTION AND MANAGEMENT

Cypress

Baldcypress (*T. distichum* (L.) Rich. var. *distichum*) and pondcypress (*T. distichum* var. *nutans* (Ait.) Sweet) are common to forested wetlands in Florida. Both varieties can occupy the same site and are adaptable to varying regimes of flood, fire, nutrients, and soils, although pondcypress is more common to Spodosols and Ultisols with pH <6.8 and sites with ponded water (Wilhite and Toliver 1990).

Although cypress is the most common wetland tree species within Florida (Ewel 1990), the sustainability of the natural cypress resource, and the industries that depend on it, is in jeopardy. From 1987-1994, net annual harvest of cypress in Florida of 41.7 million cubic feet exceeded net annual growth of 40.2 million cubic feet, due largely to 128,000 tons of cypress mulch produced annually (Brown 1995). Many swamps that once held a preponderance of cypress now contain primarily second growth tupelo, ash, oak, and gum. Stands of pure second growth cypress, on the other hand, may be overstocked and stagnating (Dicke and Toliver 1988).

Gains in pine plantation productivity from genetic improvement\silviculture suggest a similar potential for intensively managed cypress. Family variation in height and diameter suggests potential for genetic gain (Faulkner and Toliver 1983). Liu and others (1990) noted that 95% of the genetic variability in baldcypress occurred within populations, with a high number of alleles per locus. At 1x1m spacing on south Florida muck, a local baldcypress source quickly suppressed competing vegetation, was 7.9m tall after seven years, and coppiced (i.e., sprouted from the stump after harvest) consistently from 3 to 7 years of age (Rockwood and Geary 1991). Cypress is tolerant of the alternately saturated/droughty conditions that frequently occur on CSAs reclaimed from phosphate mining in peninsular Florida (Harrell 1987). Gaviria (1998) reported encouraging early results from six studies established in 1996-97 with up to 30 seedlots and various cultures on a wide range of sites in Florida.

Recent remeasurement of these tests indicated that nine baldcypress provenances and five baldcypress checklots were, on average, taller than 16 pondcypress progenies, but all were similar in survival after four years (Rockwood and others 2001). Within taxa, individual provenance/progeny differences were significant, but no provenances or progenies were consistently better across sites that ranged from bottomland in northwest Florida to wet and dry flatwoods in northeast Florida to a fertile but poorly drained CSA in central Florida. Bedding+compost on a good flatwoods site significantly increased the growth of 30 baldcypress progenies and four Florida pondcypress progenies compared to bedding alone in studies established in 1999 and 2000. In another flatwoods study planted in 2000, bedding+compost also resulted in better growth and survival than just bedding, which in turn was superior to no bedding. An intensively managed seed orchard established in December 1997 produced cones in Fall 2000 on trees up to 5.2m tall.

A 13-year-old baldcypress provenance test on south Florida muck not only illustrates cypress growth potential but also some of the factors and possible consequences of rapid growth (Table 1, Rockwood and others 2001). Individual trees were up to 13m in height and 20cm in DBH in 13 years, but tree growth rate slowed considerably after 10 years, very likely because of the shallow muck soil and dry climate. Five provenances differed in tree size but not survival, stand volume index (SVI), tree quality (i.e., tree vigor and form), and wood basic density and moisture content. An Oklawaha provenance (i.e., geographic seed source) had the tallest and largest DBH trees, but because of less than 17% survival, its stand volume index was not significantly larger. A Blountstown provenance tended toward the smallest trees and the lowest survival and SVI. The Oklawaha provenance also had favorable tree quality and the highest percentage (6.7%) of top quality trees. Basic densities of individual trees ranged considerably from .299 to .370, but at an average basic density of .330, the wood was much less dense than previously reported for cypress (.47) (Panshin and others 1964). While the Oklawaha provenance appeared to be the best for planting on southern Florida muck, various uncertainties argued for continued and expanded genetic testing in south Florida.

Table 1. Baldcypress Provenance Means for Survival (%), DBH (cm), Height (m), SVI (m^3/ha), Tree Quality, Basic Density (g/cc), and Moisture Content (%) at 13 Years on South Florida Muck (ex Rockwood and others 2001).

Provenance	Survival	DBH	Height	SVI	Tree Quality	Basic Density	Moisture Content
Blountstown	14.1a	14.0b	8.3b	43.4a	2.9a	.331a	203a
Choctawhatchee	44.4a	15.1b	9.4b	139.4a	2.9a	.320a	214a
Kennedy Creek	28.5a	15.4b	9.5b	90.4a	2.6a	.320a	213a
Ochlocknee	43.7a	14.1b	9.7b	111.6a	3.0a	.342a	193a
Oklawaha	16.7a	24.3a	11.8a	144.4a	2.5a	.338a	196a

*Provenance means not sharing the same letter for the same trait differ at the 5% level.

The specific objectives of our cypress research were: (1) identify the most productive cypress germplasm for planting on phosphate mined lands, (2) develop seed orchards, (3) define management practices for cypress plantations on mined lands, and (4) estimate the yield and economic viability of commercial cypress plantations.

Cottonwood

Cottonwood, native to the Southeast, is fast growing and easy to establish using unrooted cuttings. In an effluent treatment study at Winter Garden, Florida, cottonwood planted as unrooted cuttings was up to 3.5 m tall after 9 months (Alker and others 2000a).

Over 200 genetically improved cottonwood clones have been selected for use along the Mississippi River, but no clones are adequately tested for use in Florida. Most poplar breeding programs, including a tree improvement program for Florida initiated in

1995, have involved clonal propagation of intensive selections from thousands of seedling candidates. This is expected to produce significant genetic gains in a short time. Germplasm collection and maintenance such as clone banks are recommended (Bradshaw and others 2000).

The objectives of our cottonwood research included: (1) identify the most productive cottonwood clones for planting on CSAs, (2) establish clonal nurseries for the best clones, (3) evaluate management practices for cottonwood plantations on mined lands, and (4) estimate the yield, market, and economic viability of commercial cottonwood plantations.

Slash Pine

In preliminary tests in central and southern Florida since 1991, various Queensland slash pine taxa have been more productive than native slash pine var. *elliottii* – E), including genetically improved trees from north Florida (**FE**) (Rockwood and Nikles 2000). The F_1 hybrid between Queensland E (**QE**) and Caribbean pine (*P. caribaea* var. *hondurensis* – H) (**EH**) had over 40% more volume/ha than **FE** after nine years in southern FL, and **EH** and **QE** seemed suitable for central FL where freeze risk and native pests are not problems.

The objectives of our slash pine research were: (1) expand comparison of **QE** with **FE**, (2) extend assessment of **EH**, EH $\mathbf{F_2}$ families, hybrids involving *P. caribaea* var. *bahamensis* (B) including **EHxEB** families, hybrids of *P. caribaea* var. *caribaea* (C) and **QE** (**CE**), and EH $\mathbf{F_2}$ seed produced in a Queensland clonal seed orchard, and (3) develop recommendations for use of Queensland taxa in central Florida.

Eucalypts

Genetic, silvicultural, and propagation improvements collectively can increase the productivity of the non-invasive (Appendix C) *E. grandis* and *E. amplifolia*. *E. grandis* is best suited to southern Florida's subtropical and tropical flatwoods and organic soils but can also be grown successfully in central Florida if freeze resilient stock is used. *E. grandis* has been grown commercially in southern Florida since the 1960s, initially for pulpwood and now for mulchwood from some 6,000 ha of plantations (Rockwood and others 2006a). Commercially deployed *E. grandis* seedlots are primarily derived from GO77, a 4th-generation seedling seed orchard established in 1977 and developed through combined tree selection, progeny testing, and provenance testing. Research since the late 1970s has further developed *E. grandis* as a SRWC for energywood and dendroremediation (i.e., phytoremediation using trees) in southern and recently central Florida (Rockwood and others 2004). *E. amplifolia* can be grown as a SRWC from central Florida northward to perhaps 50 miles inland from the Gulf Coast. Development of *E. amplifolia*, the most appropriate eucalypt for more temperate climates with more frequent and severe freezes, has been less intensive but has followed a genetic improvement strategy similar to *E. grandis*. *E. grandis* and *E. amplifolia* have demonstrated high energywood productivity on reclaimed phosphate mined lands.

The objectives of our *Eucalyptus* research included: (1) identify the most productive genotypes for planting on CSAs, (2) evaluate management practices for plantations on mined lands, and (3) estimate the yield, market, and economic viability of commercial *E. amplifolia* and *E. grandis* plantations.

ECONOMICS

The economics for SRWCs grown with sewage effluent near Orlando (Langholtz and others 2005) provide goals for SRWCs grown on CSAs. Cottonwood coppice yields were roughly equivalent to those of *E. grandis*, but cottonwood first rotation yields were considerably less. Coppicing reduced establishment costs over time but lowered mean annual increments (MAI). Uncertainty analyses using probability distributions for costs, output price, and production yields were most sensitive to output price and yield. Whether or not coppicing is preferable depends on relative seedling and coppice yields, and seedling establishment costs and output prices. Average *E. grandis* "without coppice" produced the least return, and *E. grandis* average with coppice was more profitable, since coppicing was more beneficial than replanting after the first rotation. However, faster growing *E. grandis* progenies increased profitability, especially without coppicing, as land expectation value (LEV) was $2967/acre and equalized annual earning (EAE) was $118/acre/year. *E. grandis* production for landscape mulch was profitable. Cottonwood has good profit potential for either pulpwood or energywood if allowed to grow to longer rotation ages, or at short rotations with coppicing if stumpage values become higher. Energywood is likely to have higher stumpage values if tax credits are enacted for co-firing.

We also investigated the impact of CO_2 mitigation incentives on management and profitability of SRWC dedicated feedstock supply systems (DFSS) on CSAs in Polk County, Florida. An economic optimization model of a SRWC biomass production system that includes an incentive for atmospheric CO_2 mitigation was built and used to investigate how this incentive would influence LEV and optimal management of the SRWC production system.

ECOLOGICAL IMPACTS

Phosphatic clay is highly fertile and has high amounts of P, Ca, Mg and K. N is the only requirement for nonlegume crops (Stricker and others 2000). In the Philippines, high exchangeable Ca and Mg and moderate to high exchangeable K have been observed in cogongrass grasslands with montmorillonite clay due to the presence of carbonates such as calcite ($CaCO_3$) and dolomite ($Ca(MgCO_3)^2$ – feldspar (Ca, K), and mica (Ca, Mg, K). Cogongrass soils in the area had less SOM and N compared to soils under well-developed woody canopy (Snelder 2001). Due to mineralization and tree growth, N content and SOM in eucalyptus stand decreased with age (Loumeto and Bernhard-Reversat 2001).

Leaf litter is the main source of SOM. Litterfall was generally lower in eucalyptus compared to N-fixing species (Parrotta 1999) and increased with the age of the plantation (Jaiyeoba 1998). Compared to 6-year-old first rotation, a 13-year-old coppice stand (6 years of coppice) had higher leaf litterfall (Bernhard-Reversat and others 2001). In another study, litterfall and litter accumulation however, were greater in first rotation eucalyptus than in coppice (Loumeto and Bernhard-Reversat 2001). However, litter decomposition rate was slower in tropical eucalypt and pine plantations (O'Connell and Sankaran 1997).

Nutrients and SOM are lost in surface runoff. Alternate contraction and swelling of clay, however, prevents loss to some extent and helps in translocation of organic matter. This compensates for the movement of SOM which is usually retarded due to decreased infiltration after the soil is saturated (Snelder 2001). During the dry season, litter enters these cracks. In the beginning of the wet season, water conveys the surface organic matter through cracks. Both SOM and litter are trapped in the soil profile after the expansion of clay.

In the Philippines, SOM was distinct only in the surface soil in cogongrass grasslands and decreased rapidly with depth (Snelder 2001). Similar observations were made in the initial years of bioenergy crop production in areas converted from traditional agriculture where SOM was confined to the top 10cm (Tolbert and others 2002).

In phosphate mines, cogongrass often appears in wetter areas with high clay content (Segal and others 2001). Clayey soil and the allelopathic nature of cogongrass further impact the survival of native species. Cogongrass litter decomposes very slowly and its allelopathic nature suppresses the growth of native species. Seedlings that germinate in the cogongrass die due to high competition. In Indonesia, only four seedling/sapling species were found in cogongrass grassland as compared to 22 species in riverine forest (Otsamo 2000b). In the southeastern US, the advancing border of cogongrass had 41 native species (Brewer and Cralle 2003).

Fast-growing trees can suppress cogongrass, amend soil, add SOM through litter, and create suitable microclimate for seed germination for shade tolerant species. These rapid changes in the understory and lack of competition with grass make the plantations suitable for native seed germination and seedling development (Parrotta and others 1997). The addition of P reduced cogongrass clonal growth and aboveground mass (Brewer and Cralle 2003).

Intensive site preparation was used to restore cogongrass dominated grasslands in Indonesia. Sites were disked twice and harrowed with a rotavator before planting (Otsamo and others 1995). Disking cuts underground rhizomes into smaller pieces and exposes them to direct sunlight, which ultimately kills the rhizomes. Rigorous site preparation, weeding (first 2 years) and early canopy closure suppresses cogongrass, but doesn't necessarily eliminate it (Otsamo 2000b).

Exotic tree species have been used in short-rotation plantations worldwide. Once cogongrass is controlled, native species could be introduced into these exotic plantations after the first rotation (ITTO 1993). However, the species used should have the potential to amend soil and create suitable environments for native species.

In the Congo, species richness was higher in secondary forest than exotic species plantations. Within the eucalyptus plantations, species richness was higher in older plantation (26 years). Disturbance intensity was another factor for higher species richness as disturbed sites had more species. High plantation density and proximity to natural forest also had positive effects on species richness (Huttel and Loumeto 2001).

Species and density may influence plant diversity. Change in species diversity does not occur in the initial stages of succession in plantations but increases with time and soon reaches the maximum, which can be as early as 3 years (Ohtsuka 1999). Tree plantations in degraded areas bring dramatic improvement in environmental conditions, changing forest microclimate and soil. Fire is also less frequent in plantations. These ultimately increase the understory diversity in plantations. Understory biodiversity in eucalyptus plantation was lower compared to acacia and pine (Bernhard-Reversat and Huttel 2001).

Another environmental service that SRWCs could provide on CSAs is atmospheric CO_2 mitigation. Global carbon trading increased from 13 to 70 Tg CO_2 between 2001 and 2003 (Ecosystem Marketplace 2004), a trend that is likely to continue following the international ratification of the Kyoto Protocol on February 16, 2005. The establishment of tree plantations on non-forested CSAs has the potential to sequester carbon (Booth 2003). The greatest carbon sequestration benefit would come from plantations established in areas with virtually zero Mg C/ha (Chaturvedi 2004). An advantage of SRWC production on CSAs is the near-zero C density of the land prior to plantation establishment, as the land is bare of vegetation with little accumulation of soil organic carbon (SOC) following mining. Even on 20-40 year-old CSAs, C density is likely to remain low if forest cover is not established. SRWCs may sequester and maintain SOC (Joslin and Schoenholtz 1997). On a 60-year-old CSA in central Florida, SOC of a 2.5-year-old *E. grandis* plantation was 214% and 304% greater at depths of 0-30 and 30-60 cm, respectively, than in adjacent cogongrass areas (Wullschleger and others 2004).

In addition to C sequestration *in situ*, SRWCs used as a DFSS can mitigate atmospheric CO_2 by displacing CO_2 emissions associated with the combustion of fossil fuels (Sims 2002; Marland 2000; Schlamadinger and Marland 1996). This displacement of fossil fuels can be an effective way to mitigate atmospheric CO_2 because (1) CO_2 emissions can be continuously reduced, rather than reaching an eventual plateau of C accumulation in standing biomass, (2) the long-term cost per Mg of CO_2 is cheaper with displacement rather than sequestration, as land remains available for continued production in the future, and (3) reductions of net CO_2 emissions are not as risk prone as C sequestered *in situ*, which is susceptible to future events such as fire or land-use change (Eriksson and others 2002).

We assessed the ecological impacts of SRWCs on CSAs by evaluating soil and vegetation changes in response to planting *E. grandis, E. amplifolia*, cottonwood, slash pine, and cypress at two CSAs.

MATERIALS AND METHODS

SRWC SELECTION AND MANAGEMENT

This project's numerous field studies were mostly at the Kent site (28°00.99798'N, 81°52.13770'W) near Lakeland, FL (Table 2, Figure A-1). The Kent site, bordered by natural vegetation on the east, west and north, with Saddle Creek to the east, is a 50 ha CSA last mined for phosphate in the 1940s. Prior to 2000, the site was dominated by cogongrass up to 6' tall and had a history of catastrophic wildfires that destroyed the little natural vegetation in the area. The soil was a highly compacted heavy clay with pH of about 8.0, deficient in N and contained a negligible amount of organic matter (CPI 2003). The climate is semitropical. Total annual rainfall recorded at the Lakeland Airport for the "wet" year 2004 was 66.1", with >70% falling between June and September. Average monthly temperature ranged from 59.9ºF in January to 82.1ºF in both July and August. After Roundup Pro™ was applied to control cogongrass, the site was double disked (i.e., deep disked twice) and bedded (i.e., soil mounded by bedding plow to ~2' height on mostly 11' centers). Cypress, cottonwood, slash pine, *E. grandis*, and *E. amplifolia* were planted beginning in 2000.

Table 2. Characterization, Treatments, and Evaluations for Studies at Three Sites.

	Site		
	Kent	PRP	LP-9
Characterization			
Location	Lakeland	Homeland	Bowling Green
Mined Land Type	CSA	CSA	Overburden
Soil	Clay	Sandy Clay	Clay
Topography	Level	Sloping	Level
SRWCs	TD, PE, PD, EG, EA	PD, EG, EA, PE, TD	PE
Planting Date	2001	2005	2002
Treatments			
Bedded	X		
Planting Density	1, 2, and 4 rows	2 rows	1 row
Fertilization	X		
Control	X	X	X
Herbicide	X	X	
Shrub Interplants		X	
Tree Interplants			
Mulch		X	
Coppice	X		
Evaluations			
SRWCs	X	X	X
Soil	X	X	
Vegetation	X	X	
Economics	X		

The IMC-Agrico Peace River Park (PRP) site (Table 2), a rolling (sandy at the top, clayey at the bottom) cogongrass infested CSA, applies, extends, and demonstrates "bridge crop" results through 2004. Cogongrass at PRP was burned and herbicided; then, the area was deeply disked and rotovated to a 4" depth in mid-February 2005 before planting superior genotypes of slash pine, cottonwood, cypress, and finally *E. amplifolia* and *E. grandis* in five cultures in the 2.0 acre species-culture study SRWC-107. All SRWCs were planted in paired rows (0.8m apart) separated by up to 3m from adjacent pairs. By July 2005, the study was fully established with 5,120 trees and 1,280 interplanted trees and shrubs in 10-plant rectangular plots. PRP, in addition to demonstrating SRWC productivity on CSAs, also documents the potential of SRWCs for restoration of mined lands to improve soil conditions, control invasive species, sequester carbon, and provide a transition to natives.

Cypress

Development of improved cypress planting stock and management practices for phosphate mined lands involved previously established tests and a seedling seed orchard (Rockwood and others 2001) and new tests. Two new genetic tests were established on bedded CSAs: SRWC-88 at the Kent site, SRWC-89 at Mosaic site FM06. Bedding (B) and no B with and without fertilizer blocks in SRWC-89 included three replications of seedlot row plots. Tree spacing in SRWC-88 was 12 x 3', 12 x 5' in SRWC-89. All planting stock was commercially grown 1-year-old bareroot seedlings, except for potted seedlings in SRWC-89. These and two other studies (SRWC-67 and SRWC-73) on reclaimed mined lands (Table 3) involved over 60 seedlots primarily from Florida (Table 4). These baldcypress seedlots included provenance bulklots ranging from Illinois into Florida and individual tree collections from Arkansas and Florida. The pondcypress accessions were from individual trees in Florida. Collectively, these studies, which vary in age, soil type, silvicultural treatment, and seedlot composition, provided a basis for selecting superior seedlots from the seed orchard.

The 25 seedlots in SRWC-67 were also in the seedling seed orchard (CO97) established near Day, Florida, in December 1997. CO97 included the best seedlings of nine baldcypress and 12 top pondcypress seedlots (Gaviria 1998), plus ramets (i.e., rooted cuttings) of three baldcypress clones; seedlings and ramets were systematically assigned to single tree plots in 12 replications of an RCB design. Each replication was four rows of six trees at a spacing of 10 x 5'. The best seedlings of the four other pondcypress seedlots were systematically allocated to four positions at the end of each row, resulting in an orchard of 320 trees (eight rows of 40 trees). Ten additional seedlots were interplanted in CO97 through 2000, resulting in the current orchard composition of 49 seedlots (Table 5).

Tree height and survival were measured periodically in all studies. In CO97, Diameter at Breast Height (DBH) was used in calculating stand volume index [SVI = 0.00002618 * DBH^2 * Height * (2,152 Trees per ha) * (1 for a live tree, 0 for a dead/missing tree)], and tree quality on a 0 (straight stem, short horizontal branches) to 5 (crooked stem, long angular branches or forking) scale. Analyses of variance identified significant genetic, silvicultural, and site factors. As appropriate, means were tested with Duncan's multiple range test.

Table 3. Location, Planting Date, Number of Baldcypress (BC), Pondcypress (PC), and Genetic Check (GC) Seedlots, Site Type, and Bedding (B), Ripping (R), Mulch (M), Fertilizer (F), and Compost (C) Treatments for Eight Cypress Studies on Phosphate Mined Lands.

Study SRWC-	Location in Florida	Plant. Date	No. of Seedlots			Site Type	Silvicultural Treatment(s)
			BC	PC	GC		
67	Ft. Meade	1-2/97	9	16	3	CSA	No B\M\F, M, B, B+M+F
73	White Springs	2/98	21	2	1	Overburden	No B\M\F
88	Lakeland	7/00	11	1	2	CSA	B only
89	Ft. Meade	6/01	10		2	CSA	No B\M\F, B, B+F
92	Ft. Meade	3/02	8	1		Overburden	No R, R
94	Lakeland	12/01	30	5		CSA	B only
95	Lakeland	3/02	40	12		CSA	B only
106	Brooksville	1/04	35	54		Sandhills	No, F, C

Table 4. Type, Origin, and Number of Baldcypress and Pondcypress Seedlots in Eight Cypress Studies on Phosphate Mined Lands.

Type	Origin	Number of Seedlots in Study SRWC-							
		67	73	88	89	92	94	95	106
Baldcypress									
Provenance Bulk	Arkansas	1							
Provenance Bulk	Illinois	1							
Provenance Bulk	Louisiana	2							
Provenance Bulk	Northwest FL	2							
Provenance Bulk	Northeast FL	2							
Provenance Bulk	South FL	1							
Individual Tree	Arkansas		10						
Individual Tree	Northwest FL		11						
Individual Tree	Northeast FL		1	11	9	5	12	13	
Individual Tree	Southern FL					3	14	16	
Pondcypress									
Individual Tree	Northwest FL	1							
Individual Tree	Northeast FL	3	2	1		1	5	12	
Individual Tree	Central FL	4							

To expand the project's cypress genetic base population from mostly northern Florida accessions, seed collections were conducted from October through December 2000 (Table 6). Of the 59 new individual tree accessions, 35 were collected in northeast Florida, 24 in south Florida. These new accessions, along with more than 40 seedlots harvested from CO97, were processed and sown by CFL&T to produce bareroot seedlings for inclusion in the 2001 new studies.

Table 5. CO97 Genetic Composition, 2001 Seedling Production, and 2001 and 2004 Cone Production by Baldcypress Provenances, Clones, and Progenies and Pondcypress Progenies.

	Baldcypress			Pondcypress
	Provenances	Clones	Progenies	Progenies
Current Orchard Composition				
No. of genotypes	9	3	19	18
No. of trees	96	23	71	92
2001 Seedling Production				
No. of trees with seed	18	6	3	15
No. of seedlings	460	145	71	623
No. seedlings/tree	26.1	24.2	23.7	41.5
Min. no. seed/tree	5	0	0	1
Max. no. seed/tree	120	60	60	120
2001 Cone Production				
No. trees with cones	48	13	17	56
No. of cones	655	151	123	1929
No. cones/tree	13.7	11.6	7.2	34.5
Min. no. cones/tree	5	2	0	0
Max. no. cones/tree	150	25	30	300
2004 Cone Production				
No. trees with cones	44	14	16	69
Relative Quantity	1.7	2.1	1.0	2.1

Table 6. Sources and Numbers of Seedlots and Seedlings for Natural Cypress Accessions Collected in 2000 and 2001.

Source	Seedlots	Seedlings	Source	Seedlots	Seedlings
2000			2001		
Welaka Pond	3	62	Northeast Florida	8	546
Welaka River	4	225	Crescent Lake	10	911
St. Mary's	3	245	Fisheating Creek	5	60
Withlacoochee	2	28	Loxahatchee Bulk	2	2040
Suwanee	11	332	Loxahatchee	7	595
Silver River	6	528			
Oklawaha	4	32			
Lake Alice	2	320			
South Florida	6	442			
Loxahatchee X	4	1960			
Loxahatchee Q	6	546			
Loxahatchee O	7	220			
Loxahatchee L	1	9			
Total	2059			2033	6153

In 2001-02, three new genetic tests were installed to compare the three baldcypress sources collected in 2000—seed orchard of mainly north Florida origin trees, trees in northeastern Florida, and trees in southern Florida (Tables 2 and 3). SRWC-92, planted March 6, 2002, on a Mosaic (formerly Cargill) overburden site (Figure A-4), involved three progenies of each source on an upland ripped site and along a lake without ripping (Figure A-5). Source comparisons involving more progenies were part of SRWC-94 and SRWC-95 established on the Kent CSA. SRWC-94, with five replications of 4-tree cross-bed row plots on conventional forestry beds, was planted on December 16, 2001, at a spacing of 12' between beds and 3' along beds. SRWC-95 was planted March 4-6, 2002 with four replications of the three source main plots and progeny subplots of 4 trees spaced 3' apart on top of a 20' wide mound, so that the test could eventually be converted into three seedling seed orchards. All planting stock was commercially grown 1-year-old bareroot seedlings.

Additional natural cypress selections were made in 2001 (Table 6). Of the 32 new individual tree accessions, 18 were collected in northeast Florida, 14 in south Florida. These new accessions and 151 seedlots from CO97 were processed and sown by CFL&T to produce bareroot seedlings for a 2002 genetic test.

In 2003-04 to document potential productivity of older planted cypress, 17 permanent sample plots were installed in 12- to 15-year-old baldcypress plantations on PCS Phosphate lands near White Springs, FL, and on Andrews property near Chiefland, FL (Table 7). On each 1/20-acre square plot (46.7' x 46.7'), all live trees were measured for total height and DBH in order to calculate stand volume. Representative codominant\dominant trees were felled to estimate stand growth via stem analyses.

Table 7. Number of Permanent Sample Plots Installed in Baldcypress Plantations in 2003-04 by Location and Age.

Location	Age	No. of Plots
White Springs, Florida	15	10
Chiefland, Florida	12	7
	Total	17

A new cypress orchard (Study SRWC-106) was initiated at the Withlacoochee State Forest near Brooksville, FL, in collaboration with the Florida Division of Forestry in January 2004. A total of 89 seedlots (35 baldcypress and 54 pondcypress; 2,432 total bareroot seedlings) were systematically allocated to 30 replications of 48, 10, and 10 single-tree plots receiving compost, slow release fertilizer, and no fertilizer, respectively.

Commercial plantings of cypress and cottonwood, approximately 71 and 20 acres in size, respectively, were established to supplement yields estimated in the project's research studies. About 45,000 potted trees of 10 of the 14 cypress seedlots in studies SRWC-88 and SRWC-89 were planted at 10 x 7' spacing on three site types following CSA reclamation at Mosaic: 40 acres of sand-clay mix (FM03/04 - 7 bed strips of seedlots A, E, F, H, I, J, L, Local), 21 acres of sand over clay (FM06 - 7 row strips of seedlots A, B, C, F, H, I, J, L, Local), 10 acres of unbedded clay (FM06 - 7 row strips of seedlots B, E, F, H, I, L, Local) from April to June 2001.

A few cypress were included in one rep of three cultures in SRWC-107 at the PRP: (1) control, (2) herbicide as applicable, and (3) mulch – up to a 6" layer between rows and trees to suppress weeds. The 162 cypress representing two baldcypress, three pondcypress, and two Montezuma cypress (*T. mucronatum*) progenies were planted during Summer 2005.

To provide an unmined comparison for cypress in Polk County, the same cypress in SRWC-107 and other accessions were included in a multi-species study on a chopped, minimally bedded flatwoods site at the Avon Park Air Force Bombing Range (APAFBR) in August 2005. A total of 31 container-grown accessions (11 baldcypress, 14 pondcypress, and 6 *T. mucronatum*) were planted in 6-tree row plots within 3' and 6' spacing blocks with 2 or 3 replications according to a randomized complete block design. Height and survival were assessed in December 2005.

Cottonwood

Cottonwood studies at the Kent site (Figure A-1) included two clone tests, a clone-configuration-fertilizer study, a clonal nursery, a demonstration area, and an operational planting. Cuttings for clone test SRWC-87 were obtained in Mississippi and Florida in January 2000 and rooted in the greenhouse three months prior to planting in June 2000. SRWC-87 compared 73 clones within a 3 x 3 Latin Square design with cottonwood, *E. amplifolia*, and *E. grandis* main plots, four replications within main plots, and single-tree subsubplots. Height, diameter, and leaf number were recorded in November 2000, February 2001, and May 2001. In February 2001, stem biomass was measured and collected. Due to missing trees, Proc GLM was performed along with cluster analysis using least square means for each variable at the three measurement dates (Statistical Analysis System 1990). For the cluster analyses, all clones with only one tree were dropped, but were still included in the total trees and clones counts. Clones were also ranked according to performance. A cottonwood main plot that was felled in April 2001 to examine clonal differences in coppicing ability and measured for coppice height and diameter in May 2001 was remeasured in December 2001.

Clone-configuration-fertilizer study SRWC-90 involved six of the 73 clones in SRWC-87 (Ken 8, S7C1, S13C20, ST-240, -259, -261), two planting configurations (single or double rows per bed), and fertilizer levels (rates of ammonium nitrate) in a split-plot design with configuration main plots, cottonwood, *E. amplifolia*, and *E. grandis* subplots, and clones in 6-tree row subsubplots for a total of 960 trees including borders. Spacing in both SRWC-87 and SRWC-90 was 11' between beds, 3' between trees on a bed. The initial planting for the study was done in March 2001. Fertilizer treatments were implemented in June 2002. Tree size and survival were measured in December 2001, August 2002, December 2003, and August 2004.

The clonal nursery contained 13 promising clones for central Florida: Ken8, S7C1, S13C20, ST-66, -70, -72, -124, -148, -163, -240, -244, -259, -261. Cuttings for Clones Ken8, S7C1, and S13C20 were obtained from 3-year-old trees in a sewage effluent study at Winter Garden, Florida. Cuttings for the other 10 clones were supplied by a commercial nursery in Mississippi. In April 2001, each clone was planted in double row configuration (two rows 30" apart, 1' spacing between cuttings within rows) on one or more ~500' long beds. Preliminary survival and height were estimated in August 2001, and a more intensive measurement was taken in December 2001. All nursery trees were felled in February 2002 to produce juvenile shoots for possible planting in 2003.

Five cottonwood clones were planted in two configurations in a demonstration area at Kent in April 2001. Each clone was established at 3' spacing within single or double row blocks as ~60 cuttings on top of a bed spaced 11' apart. After periodic size and survival measurements, approximately half of each block was felled in February 2002. Mulching and compost treatments were superimposed on harvested areas in May.

The cottonwood clone test portion of SRWC-94 was planted in March 2002 with the 22 best clones in SRWC-87, SRWC-90, and the clonal nursery, using unrooted cuttings obtained from one or more of those studies. The clones were planted in 14 replications as single-tree plots arranged as four trees 1m apart across the top of 20' wide mounds and 1m apart along mounds. Survival was assessed in June 2002.

The commercial cottonwood planting at Kent involved unrooted cuttings of three clones machine planted on beds at 10 x 2.5' spacing from April to May 2001. Over 25,000 cuttings were obtained from about 1,000 ramets of Clones Ken8, S7C1, and S13C20 in a study at Winter Garden, Florida. Most of the cuttings were planted in a single row configuration; only a few beds were planted with double rows (30" apart) on a bed.

For the cottonwood in SRWC-107 at the PRP, 1,072 unrooted cuttings of 120 promising clones, including the best from the Kent studies, were established in single tree plots within two replications of a split plot with five cultures assigned to 30 x 60' main plots: (1) control, (2) herbicide, (3) mulch, (4) interplanted shrubs (wax myrtle (*Myrica cerifera*), gallberry (*Ilex glabra*), saw palmetto (*Serenoa repens*), buttonbush (Cephalanthus occidentalis)), and (5) interplanted trees (sweetgum (*Liquidambar styraciflua*), redbay (*Persea borbonia*), swamp bay (*Magnolia virginiana*), black tupelo (*Nyssa sylvatica*)). Within the main plots, all clones were planted at 3' spacing in three paired rows (0.8m apart) separated by up to 3m. The first replication was planted in January 2005, the second in February 2005. The shrubs and trees were established in two plots of two rows of five plants in between the paired SRWC rows in each replication-culture. Post-planting watering was diligent. Height and survival of all plants were measured in March 2006.

Slash Pine

Slash pine research activities involved arranging for genotypes and designing, preparing, planting, and analyzing four studies. Seedlots especially suited to central

Florida climatic and edaphic conditions were acquired from the QFRI, and very fast-growing north Florida seedlots were arranged. Taxa **FE** and **QE** were each represented by 12 seedlots (Table A-1). The F_1 taxon **EH** and F_2 families had common pedigrees with three QE and F_1 seedlots and were not previously tested in Florida. The **EHxEB** taxon included 12 families. Three families of the hybrid between C and E (**CE**), and a bulk seedlot (**F_2B**) of EH F_2 produced by wind-pollination in a clonal seed orchard, were also included. QFRI provided approximately 250 seed of each **QE**, **EH**, **F_2**, **EHxEB**, **CE**, and **F_2B** seedlot, and all seedlots were sown in containers in June 2001.

A split-, split-plot randomized complete block design with taxa main plots and row subplots for seedlots within taxa was used for studies SRWC-94 at Kent and SRWC-92 at Mosaic (Table 8). Bedding and initial herbiciding for SRWC-94 were completed in April 2001. Disking and ripping for SRWC-92 were done by June 2002.

Table 8. Number of Seedlots (No.) and Mean/Range for Height (H in m) and Survival (S in %) of FE, QE, EH, F_2, EHxEB, CE, and F_2B Taxa Seedlots in Slash Pine Studies SRWC-92 and SRWC-94 at Indicated Ages in Months.

	SRWC-92					SRWC-94				
Taxon	No.	H15	H28	S15	S28	No.	H18	H31	S18	S31
FE	11	.55 .30-.64	1.0 0.7-1.2	95.1 88-100	85.6 54-100	8	.91 .65-1.07		28.0 8-46	
QE	12	.58/ .32-.68	1.1 1.0-1.3	94.1 90-100	89.8 83-100	9	.80 .50-.96		24.1 14-36	
F1	12	.58 .44-.68	1.4 1.3-1.5	88.5 75-100	82.4 68-92	7	1.16 .99-1.45		26.7 14-33	
F2	11	.54 .31-.68	1.3 1.0-1.5	85.1 68-100	83.2 58-96	10	1.07 .82-1.25		21.2 10-32	
EHxEB	8	.53 .42-.60	1.3 1.0-1.5	92.0 83-100	70.3 54-83	5	1.02 .86-1.19		29.4 0-50	
F2B			1.4		87.5					
Total	54	.56	1.2	91.0	83.1	34	.98	1.6	25.0	7.7

SRWC-92 had 24 replications with single-tree subplots at 3' spacing in rip lines and 10' between lines (including borders, 2,480 trees in 31 lines of 80 trees); all trees were planted in June 2002. SRWC-94 had six replications of 4-tree cross-bed row subplots (in total with borders, six sets of 36 trees planted at 3' spacing on four beds spaced 11' apart). Mortality noted in July 2002 was replanted as possible with residual seedlings.

In February-March 2005 in the eastern half of SRWC-107 at PRP, slash pine was established in the northern two replications (i.e., north of cottonwood) of the five culture main plots as single-tree subplots for genotypes (Figure A-7). The 1,280 propagules, grown in containers since June 2004 from 99 clones and 10 seedlots of five fast-growing taxa suited to central Florida climatic and edaphic conditions, were watered diligently after planting. Height and survival of all plants were measured in March 2006.

As an unmined comparison for slash pine in Polk County, the same slash pine in SRWC-107 were included in a 4,308 tree, multi-species study on a chopped, minimally bedded flatwoods site at the APAFBR in January-March 2005. Slash pine was represented by 108 container-grown genotypes (98 clones, 10 seedlots) and five bareroot taxa (Andrews X (BAX), High Growth (BHG), Rust Resistant (BRR), South Florida Slash from Avon Park (BAS), South Florida Slash from Dade County (BDS), while longleaf pine (*P. palustris*) was represented by one bareroot (Avon Park (BAL)) and three containerized [Avon Park (CAL), Blackwater (CBL), and Withlacoochee (CWL)] taxa. The BAX, BHG, BRR, BAS, and BDS taxa were planted at 6 x 10' spacing in 49-tree (7 x 7) block plots with six replications in a randomized complete block design on January 30, 2005, and the CAL, CBL, and CWL were planted in an adjacent area in Summer 2005 using the same design. BAX, BHG, BRR, BAS, BDS, and BAL were also planted along with 12 of the genotypes in four replications of 6-tree row plots at 6 x 10' spacing. At 3' spacing, all 108 genotypes were planted to the east of cypress east of the above two plantings in single-tree plots with nine replications, while BAX, BHG, BRR, BAS, BDS, CAL, CBL, and CWL were planted in nine replications of 6-tree row plots further to the east. Height and survival of all trees were measured in March 2006.

Eucalypts

E. amplifolia and *E. grandis* studies established at the Kent site (Figure A-1) included clone-configuration-fertilizer study SRWC-90, a demonstration area, and an operational planting in the eastern portion of the site. *E. grandis*, *E. amplifolia*, and cottonwood were planted at different dates and densities in the operational area (Table 9): *E. grandis* in single row/bed (Single-EG), double row/bed (Double-EG), quadruple row/bed (Quadruple-EG) and cottonwood in double row/bed (Double-PD). Trees were planted on beds on 11' centers, except for Quadruple-EG which involved four rows of trees on beds on 23' centers. Spacing between trees on a bed was 3'.

Table 9. Kent Operational Area: Description, Number of 15 x 15 m Study Plots, and Associated Average Tree Height (m), DBH (cm), Density (Trees/ha), Basal Area (m^2/ha) and Quadratic Diameter (cm) in December 2003.

Description	Culture			
	Single-EG	Double-EG	Quadruple-EG	Double-PD
Planting date	Jun. 2001	Jul. 2001	Jun. 2002	Feb. 2002
Planting density	4,836	9,773	7,487	9,773
No. of plots	7	5	4	8
Height	14.6^a (0.9)	11.5^b (1.8)	8.8^c (0.6)	7.0^d (0.7)
DBH	12.0^a (0.9)	8.6^b (1.4)	7.0^c (0.7)	4.9^d (0.3)
Stand density	814^b (248)	886^b (344)	1747^b (231)	3175^a (950)
Stand basal area	13.4^a (4.3)	8.1^a (2.5)	11.0^a (0.6)	9.0^a (3.3)
Quadratic diameter	14.4^a (0.8)	10.9^b (1.7)	9.0^c (0.7)	6.0^d (0.4)

Note: Standard deviations in parentheses; Means in the same row with same letter are not significantly different at 5% level.

E. grandis and *E. amplifolia*, each represented by five or six genotypes, were planted in SRWC-90 in two planting configurations (single or double row/bed) with two fertilizer treatments (0 or 100 pounds ammonium nitrate per acre) in a split-plot design (Table 10). Initial planting was done in March 2001, and fertilizer was applied in June 2002. Spacings between beds and trees were similar to respective cultures in the operational areas. However, a 7.1m gap separated each treatment.

Table 10. Clone-Configuration-Fertilizer Study SRWC-90: Description and Number of 8 x 5 m Study Plots.

Description	Treat. 1	Treat. 2	Treat. 3	Treat. 4	Treat. 5
Culture	Single	Double	Single	Double	Double
Fertilizer*	0	0	1	1	0
Planting density (trees/ha)	4,836	9,773	4,836	9,773	9,773
No. of plots#	4	4	4	8	8

Notes: Planted in March 2001; *0 – unfertilized, 1 – fertilized; #Equal number of plots in *E. grandis* and *E. amplifolia* subplots.

A planting of 640 *E. amplifolia* seedlings (6 progenies) and 1,920 *E. grandis* (14 progenies) in 5- and 4-tree row plots, respectively, in July 2005 completed SRWC-107 at the PRP. Both species were established in each of the five cultures (control, herbicide, mulch, with shrubs, with trees), but *E. amplifolia* was unreplicated while *E. grandis* had three replications.

ECONOMICS

To identify products and prices for our economic analyses, a SRWC market assessment was made in July 2004 in and around Polk County, Florida. On-site and phone interviews were done with individuals from the Florida Division of Forestry, mulch industries, nurseries, electricity generation facilities, and potential biomass producers. Though not all companies interviewed shared market information, a range of price values and demand quantity were derived from the interviews.

As described by Langholtz (2005), SRWC growth and yield functions on CSAs were modeled from *E. grandis* and *E. amplifolia* height, DBH, and survival measurements taken in SRWC-90 on August 20, 2002, July 16, 2003, December 23, 2003, August 27, 2004, and January 11, 2005. A modified volume prediction equation developed by Max and Burkhart (Bredenkamp 2000) predicted volumes of 66 destructively sampled trees (R^2>0.99) and converted height and DBH measurements to per-hectare yields assuming specific gravity of 0.40 (Rockwood and others 1995). Nonlinear regression was used to fit the yield data.

An LEV equation was modified to allow for coppicing forestry systems, which includes *n* number of growth stages (initial growth stage and subsequent coppice stages).

To assess the divergence between private and societal benefits derived from the system, LEVs were then compared to those calculated incorporating a non-timber benefit (NTB) for each growth stage *s.* Quantification and incorporation of the NTB required a functional form which reflects the nature of the benefit provided by the forestry system. In this scenario, the externality to be incorporated is atmospheric CO_2 mitigation.

Tree sequestered atmospheric CO_2, standing aboveground C at time *t* for coppice stage *s,* assuming stage growth function *g(t),* carbon content of 47% by weight (Althoff and others 1996), and multiplying by 1.7 to convert stem inside bark to total aboveground biomass (Mg ha^{-1}) (based on Segrest 2007; Patzek and Pimentel 2005) was estimated. Once carbon is sequestered there is no further benefit from it, so the derivative was used to calculate the marginal benefit of the C sequestration service.

Central to the concept of carbon sequestration is the life span of the sequestered carbon, either in the ecosystem or in products derived from the ecosystem (Murray 2003). As wood products burn or decay, sequestered carbon is re-emitted as CO_2, countering the benefit achieved by the sequestered C. This societal cost of the decay or oxidation of the sequestered carbon was calculated and subtracted. The rate of re-emission depends on the end use of the wood products. The two most likely products identified by a SRWC market survey in Polk County (below) are mulch and biofuel. Decay of C sequestered was handled differently for these two products.

The societal cost of CO_2 emissions from the decay of mulch harvested from stage *s* at age *t,* where *y* is the life of the biomass in years assuming linear decay, discounted first to the end of the growth stage at discount rate *r*, was estimated (Langholtz 2005). For example, for y = 5, $1/5^{th}$ of the harvested mulch would decay during each of five years, based on (Duryea and others 1999; Duryea 1999). Though actual mulch decay may be non-linear and may take longer than five years, the decay function simplified the analysis and provided a conservative estimate of the net C sequestration benefit. This NTB was then included in the optimization model for each growth stage of the mulch scenario and discounted to the beginning of the coppice cycle.

Calculation of the societal costs associated with biofuels emissions was handled differently. SRWCs harvested as DFFSs for gasification or co-firing with coal are likely to be oxidized and returned to the atmosphere as CO_2 within six months of harvest. However, as described above, CO_2 emissions from sustainably produced (i.e., closed-loop) biofuels are re-sequestered in the subsequent rotation, resulting in no net emissions from biomass combustion, and displacing the use of fossil fuels with closed-loop biofuel reduces net CO_2 emissions. Thus, bioenergy from DFSSs produces no net CO_2 emissions, eliminating the need to calculate the costs of post-harvest biomass C decay. However, recognizing that there are fossil fuel inputs to the cultivation, harvest, and processing of SRWC DFSSs consuming up to 10% of the energy produced by the bioenergy system (Forsberg 2000; Heller and others 2004; Klass 1998), 10% of the carbon sequestration benefit achieved at stage age *t* was discounted to the beginning of the stage and subtracted from the carbon benefit. The net NTB calculated for each growth stage for the biofuel scenario was then added.

Models for incorporating C externalities in mulch and biofuel production scenarios, respectively, optimized without incorporation of externalities, were used to calculate LEV and optimum age of each of *n* number of growth stages (Langholtz 2005). The process was repeated iteratively adding an additional growth stage for each scenario until the marginal benefit of the additional stage was negative, identifying the optimum number of growth stages per coppice cycle and associated LEVs. Finally, the sensitivity of these LEVs to variation in the below model inputs was assessed.

While estimates for world carbon prices range from \$4 to \$27 Mg^{-1} C, \$10 Mg^{-1} C was identified as a likely value (Vogt and others 2005; Best and Wayburn 2001). C prices assumed in this model ranged from \$0 to \$35 Mg^{-1} C.

Operational costs on CSAs are higher than those of conventional forestry, due to heavy clays and/or cogongrass infestation. A commercial SRWC on a CSA near Lakeland, Florida incurred costs of \$1,800 ha^{-1} for site preparation and \$1,200 ha^{-1} for planting. To assess the sensitivity of LEV to changes in operational costs, \$900-1,800 ha^{-1} for site preparation and \$600-1,200 ha^{-1} for planting were used, assuming decreasing costs with increased commercialization and economies of scale. Weeding costs of \$0 and \$200 ha^{-1} with the beginning of each growth stage were tested. The model was run assuming interest rates of 4%, 7% and 10%.

Because the response of below-ground C accumulation to harvest scheduling is not known, below-ground C sequestration was not modeled. However, below-ground C sequestration can be estimated and added to LEV as an additional NTB. Root systems of *E. grandis* grown in a CSA in central Florida were 40% of the total biomass (Segrest 2007), roughly equivalent to the above-ground inside-bark biomass. Under SRWC management, root biomass was assumed to peak during the coppice stage that produces the greatest above-ground biomass, and remain steady in subsequent coppice stages and cycles, where decay of dead roots is replaced by re-growth. Anecdotal evidence suggests that greatest yields at the Kent site occur during the first coppice stage and decline in subsequent coppice stages. Therefore, C sequestration in root systems for the first coppice stage (s = 1) at time t was defined to remain constant for the life of the plantation.

Information about SOC accumulation on CSAs in Florida is limited. Wullschleger and others (2004) found that a 2.5-year-old *E. grandis* SRWC planted at 9,800 trees ha^{-1} accumulated 151 and 96 Mg ha^{-1} more SOC than cogongrass at soil depths of 0-30 cm and 30-60 cm, respectively, and estimated that the SRWC would store an additional 274 Mg C ha^{-1} after 25 years, reaching an additional 354 Mg C ha^{-1} after 50 years. A polynomial function was fit to the data as a function of time t (years) after SRWC plantation establishment on a CSA. NPV of the carbon benefit was then calculated. The additional benefit of below-ground (root + SOC) C sequestration was calculated.

As a result of high bulk density, high pH, and the invasion of cogongrass, CSAs are slow to naturally revegetate and are difficult to put into agricultural or forestry production. Tree plantations can contribute to ecosystem restoration of degraded lands by facilitating natural regeneration (Haggar and others 1997; Lamb 1998; Lugo 1997; Powers and others 1997; Parrotta 1992; Parrotta and others 1997) especially in areas dominated by cogongrass (Otsamo 2000; Kuusipalo and others 1995). The establishment of SRWCs on CSAs can reduce soil bulk density, exclude cogongrass, and facilitate the establishment of natural regeneration of native tree species and ecosystem functions. Chapter 378 of the 2007 State of Florida Statutes includes provisions for reimbursement of CSA reclamation costs, ranging from \$2,500-\$4,000 acre^{-1}, funded from taxes on the phosphate mining industry (State of Florida 2007). Because it is not known if SRWC establishment would be recognized as a form of CSA reclamation, and because payment would not be a function of stand growth, mined land reclamation incentives are not included in this model. However, this reclamation compensation to SRWC systems would contribute to the LEV of SRWC production on CSAs.

The model was run for the three scenarios (no NTB, C sequestration in mulch production, and C sequestration/CO_2 displacement in biomass production), under all 288 combinations of interest rates (4% and 7%), site preparation costs (\$900 and \$1,800 ha^{-1}), planting costs (\$600 and \$1,200 ha^{-1}), weed control costs (\$0 and \$200 ha^{-1}), growth functions (low and high) and biomass stumpage prices (\$10, \$20 and \$30 dry Mg^{-1} assuming whole-tree above-ground harvesting) for a fixed C sequestration incentive of \$5 Mg^{-1}, allowing as many growth stages as needed until LEV begins to decline, assuming growth stages decline by 20% per stage. Additionally, sensitivity of LEV and harvest scheduling to C prices of \$15, \$25 and \$35 was tested at a base scenario, as was increasing the cost of capital to 10%. LEVs exclude below-ground C sequestration benefits, the values of which are estimated independently below.

To facilitate economic assessments, the spreadsheet SRWC Decision Support System (DSS) was developed for *E. amplifolia* (Figure A-9). Spreadsheet inputs include all economic, establishment, and management variables, and outputs are LEVs, Equal Annual Equivalents (EAE), and other economic evaluators.

ECOLOGICAL IMPACTS

Ecological impacts of SRWCs on CSAs were assessed through tree, soil, and vegetation responses in studies at Kent and PRP (Table 2). In April 2004, SOC and N analyses of cogongrass-dominated and *E. grandis*-dominated portions of the commercial site at Kent were initiated (Wullschleger and others 2004). Soil samples were collected at two depths (10-20 and 40-50 cm) in two cogongrass and two 3-year-old *E. grandis* areas.

Monitoring of cottonwood, *E. grandis*, and *E. amplifolia* stands for controlling cogongrass and for changes in vegetation composition and soil quality began Summer 2004 at Kent. Twenty-four 15x15m plots were installed in commercial plantings (Table 9), and 30 8x5m plots were taken in SRWC-90 (Table 10). Four stands were selected in the operational area based on species culture, i.e., Single-EG, Double-EG, Quadruple-EG and Double-PD. A representative bed in each stand was identified and a series of 15x15m plots were systematically established along the row at 35m intervals, with the representative bed in the middle of the plot (Table 9, Figure 1). The distance to the first plot was 50m from the stand edge. Five beds and four interbed spaces were inside each plot in Single-EG and Double-EG cultures, whereas only three beds and two interbed spaces were inside Quadruple-EG culture. Understory shrubs/subshrubs and herbaceous species within the plots were quantified using 1x4m and 1x1m quadrats, respectively.

In SRWC-90, 8x5m plots were established taking *E. grandis* and *E. amplifolia* subplots as individual plots (Table 10, Figure 1). Only four plots, two each in *E. grandis* and *E. amplifolia* were taken in Treatments 1 through 3, as cogongrass was dominant and native vegetation was minimal. In Treatments 4 and 5, where the trees were dominant, plots were established in all eight subplots of both *E. grandis* and *E. amplifolia*. cottonwood subplots were not included in this study. Since each treatment had four beds, the middle interbed space was taken as the middle of the subplots to exclude a border row on either side of the plot. There were only two beds and three interbed spaces in each plot. Understory shrub/subshrub and herbaceous species were quantified using 1x4m and 1x1m quadrats, respectively.

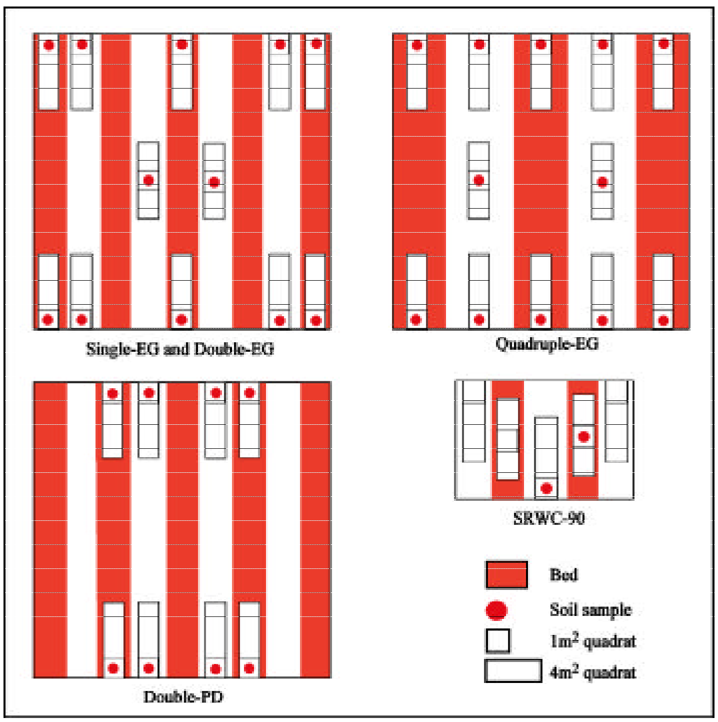

Figure 1. Herbaceous and Shrub/Subshrub Sampling in 15 x 15 and 8 x 5m Plots.

Height and DBH of all trees within the plots in the operational area were measured in August 2004, those in SRWC-90 in January 2005. Vegetation sampling in the operational area and SRWC-90 was done in August 2004 and April 2005, respectively. Herbaceous and shrub/subshrub vegetation cover by species was measured using foliar ocular observation in 1x1m and 1x4m quadrats, respectively. Modified Daubenmire scale (trace, 1-5, 6-10, 11-15, 16-26, 27-49, 50-80, 81-95, or 96-100%) was used to quantify cover (Daubenmire 1959). Both herbs and shrubs/subshrubs were quantified separately for bed and interbed positions. Since all hardwood species were saplings, they were all included in the shrubs/shrubs. The number of individual trees inside each 15 x 15m and 8 x 5m plots was counted while herbs and shrub/subshrub were counted in 1 x 1m and 1 x 4m quadrats, respectively. Only the species rooted inside the quadrat were included. Individual shoots or stems were counted in case of rhizomatous and stoloniferous plants. The whole clump was counted as an individual in case of plants growing in clumps. The canopy of each species was included in the cover estimates regardless of any overlap with other species. Canopy extending over the quadrat was also included in cover estimation, even if the plants were not rooted in the quadrat.

Six bed and six interbed quadrats, both for herbs and shrubs/subshrubs, were taken in each plot in three *E. grandis* cultures in the operational area, while only four bed and four interbed quadrats were taken in the cottonwood stand. In SRWC-90, two bed and three interbed quadrats each for herbs and shrubs/subshrubs were taken (Figure 1). Since canopy cover could not be measured for the trees due to hurricane damage, tree basal area was used instead of canopy cover for correlation. Estimated cover of herbs and shrubs/subshrubs was used to calculate percent cover and species composition.

Soil cores (15cm deep) were taken in the middle of each herbaceous quadrat in the operational area using a 10cm soil corer. Due to small plot size, only a bed and an interbed samples were taken in the middle of the SRWC-90 plots. Samples were air dried, ground and sieved with a 2mm screen. All bed and interbed samples from the same plot in the operational area were mixed, homogenized and composited separately to prepare a bed and an interbed sample per plot. The samples were tested for SOM, N, macronutrients (Ca, Mg, P, K) and pH at the Analytical Research Lab at the University of Florida. SOM was determined using the loss-on-ignition method and total N by Kjeldahl Method. Metals were extracted using Mehlich 3 solution.

Since the Kjeldahl Method could not be used in SRWC-90 samples because of high carbonate content, total N was estimated using NCS 2500 Elemental Analyzer (CE Instruments, Milan, Italy) using Dumas combustion. Samples were combusted yielding a gas mixture in which N was detected by a thermoconductivity detector. A large volume of water was used to extract nutrients in SRWC-90 soil samples as Mehlich 3 could not be used because of high carbonate content.

Procedures for calculating and testing tree, soil, and vegetation parameters at the Kent site are documented by Tamang (2005). Percent coverage, frequency and species composition were calculated separately for individual herbs and shrub/subshrub using the Daubenmire (1959) scale. The Shannon-Wiener diversity index (Shannon and Weaver 1963) was calculated for each species culture in the operational area and in SRWC-90. The Jaccard index (Jaccard 1912) was calculated to see community similarity between different species cultures. Importance Value Index (IVI), the function of cover, density and frequency, was calculated for each species as the sum of relative cover, relative density and relative frequency. Correlations between IVI of the five species with the highest IVI in each culture with stand basal area at 5% significance determined relationships between tree dominance and the vegetation parameter.

At the PRP site, soil and vegetation analyses were initiated in 2005 in three areas: SRWC-107 as described previously, an adjacent natural area (NA), and a cogonmash (CM) area on a nearby CSA. In SRWC-107, each cultural treatment had 8 plots, four each in the summer and winter plantings. Four quadrats were established per plot: a 1x1m quadrat for herbs and a 1x4m plot for shrubs. In each plot, two quadrats were placed on the center row 6 m deep from each end to avoid edge effects. Two quadrats were placed to the left for comparison to plots without SRWCs. In the center of each 1 x 1m herb plot, a 24cm soil core was taken with a 10cm diameter soil corer and analyzed for macronutrients (Ca, Mg, P, and K), pH, NO3, bulk density, and organic matter. Soil samples were collected once during the winter. Vegetation samples were collected in September 2005, and March and May 2006 as described previously for the Kent site to quantify percent cover and species composition. All SRWC trees were measured for height, DBH, and vigor in January 2006, and cottonwood again in late April 2006.

The NA was sampled similarly to SRWC-107. Three 10 x 10m tree plots were installed on two 55 m transects: the first plot 6m from the start of the NA to avoid edge effects, the middle plot 14m from the first plot, and the last plot 14m from the middle plot. Within the tree plots, two 1 x 4m vegetation plots were located on opposite corners of the plot. Tree assessment was performed, and species, count, and percent cover were recorded. Soil cores were taken within the 1 x 1m herb quadrat. The NA was sampled 3 times in a year; soil samples only once in the winter.

The CM site, prepared by "mashing" existing cogongrass into a thick mat with tractor tires and herbiciding any regrowth, had two elevations and was sampled with 6 plots 8m apart on two transects. Therefore, six plots, three per transect, were at high elevation and six at low elevation. Vegetation surveys were performed in March and May of 2006. Twelve 24cm deep soil samples taken in the winter were combined based on their north or south orientation in the two transects to make four composite samples.

Each soil sample, to a depth of 24cm, was placed in a plastic bag. The soil cores were homogenized, air-dried, broken down, and sieved through a 2mm screen, and analyzed for pH, total C, nitrate-nitrogen, and macronutrients (Ca, P, K, Mg). SOM was determined using the Loss-on-Ignition method. Loss-on-Ignition method is used when organic matter is greater than 6%. Metals were extracted using Mehlich-3 solution. Samples were processed by the Analytical Research Lab at the University of Florida.

A separate sample was collected using a bulk density sampler; its total weight and volume were recorded for bulk density calculations. At 110ºC, the sample was oven dried for 24 hours to determine moisture content. Bulk density was calculated based on the dry weight.

Percent coverage, frequency, and density were calculated for individual herbs and shrubs and analyzed separately using SAS. IVI was calculated based on relative cover, relative frequency, and relative density. Analyses of variance compared richness and diversity, and Pearson's correlation analyses explored relationships among growth data and soil variables.

Wallace Laboratories of El Segundo, CA, provided additional soil analyses of the Kent and PRP sites. Some 35 properties were assessed for one SRWC sample from each site. Polyacrylamide (PAM) application suggestions were made for four samples from each site.

RESULTS AND DISCUSSION

SRWC SELECTION AND MANAGEMENT

Cypress

In SRWC-67, nine baldcypress (**BC)** provenances, three **BC** checklots, and 16 pondcypress (**PC)** progenies were generally similar in early height and survival and comparable to a commonly planted baldcypress genetic check (Table 11). Within taxa, individual provenance/progeny differences were significant, but no provenances or progenies were consistently better across cultures.

Table 11. Baldcypress, Pondcypress, and Genetic Check (GC) Minima, Maxima, and Means for Survival and Height at 9 Months in Study SRWC-67.

Survival (%)			Height (m)		
Baldcypress	Pondcypress	GC	Baldcypress	Pondcypress	GC
- , -	- , -	- , -	0.68,1.01	0.57,0.80	0.84,0.96
85.2a*	77.6a	85.4a	0.82a	0.70b	0.90a

*Taxa means not sharing the same letter for the same trait differ at the 5% level.

While overall differences among the four cultures in SRWC-67 were not significant for 9-month tree height, the cultures differed significantly for survival. Both Bedding (B) alone and hay mulch (M) alone increased survival and height over the unbedded, unmulched, and unfertilized control (90.8 and 94.6 vs. 77.9% for survival, 0.75 and 0.87 vs. 0.64m for height), and B + M + fertilizer culture increased height over the control (0.88 vs. 0.64m) but decreased survival (65.4 vs. 77.9%), possibly due to root burn resulting from putting the slow release fertilizer pellets in the planting holes. On CSAs, M effectively controls cogongrass for one year and B improves soil moisture.

Inconsistent topsoil redistribution hindered the growth of 21 **BC** and two Florida **PC** progenies planted on a reclaimed phosphate mine (SRWC-73) near White Springs. After three years, overall survival was 96.4%, but total height was only 0.84m. The 10 **BC** progenies from Arkansas were similar to the 10 from Florida in survival and height.

In SRWC-88, B on another fertile but poorly drained CSA resulted in good initial growth after the July planting (Table 12). All seedlots had 100% survival and were at least 0.9m tall in just seven months, in spite of below normal rainfall and considerable cogongrass competition on the high beds, but growth slowed subsequently. Herbiciding part of SRWC-88 with 5% Roundup Pro™ in November 2003 resulted in renewed cypress growth in 2004 as herbicided and untreated trees were 2.0 and 1.8m tall, respectively, at 49 months of age; herbicided trees had more foliage, as the herbicide was very effective.

Six weeks after planting SRWC-89, as in SRWC-88, good bedding provided excellent initial control of cogongrass, willows, and other vigorous competition common on CSAs in central Florida. Based on a sample of 180 of 1,980 measurement trees, survival was 82.2% survival, and heights ranged from 18 to 38 inches.

Table 12. Minimum, Maximum, and Average Survival (%) and Height (m) at Seven Months for 12 Baldcypress Progenies, One Pondcypress Progeny, and Two Checklots (GC) in Response to Bedding in Study SRWC-88.

Trait	Baldcypress	Pondcypress	GC
Height	0.90,1.10 1.00a*	-,- 0.90b	1.04,1.06 1.05a
Survival	100,100 100a	-,- 100a	100,100 100a

*Taxa means not sharing the same letter for the same trait differ at the 5% level.

In the seed orchard CO97, many of the 12 **PC** progenies, nine **BC** provenances, and three **BC** clones grew well in response to irrigation and weed control (Table 13). Overall, the **BC** provenances had the best survival and largest tree size and SVI, while the **PC** progenies had the best tree quality. The **BC** clones had low survival and the worst tree quality. The ranges among **PC** progeny means were always greater than among **BC** provenance means, suggesting the potential for making more genetic gain by selecting among progenies instead of among provenances. Several **PC** progenies combined good survival with large tree size and desirable quality characteristics. Individual **BC** and **PC** trees were up to 5.2m tall in four years. After 90 months, trees averaged 7.5m in height, and average DBH had increased nearly 10 cm to 13.7cm, with **BC** provenances and clones being near 5cm larger than **PC** progenies.

Production of improved seed for potential commercial planting on phosphate lands began unexpectedly early in CO97 with cones produced in Fall 2000 on trees five years from seed, and the level of production increased for a while (Table 4, Figure A-2). In Fall 2000, 40+ orchard trees produced seed that gave rise to the 2001 seedling production. In 2001, over 90 more trees had cones. Of the 5-year-old **BC** and **PC**, 50% or more of the trees had cones, whereas cone production in the one year younger **BC** progenies occurred on only about 25% of the trees, similar to the level in the **BC** provenances in 2000. Seed and cone production was far heavier in **PC** than **BC** as seed yields per tree were about 50% higher in **PC**, and **PC** cone yield/tree was more than twice as high. While a paclobutrazol treatment was applied in time to influence the 2000 cone crop, its significance for enhancing cypress seed production was unquantified. In 2004, however, no more **BC** trees were producing cones and those that were still had low yields, but more **PC** had cones. Notably, very few orchard trees produced pollen in 2004 or previous years. In 2005, the orchard produced no seed.

A genetic influence on **BC** and **PC** cone production and seed yield was evident in CO97. Individual provenances or progenies in both taxa varied considerably in the onset and degree of flowering, as has been observed in other species. Maximum genetic improvement will be achieved when all orchard trees are flowering and genetically inferior (based on progeny test results) trees are rogued from the orchard.

Table 13. Minimum, Maximum, and Average Survival (S in %), Height (H in m), DBH (D in cm), Stem Volume Index (SVI in m^3/ha), and Tree Quality (Q) of Nine Baldcypress (BC) Provenances, Three BC Clones, and 12 Pondcypress (PC) Progenies in Seedling Seed Orchard CO97 (ex Rockwood and others 2001) at Indicated Ages in Months.

Taxon	S48	H48	D48	SVI48	Q48	D90
BC Provenances	75.0-91.6 88.9a*	2.9-3.7 3.3a	4.0-5.2 4.6a	3.63-6.74 4.91a	2.3-3.5 3.1b	14.8-17.5 15.6
BC Clones	41.7-93.3 63.9b	2.9-3.0 3.0a	3.2-4.0 3.7b	2.37-3.86 2.91b	3.5-5.1 3.9a	13.6-17.5 14.9
PC Progenies.	33.3-75.0 56.3b	2.4-3.8 2.9a	1.6-5.5 3.2b	1.30-3.58 2.44b	1.6-3.5 2.6b	7.2-13.5 10.6

*Taxa means not sharing the same letter for the same trait differ at the 5% level.

High mortality in the commercial cypress planted at Cargill in April 2001 is attributable to the dry conditions that persisted into June. On CSAs, there is obvious need for strict adherence to optimum planting windows and site conditions and for weed control, perhaps through the use of widely spaced planting beds that permit mowing between rows\beds at least twice during the first year.

Survival in the three most recent cypress studies (Table 14) provides further indication of necessary establishment conditions. The high initial survival in SRWC-92 suggests that bareroot cypress can be successfully planted on overburden as late as early March if the site is ripped and has adequate soil moisture. The high mortality and low vigor in SRWC-92 after two years, however, indicates that cypress is not suited to ripped overburden sites with compacted clay soil. On CSAs, December planting of bareroot seedlings on beds can result in high survival, as evidenced by SRWC-94 with 84% survival and 2.6m average height with trees as tall as 4.3m in 31 months, but later planting on mounds without watering is likely to fail. Across all three studies, seed orchard seedlings had 90% or higher survival when planting conditions were favorable and survived better under rigorous conditions. Variation among progenies for survival appears significant.

Bareroot and potted (Figure A-2) cypress seedlings are available from CFL&T to extend genetic and silvicultural studies and for commercial plantings. In addition to the seedlings from new accessions (Table 6), seedlings from over 100 trees in CO97 afford ideal opportunities to utilize the superiority of tested genotypes.

The older **BC** plantations near White Springs, FL, and Chiefland, FL, had modest tree sizes and medium stand densities (Table 15) at the time of measurement. Consequently, stand volume growth was only ~60 cubic feet/acre/year. Stem analyses suggest that tree growth, especially height increment, was rapid for the first five years, then began decreasing.

A new cypress orchard (Study SRWC-106) at the Withlacoochee State Forest failed due to an extremely dry spring in 2004. At initial flush, survival and vigor were good, however.

Table 14. Number of Seedlots (No.) and Mean/Range for Height (H in m) and/or Survival (S in %) of Baldcypress and Pondcypress Sources in Cypress Studies SRWC-92, -94, and -95 at Indicated Ages in Months.

Source	SRWC-92			SRWC-94					SRWC-95	
	No.	S03	S28	No.	H20	H31	S20	S31	No.	S08
Baldcypress										
CO97	1	92 92	13 13	4	1.6 1.6-1.7		82.5 75-90		9	26 4-46
North	3	94 91-96	14 4-29	12	1.7 1.4-1.8		81.2 65-95		13	4 0-8
South	3	81 78-87	10 4-13	14	1.9 1.7-2.1		88.1 80-95		18	3 0-8
Pondcypress										
CO97	2	92 90-92	27 21-33	5	1.6 1.6-1.7		85.0 80-95		12	14.2 0-29
Total	9	89	15	35	1.8	2.6	84.3	84.3	52	9

Table 15. Characterization of Older Baldcypress Plantations by Location and Age.

Location	Age	Ht (m)	DBH (cm)	Trees/Acre	Cu. Ft./Acre
White Springs, Florida	15	9.1	15.7	488	
Chiefland, Florida	12	8.8	14.8	417	900

In cypress plantings at PRP and APAFBR, early survival has been good while growth has been modest. All 162 8-month-old cypress at PRP were alive, but no progeny averaged more than 1m in height (Table 16). Cypress at the APAFBR had over 90% survival while averaging only 0.6m in height following a mid-2005 planting (Table 17).

BC and **PC** comparisons in the current studies are inconclusive. No single study includes a wide enough representation of **BC** or **PC** provenances or progenies to make extensive taxa level comparisons. Different **BC** and **PC** seedlots, and genetic checklots, across the studies also limit comparisons. In addition, these young studies can now only provide preliminary conclusions of rotation length trends.

Still, our results on phosphate mined lands, in combination with FIPR studies (e.g., weeded 6-year-old cypress up to 6.2m tall and 12cm in DBH) and studies elsewhere (Rockwood and others 2001a), suggest potential for cypress plantations on CSAs. Silvicultural enhancements, notably good site preparation, vegetation control, and nutrition amendments, and good quality sites, are essential. Bedding of CSAs is required for successful establishment, and watering at planting appears critical. On overburden sites, ripping alone does not provide for suitable survival and rapid early growth. Bareroot seedlings should be planted before March. Weed control through fall herbicide applications and intense disking before bedding is imperative, and post planting weed control for at least the first growing season is helpful. Genetic improvement particularly through progeny selection can contribute to productivity enhancements as significant differences have been noted among progenies.

Table 16. Mean Height (Ht in m) and Survival (Sur in %) of *E. amplifolia*, *E. grandis*, Cottonwood, Slash Pine, and Cypress by Control (C), Herbicide (H), Mulch (M), Shrub (S), and Tree (T) Cultures and Overall in SRWC-107 at Indicated Ages (in Months).

	Culture										Species Average	
	C		H		M		S		T			
Age	Ht	Sur	Ht	Sur	Ht	Sur	Ht	Sur	Ht	Sur	Ht	Sur
E. amplifolia												
8	0.49	25.0	0.53	37.5	0.89	75.0	1.16	83.3	0.82	96.8	0.86	63.3
E. grandis												
8	1.01	45.8	0.93	50.0	0.95	76.4	1.17	45.8	0.94	56.7	0.99	54.9
Cottonwood												
2	0.18	83.3	0.14	88.9	0.15	65.8	0.13	83.3	0.10	79.2	0.16	80.1
11	4.08	75.0	3.78	63.8	3.17	36.8	2.89	43.8	2.82	29.2	3.48	48.1
Slash Pine												
2	0.15	100	0.16	100	0.14	97.9	0.16	97.9	0.14	97.9	0.10	98.8
11	0.34	50.0	0.35	47.9	0.37	81.3	0.39	29.2	0.29	39.6	0.35	49.6
Cypress												
8	0.89	100	0.92	100	0.84	100					0.89	100
Ave	1.69	58.0	1.53	55.0	1.17	74.0	1.08	54.0	1.21	57.0	1.29	58.8

Table 17. Number of Trees (No), Age (Months), and Mean Height (H in m) and Survival (S in %) in January 2006 for Cypress and Slash Pine in the Avon Park Study.

Component	No.	Age	H	S
Cypress	728	6	0.61	92.6
Slash Pine	972	12	0.28	87.9
All	6683		0.39	70.9

Cottonwood

Cottonwood in SRWC-87 was impacted by weed competition. For November 2000 height and diameter, variation among 73 clones and 10 reps was significant. Because of heavy *Sesbania* in Reps 5 to 10, Reps 1 to 4 were more reliable for further comparison, and in February 2001, were harvested and measured. For height and diameter, variation among 71 clones and four reps was significant. For biomass, clones were not significant, but reps were. For May 2001 height and leaf number, variation among 72 clones and four reps was significant. For diameter, reps but not clones were significant.

Cluster analysis was useful for grouping clones at each measurement date (Table 18). The better performing clones in May 2001 were: 110226, 112127, 112620, ST-67, -70, -72, -107, -240, -265, and -275.

The cottonwood clone-configuration-culture treatments in study SRWC-90 were greatly impacted by drought after hand planting of the 960 cuttings in March 2001. Cuttings were outplanted in March due to concerns that further cold storage would decrease cutting vigor and that later planting would subject the cuttings to excessive weed competition. Unfortunately, the unrooted cuttings stuck in March in soil that was dry at the surface but moist at a depth of about 3" did not have sufficient opportunity to root in the even drier conditions that prevailed into June. Survival dropped to about 30% as the surface soil dried before the cuttings could develop effective root systems. Interplants were established to restore the original study composition.

Consequently, cottonwood compared poorly to *E. amplifolia* and *E. grandis* through 41 months (Table 19). Cottonwood survival was less than 40% in all fertilizer and planting density combinations, and no cottonwood clone displayed tolerance to the high stress planting conditions experienced by the unrooted cuttings. *E. amplifolia* and *E. grandis* seedlings typically have >70% survival, and *E. amplifolia* survival usually was over 90%, even at double row configuration of 3,392 trees/acre. Cottonwood heights and DBHs were usually less than those of *E. amplifolia* and *E. grandis*, especially in the single row configuration, which allowed cogongrass to outcompete cottonwood**.** *E. amplifolia***,** although not necessarily as vigorous as *E. grandis*, tended to highest productivity.

Table 18. Cluster Means for Tree Height (m), Diameter (cm), Leaf Number, and/or Weight (g) and 1st Cluster Clones in SRWC-87 in November 2000, February 2001, and May 2001.

Trait	Cluster				
	1	2	3	4	5
November 2000					
Height	1.31	1.08	0.95	0.81	0.57
Diameter	1.6	1.4	1.1	1.0	0.7
1st Cluster Clones	ST-67, -107, -240				
February 2001					
Height	1.61	1.33	1.30	1.01	0.70
Diameter	1.7	1.6	1.4	1.1	0.9
Weight	82.0	77.4	47.7	25.1	3.4
1st Cluster Clones	ST-67, -153, -240, -261				
May 2001					
Height	1.41	1.31	1.12	0.88	0.34
Diameter	1.4	1.3	1.2	0.9	0.5
Leaf No.	33	46	32	26	12
1st Cluster Clones	ST-63, -67, -70, -72, -107, -213, -240, -265, -274, -275, 110226, 112127, 112620				

Table 19. Cottonwood, *E. amplifolia*, and *E. grandis* Mean Height (m), DBH (cm), and Survival (%) at 28, 33, and 41 months by Unfertilized (U) and Fertilized (F) Treatments with Single (S) and Double (D) Row Planting Configurations on Beds in SRWC-90.

Config.	Fert.	Height			DBH			Survival		
		28	33	41	28	33	41	28	33	41
Cottonwood										
S	U	2.6	3.8	5.1	1.4	2.6	3.5	39	39	38
	F	2.6	3.2	3.7	1.2	1.9	2.3	36	33	32
D	U	6.0	6.8	6.2	5.0	5.4	5.4	29	23	23
	F	8.0	7.9	9.1	5.8	5.9	6.6	36	38	38
E. grandis										
S	U	6.5	8.0	8.8	5.0	6.0	6.5	71	69	88
	F	7.5	8.5	7.5	5.4	6.0	6.6	72	71	79
D	U	6.9	7.5	6.8	4.4	4.6	4.4	72	72	83
	F	10.2	10.5	11.0	6.3	6.6	7.5	69	72	68
E. amplifolia										
S	U	4.7	5.7	6.0	4.1	4.8	5.1	93	92	93
	F	8.2	8.9	8.6	6.8	7.4	7.9	89	90	90
D	U	6.1	6.5	4.8	4.4	4.8	3.6	92	93	91
	F	8.7	9.2	10.0	6.1	6.7	7.4	92	92	91

Based on performance in SRWC-90, cottonwood requires bedding with double row planting on CSAs and fertilization with ammonium nitrate at planting and annually thereafter as feasible. *E. amplifolia* can be expected to have high survival on well prepared bedded CSAs, respond favorably to fertilization, tolerate high stand densities, and coppice reliably. *E. grandis* has the potential to be the most productive species with thorough site preparation and fertilization and properly timed harvesting. *E. grandis* is best suited for immediate commercialization because of its ample availability of seed, while seed of *E. amplifolia* is limited, and cottonwood cuttings are in short supply.

In the demonstration area at Kent, species comparisons before coppicing were similar to the SRWC-90 results, as cottonwood trailed the eucalypts. Cottonwood similarly had poor survival because of droughty conditions. Clonal differences in storage/drought tolerance were observed as one of the five clones failed completely. Growth of surviving cottonwood exceeded 2.5m in height in less than five months. In general, coppice growth initiated by a Spring 2002 felling of each species has been similar to, or greater than, first rotation growth. *E. amplifolia* coppice, though, appears to be more reliable and vigorous than that of *E. grandis*, which in turn, seems better than cottonwood coppicing because of cogongrass resurgence in cottonwood.

The clone nursery planted with 13 promising clones in April 2001 under slightly better moisture conditions than the other 2001 cottonwood studies was less affected by post-planting drought. Based on low survivals and heights in December 2001 (Table 20), several clones are not suitable for plantings on CSAs As most of the clone nursery was leveled and mulch-matted in 2005, the surviving ramets have the potential for annually producing only some 10,000 unrooted stem cuttings for future plantings.

Table 20. Age (Months), Contributing Clones, Range and Mean Height (m) and Survival (%) of Cottonwood in the Clonal Nursery at the Kent Site.

Age	Clones	Survival		Height	
		Range	Mean	Range	Mean
4.6	ST-148 and ST-240.	45-63	54	1.2-1.2	1.2
9	Ken8, S13C20, S7C1, ST-66,-70,-72,-124,-148,-163 -240, -244, -261	3-90	46	1.3-3.5	2.6

The 2001 cottonwood commercial planting at the Kent site was influenced by site conditions, planting date, and planting method. Due to constraints of site preparation and availability of planting equipment, planting was delayed until late April-early May 2001, at which time soil conditions were even more critical and cuttings less vigorous. An automated planting machine, imperfectly matched to the soil conditions, generally failed to "stick" the cuttings adequately into the bedded soil. Accordingly, overall survival of the 10,000+ trees was about 10%. However, the surviving trees were an on-site source of cuttings that was used by CPI to reestablish the commercial planting in 2002.

Early performance of cottonwood at the PRP offsets the species mostly unsatisfactory performance at the Kent site. While its survival under different cultures was as low as 29%, survival was as high as 75% after 11 months with average height exceeding 4m (Table 16). Individual clones were nearly 6m tall. Given ideal establishment conditions and post-planting management, cottonwood could be very productive on certain CSAs and, as evidenced by wind damage at the PRP site, potentially more windfirm than eucalypts.

Current guidelines for cottonwood site preparation, establishment, and management on CSAs are similar to, yet more intensive than, cottonwood culture elsewhere in Florida. Thorough site preparation of flat, poorly drained CSAs through herbiciding, chopping\disking, and bedding by the end of December is desirable. On sloping CSAs, herbiciding, double disking, and rotovating can provide good planting conditions. Only fresh cuttings of tested superior clones should be used, as some commercial clones have performed poorly on CSAs. Fresh cuttings should be planted from January through February and immediately watered and packed. Mechanical planters that apply water and pack simultaneously are advantageous. Close spacing combined with post-planting weed control measures such as mulching may suppress herbaceous competition. Cottonwood harvesting appears best done in the winter by the end of February, so that coppice regeneration suppresses weeds.

Slash Pine

Nearly 60 seedlots (Table A-1) were evaluated in two studies. Early survival of **FE**, **QE**, **EH**, **F_2**, and **EHxEB** suggests that taxa differences are minor when planting conditions are adequate on overburden but may be large when containerized slash are planted late on difficult CSAs (Table 21). Although **FE**, north Florida slash pine, had high initial survival in SRWC-92, many **FE** seedlots survived poorly in SRWC-94. Some **QE** seedlots had acceptable survival on the CSA site, as did some seedlots of the other taxa. After three years on overburden, several **FE**, **QE**, **EH**, and **F_2** seedlots still had over 90% survival, but tree growth was impacted by the compacted clay. On the CSA site, weed competition greatly reduced 3^{rd}-year survival and growth.

Table 21. Number of Seedlots (No.) and Mean/Range for Height (H in m) and Survival (S in %) of FE, QE, EH, F_2, EHxEB, CE, and F_2B Taxa Seedlots in Slash Pine Studies SRWC-92 and SRWC-94 at Indicated Ages in Months.

	SRWC-92					SRWC-94				
Taxon	No.	H15	H28	S15	S28	No.	H18	H31	S18	S31
FE	11	.55ab .30-.64	1.0d 0.7-1.2	95.1 88-100	85.6ab 54-100	8	.91 .65-1.07		28.0 8-46	
QE	12	.58a .32-.68	1.1c 1.0-1.3	94.1 90-100	89.8a 83-100	9	.80 .50-.96		24.1 14-36	
F_1	12	.59a .44-.68	1.4a 1.3-1.5	88.5 75-100	82.4ab 68-92	7	1.16 .99-1.45		26.7 14-33	
F_2	11	.55ab .31-.68	1.3b 1.0-1.5	85.1 68-100	78.4b 58-96	10	1.07 .82-1.25		21.2 10-32	
EhxEB	8	.53b .42-.60	1.3b 1.0-1.5	92.0 83-100	76.7b 54-83	5	1.02 .86-1.19		29.4 0-50	
F_2B			1.4		87.5					
Total	54	.56	1.2	91.0	83.2	34	.98	1.6	25.0	7.7

Note: Taxon means in the same column with the same letter are not significantly different at the 5% level.

After nearly four years, growth and taxa differences in SRWC-92 were greater but slash pine overall performance was still low because of difficult site conditions (Table 22). The F_1 taxon was significantly larger that the native FE taxon, but even the best hybrid family was less than 3m tall. For best growth of slash pine on this overburden site, more intensive site preparation, minimally bedding but ideally bedding + subsoiling with organic amendment, is needed.

Table 22. Mean/Range for Height (m), DBH (cm), and Survival (%) of FE, QE, EH, F_2, EHxEB, CE, and F_2B Taxa Seedlots in SRWC-92 at 46 Months.

Taxon	Height	DBH	Survival
FE	2.1c/1.5-2.4	2.6c/1.9-3.1	84.4ab/54-96
QE	2.2c/1.7-2.5	2.9b/1.5-3.4	87.6[a]/45-96
F_1	2.6a/1.3-2.8	3.7a/1.9-4.1	80.3abc/50-92
F_2	2.4b/1.9-2.9	3.0b/2.5-3.7	76.7bc/50-92
EhxEB	2.4b/1.0-1.5	3.1b/1.9-3.9	74.4c/52-100
Total	2.3	3.1	81.3

Note: Taxon means in the same column with the same letter are not significantly different at the 5% level.

Similarly, the slash pine clones evaluated at the PRP and APAFBR sites in 2005 grew modestly. At the PRP, no clones differed greatly from an overall survival of less than 50% and height of only 0.35m after 11 months (Table 16). In general, the clones survived and grew better in the mulch culture, suggesting that weed control was important for best growth.

At the less fertile Avon Park site, the clones survived well but were even shorter (Table 17). While limited moisture early in 2005 contributed to poor performance at the PRP site, too much water on the flatwoods site at Avon Park during most of the summer restricted growth.

To date, no culture on a CSA, as represented by the flat, poorly drained Kent site or the sloping sand to clay PRP site, has demonstrated adequate suitability for slash pine site preparation and establishment on CSAs. Thorough site preparation through herbiciding, chopping\disking, and bedding by the end of November is desirable. The best **FE** progenies may be obtained as bareroot seedlings from specific forest nurseries. Tree planting should be completed by March and can be done by mechanical planters that apply water and pack simultaneously. Post-planting weed control is imperative for at least the first two years.

Eucalypts

The potential of *E. grandis* and *E. amplifolia* on CSAs was derived from several sets of observations. The limited number of progenies represented at the Kent site in the operational area and SRWC-90 were monitored for almost four years. More progenies in the PRP site have been measured only once.

At the Kent operational area, average tree height and DBH differed significantly among cultures ($p < 0.0001$), ranging from smallest for Double-PD to largest for Single-EG (Tables 9 and 23). Though the planting density of Double-EG was the highest (9773 trees/ha) of the three eucalyptus cultures, their densities in August 2004 were not significantly different. Double-PD density was significantly higher than the three eucalyptus cultures.

Table 23. *E. grandis* Mean Height (m), DBH (cm), Trees/ha, and Productivity (Dry Mg/ha/Year) by Age and by Planting Configuration for Two Plot Types (Square/Rectangular) in the Kent Operational Area.

Configuration	Height	DBH	Trees/ha	Productivity	Age (Years)
Single	12.3/11.7	8.5/8.9	3,118/1,584	35.2/18.8	2.5
Quad	6.4/8.6	5.3/6.7	1,188/1,941	3.1/8.2	1.5

Single-EG had the highest average total basal area (13.4 m^2/ha); the smallest was for Double-EG. However, average total basal area was not significantly different among the different cultures of eucalyptus and cottonwood. The high total basal area in Single-EG was due to larger diameter trees. Higher total basal area in Quadruple-EG and Double-PD compared to Double-EG, however, was due to the higher stand density rather than tree diameter. Quadratic diameter was the largest for Single-EG, while it was the smallest for Double-PD.

Eucalyptus grew comparatively better than cottonwood. *E. grandis* was up to 6.7m in 2.5 years whereas cottonwood was up to 1.3m, when planted in single row (CPI 2003), with average annual yields of 36.1 and 19.9Mg/ha for *E. grandis* and cottonwood, respectively (Stricker and others 2000). Except in Single-EG, both DBH and total basal area in two other cultures were in the range of 3-year-old *E. grandis* in Australia treated with different effluent rates (Myers and others 1996). Early planting of Single-EG and Double-EG contributed to larger height and DBH. Both were planted a year earlier than Quadruple-EG and about 8 months earlier than Double-PD (Table 23). Though Single-EG and Double-EG were planted about a month apart, Single-EG had significantly greater height than Double-EG. Cogongrass in Single-EG had less effect on growth. In spite of later planting date and higher planting density, height of Quadruple-EG was greater than that of Double-PD by 1.8m.

Tree mortality was high in the Kent operational area. Average survival in Single-EG was about 16% and in Double-EG was about 9%. Only 3 rows of trees were present in most Quadruple-EG plots. Survival was 23% in Quadruple-EG and 32% in Double-PD. Low survival in all the stands might be due to the adverse edaphic conditions such as low SOM, drought, and periodic stand ponding. Rainfall in the area was below normal for three months following planting beginning October through December 2001 (17.8, 13.5 and 31.2mm, respectively). August and September, however, were above normal (241.2 and 341.7mm, respectively). Though clay soils retain more moisture, water is lost quickly during the summer, and air pockets around roots create severe stress to newly planted seedlings. Packing/closing planting holes is essential for seedling survival. Though these factors were addressed as possible during planting, they might have contributed significantly to seedling mortality. No replanting was done.

In SRWC-90, Treatment 4 had the largest *E. grandis* and *E. amplifolia* trees as well as the highest stand basal area and quadratic mean DBH (Table 24). *E. grandis* was shortest in Treatment 2 and *E. amplifolia* in Treatment 1. *E. grandis* was taller than *E. amplifolia* except in Treatment 3. Stand density was well maintained in SRWC-90 because dead seedlings were replaced within a few months after the initial planting. Ammonium nitrate applied to both Treatments 3 and 4 a year after planting had a positive effect in tree responses. *E. grandis* leaf area, volume and biomass accumulation were comparatively higher for higher effluent treatment rates in Australia (Myers and others 1996).

Table 24. Average 3.75-year-old Tree Height (m), DBH (cm), Density (Trees/ha), Basal Area (m^2/ha) and Quadratic DBH (cm) by Treatment and Species in SRWC-90.

Response	Treatment 1 (n = 2)	Treatment 2 (n = 2)	Treatment 3 (n = 2)	Treatment 4 (n = 4)	Treatment 5 (n = 4)
E. grandis:					
Height	8.8^{ad} (2.5)	7.3^{bcd} (1.1)	7.6^{bcd} (1.4)	11.4^{a} (0.9)	9.8^{ac} (1.1)
DBH	6.6^{ab} (2.7)	4.3^{b} (0.7)	5.7^{ab} (0.9)	7.8^{a} (0.3)	6.3^{ab} (1.1)
Density	4200^{bc} (848)	8542^{a} (883)	3800^{bc} (282)	5500^{ab} (1000)	6800^{ac} (1758)
Basal Area	16.7^{b} (10.2)	15.3^{b} (6.8)	14.6^{b} (6.3)	32.9^{a} (5.1)	27.2^{ab} (1.3)
Quadratic DBH	7.1^{ab} (2.9)	4.7^{b} (0.8)	6.9^{ab} (1.3)	8.7^{a} (0.4)	7.3^{ab} (1.1)
E. amplifolia:					
Height	5.2^{cd} (1.3)	6.1^{bd} (0.5)	8.7^{ab} (0.7)	10.4^{a} (0.9)	9.3^{ac} (0.7)
DBH	4.6^{b} (0.9)	4.3^{b} (0.8)	7.1^{a} (0.1)	7.6^{a} (0.8)	6.9^{a} (0.7)
Density	4200^{b} (282)	8958^{a} (883)	4600^{b} (282)	8700^{a} (683)	8600^{a} (692)
Basal Area	8.5^{b} (2.2)	14.6^{b} (2.3)	19.4^{bc} (0.2)	46.7^{a} (12.6)	37.8^{ac} (5.1)
Quadratic DBH	5.1^{b} (0.5)	4.6^{b} (0.6)	7.3^{a} (0.2)	8.2^{a} (0.8)	7.5^{a} (0.7)

Note: Standard deviation in parentheses; Means in the same row with the same letter are not significantly different at 5% level.

Based on performance at the Kent site (Table 19), *E. amplifolia* seems most promising for CSAs due to a) greater frost resistance than *E. grandis*, which allows flexibility to plant in late summer during increased rainfall with minimum frost damage to small trees the subsequent winter and b) higher yields than EG despite being planted two months later. Per-hectare inside-bark aboveground yields (dry Mg ha^{-1}) of EG and EA under five treatments are shown in Figures 2, 3, and 4 and Table 25. Decreasing rates of productivity were observed on January 11, 2005 at 3.5 years of age, suggesting an optimizable function could be used for modeling. Based on a 1995 aerial photo, Treatments 1 and 2 had been established on areas where cogongrass was more densely established than the other treatments, probably explaining their lower yields. Treatments 3 and 4 were representative of moderately low and moderately high yields. Considerable variation was observed among the five *E. grandis* and six *E. amplifolia* progenies, with the best progenies such as *E. grandis* 3469 and *E. amplifolia* 5108 as much as tripling the productivity of the poorest progeny in their respective species, depending on treatment. Maximum sustained yields are 17 and 32 dry Mg ha^{-1} $year^{-1}$, comparable to 20-31 dry Mg ha^{-1} year estimated for Eucalyptus in Florida (Rahmani and others 1997) but higher than the estimated 9-17 dry Mg ha^{-1} yr^{-1} estimated by Klass (1998).

Based on early performance at the PRP site (Table 16) combined with experience at Kent, however, growing *E. amplifolia* and *E. grandis* on CSAs has some obvious requirements. Due to a relatively late planting with less than optimal seedlings and minimal post-planting weed control, *E. amplifolia* averaged only 63% survival and *E. grandis* 55%, and both were less than 1m tall after 8 months. Their higher survival in the mulch treatment reinforces the necessity for weed management during the year following planting.

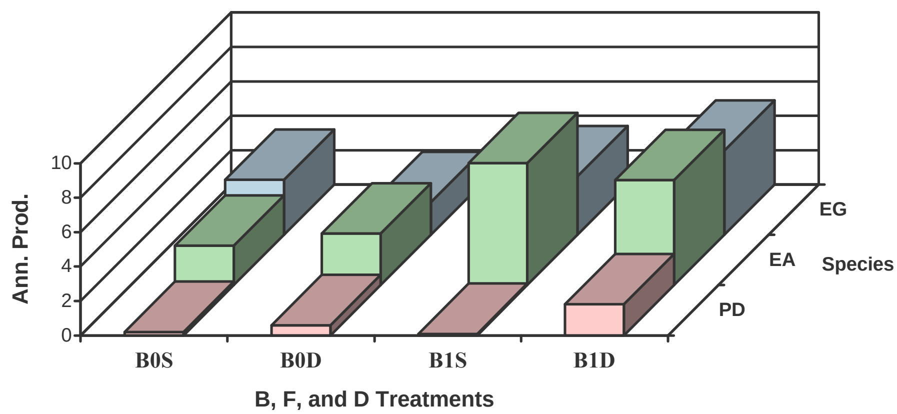

Figure 2. Cottonwood (PD), *E. amplifolia* (EA), and *E. grandis* (EG) Annual Productivity (Dry Mg/ha/year) by Unfertilized (0) and Fertilized (1) Treatments with Single (S) and Double (D) Row Configurations on Beds (B) in SRWC-90.

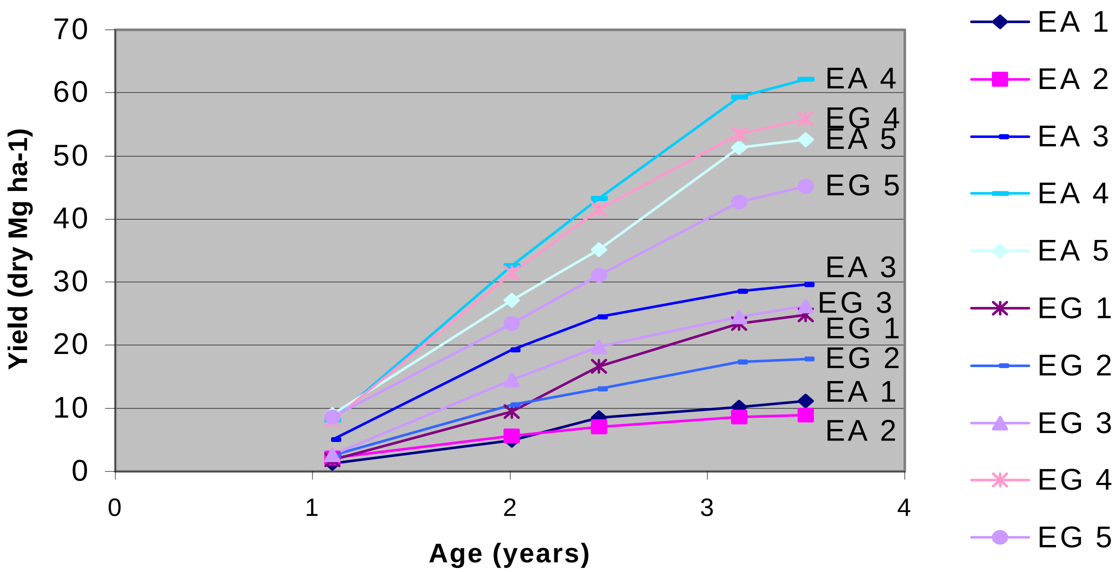

Figure 3. Inside Bark Yields (Dry Mg ha^{-1}) of *E. amplifolia* (EA) and *E. grandis* (EG) in SRWC-90 for 5 Treatments: (1) 4,200 Trees Per Hectare, Unfertilized, (2) 8,400 Trees Per Hectare, Unfertilized, (3) 4,200 Trees Per Hectare, Fertilized with 150 kg ha^{-1} Ammonium Nitrate on May 20 2002 at 11 months, (4) 8,400 Trees Per Hectare, Fertilized as Treatment 3, and (5) same as Treatment 2.

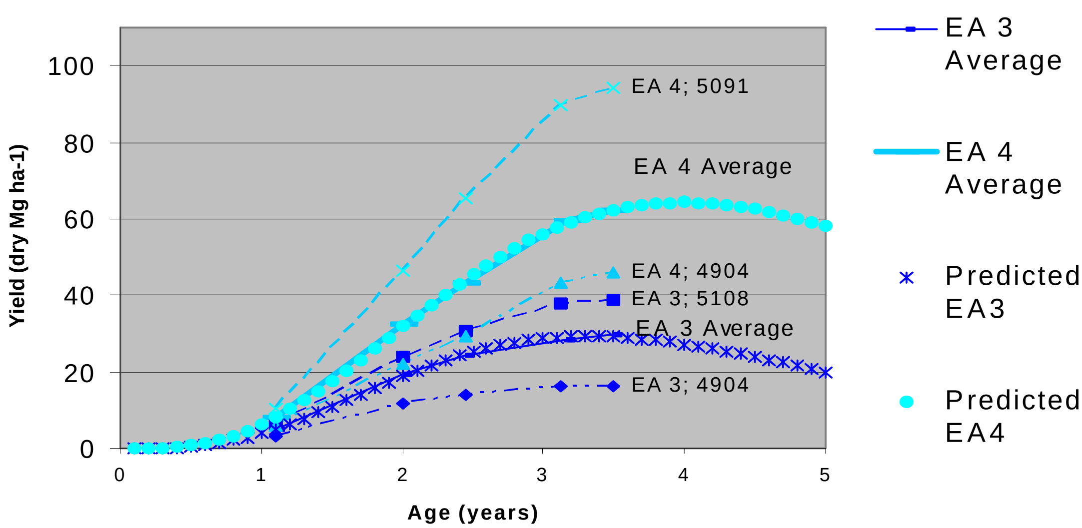

Figure 4. Observed and Predicted Inside Bark Stem Yields of *E. amplifolia* (EA) Treatments 3 and 4, 4,200 and 8,400 Trees per Hectare, Fertilized, and Low and High Progeny Yields for Each Treatment.

Table 25. Number of Trees (n) and Average DBH (cm), Height (m), and Inside-Bark Dry Above-Ground Biomass Yields (Mg ha^{-1}) by Progeny of *E. grandis* and *E. amplifolia* Planted at 4,200 (Single) and 8,400 (Double) Trees ha^{-1}, Unfertilized (0) and Fertilized (1) on May 20, 2002, with 150 kg Ammonium Nitrate ha^{-1}, at 3.5 Years (January 11, 2005) in SRWC-90.

Progeny	Single 0				Double 0				Single 1				Double 1				Double 0 (2)			
	n	DBH	H	Yield	n	DBH	H	Yield	n	DBH	H	Yield	n	DBH	H	Yield	n	DBH	H	Yield
E. grandis																				
3242	11	5.3	7.5	19.3	18	4	7	10.8	10	4.5	6.9	13.7	15	6.0	9.1	29.4	12	5.0	8.2	19.3
3469	12	6.6	8.5	27.2	20	5.5	8.6	23.8	9	8.3	9.7	36.1	15	9.4	12.6	77.3	21	7.0	10	65.9
4064	9	7.7	8.9	30.4	21	3.9	6.9	14.6	10	6.5	9.2	25.5	14	9.4	12.6	78.2	17	5.4	8.9	28.9
4200	10	7.6	9.4	27	20	5.4	8.6	27.2	9	8.5	10.3	36.5	12	7.9	11.9	38.4	19	6.9	10.2	57.8
4223	9	7	8.9	20.2	20	3.7	6.8	12.5	11	6.2	8.4	19.5	15	8	11.3	55.9	16	6.5	9.7	54.5
E. amplifolia																				
4904	12	4.7	5.5	11	18	3.8	5.6	9.7	10	6.5	7.5	16.0	20	6.1	8.3	46.1	20	5.7	7.9	31.6
4907	11	4.2	5.2	5.6	22	2.6	4.0	3.2	12	7.7	9	31.8	19	7.6	10.4	54.8	20	5.9	8.4	32.7
5025	10	3.7	4.6	5.4	23	3.8	5.6	11.2	9	7.4	8.7	23.2	22	7.7	10.4	57.2	19	7.5	10	55.5
5033	12	5.9	6.5	12.1	23	3.8	5.6	10.2	10	8.7	10.0	32.7	23	6.9	9.7	46.6	24	7.4	9.9	68.2
5091	11	5.7	6.5	10.4	23	4.1	5.9	11.1	12	8.3	9.5	35.3	24	8.8	11.2	94.2	22	8.1	10.6	68.9
5108	11	7.3	7.8	22.3	21	3.6	5.3	8.2	12	8.2	9.5	38.8	22	8.1	10.7	73.7	23	7.1	9.5	58.6

ECONOMICS

Potential products from SRWCs on CSAs include mulch, energy, timber, pallets, fiberboard, and biofuels. Our interviews suggest that the most likely products are (1) mulch, an existing multimillion dollar market in Polk County annually, (2) feedstock for electricity generation, a prospective market with much potential for expansion, and (3) biofuels such as ethanol. Prior to the investment in biomass production, purchasing contracts with specific buyers would need to be developed.

Mulch production is a major industry in central Florida, involving companies such as Seaboard Supply in Ft. Green, Greenleaf Products in Haines City, Florida Fence Post in Ona, Forest Resources in Tampa, and Aaction Mulch in Fort Myers. These companies produce mulch from various sources, including sawmill waste of cypress and pine, pine harvests and forest thinnings, eucalyptus plantations in south central Florida, and melaleuca (*Melaleuca quinquenervia*) eradication harvests in southern Florida.

Mulch consumers demand a product that will resist decay, has a desirable appearance, and is reasonably priced. Cottonwood, lacking in decay resistance, is undesirable as mulch. *E. grandis* is desirable due to its red heartwood, attractive scent, and resistance to rot and termites (Milliken 2004). Some mulch users express concern about over-harvesting of cypress and want an alternative to cypress mulch products (Robins 2004). While demand for cypress mulch could serve as an incentive for sustainable cypress management and the establishment of cypress plantations, eucalyptus mulch marketed as "cypress-free" is likely to appeal to consumers concerned about loss of cypress trees.

Mulch is currently produced in part from byproducts from sawmills and small-diameter trees from forest thinnings (Kiella and Zipper 2004). Sawmills convert waste into a product, and forest managers in some cases can reduce costs associated with forest management, forest fuel load control, and eradication of melaleuca. It is uncertain how much of the current biomass market might be displaced if additional biomass is grown on CSAs. However, the market is constrained by supply of desirable material, not demand (Milliken 2004).

Stumpage prices and demand were obtained from two mulch producers (Table 26). Greenleaf Products would pay \$14 green ton^{-1} stumpage (up from \$10 green ton^{-1} in 2002), assuming a minimum supply of 144,000 bags, or 2,600 green tons (Milligan 2004), and could purchase 50 semi loads per day (~26 green tons of eucalyptus load^{-1} for 200 days per year) totaling about 260,000 green tons per year. This would require 17,500 acres in Polk County, assuming 15 green tons acre^{-1} year^{-1}.

Seaboard Supply would pay \$30 green ton^{-1} delivered to its mill 30 miles from Lakeland, FL. At \$2.10 loaded mile^{-1}, a 25 ton load (Hoyer 2006), a 30 mile hauling distance suggests a stumpage value of about \$11.48 green ton^{-1}. Estimated high and low transportation cost scenarios and equivalent stumpage values are shown in Table 27. Seaboard Supply would be willing to purchase up to 25,000 green tons year^{-1}. Assuming

15 green tons acre^{-1} year^{-1}, 1,600 acres of CSAs would meet this demand, a relatively small portion of the estimated 20,000 acres of CSAs in Polk County.

Table 26. Estimated Price (Stumpage for Mulch, Delivered for Biofuels - $ Green Ton^{-1}), Annual Quantity Consumed (Green Tons), and Area Needed[a] (Acres) for Potential Eucalyptus Biomass Markets in Polk County.

Market	Price	Quantity	Note:	Area
Mulch				
Greenleaf (a), Haines City, FL	$8	500 per purchase	Minimum purchase, mixed with other products.	n/a
Greenleaf (b)	$14	2,600	Approx. minimum amount needed per week = 135,000 tons year^{-1}.	8,600
Greenleaf (c)	$14-$16	10,000	Minimum amount needed for Lowes or Home Depot. Up to 260,000 tons year^{-1}.	17,500
Seaboard Supply Ft. Green, FL	$12	up to 25,000 year^{-1}	Based on $30 green ton^{-1} delivered price	1,600
Biofuels				
Lakeland Electric, Lakeland, FL	$10	70,000-140,000	Delivered Price	5,000-10,000
Big Bend, Apollo Beach, FL	$10	50,000	Delivered Price	3,500
Ridge Energy, Auburndale, FL	$0	100,000-200,000	Economic incentives could be applied.	6,000-13,000
Tampa Electric, Mulberry, FL	$10	n/a	Likely to favor herbaceous biomass.	n/a

[a] Approximate area needed for sustained production over a year, assuming growth of 15 green tons acre^{-1} year^{-1} (i.e., annual demand divided by annual production).

Table 27. Estimated Equivalent Stumpage Prices for High and Low Transportation Cost Scenarios.

	High Cost Scenario	Low Cost Scenario
Transportation	40 miles @ $0.08 ton^{-1} mile^{-1} = -$3.36 ton^{-1}	20 miles @ $0.08 ton^{-1} mile^{-1} = -$1.68 ton^{-1}
Harvest Cost (conventional equipment)	-$16 ton^{-1}	-$8 ton^{-1}
Price (delivered)	+$25 ton^{-1}	+$30 ton^{-1}
Equivalent Stumpage Value	$5.64 ton^{-1}	$20.32 ton^{-1}

Note: All tons are green weight.

Large-scale SRWC production on CSAs could make using existing waste biomass resources for mulch economically unviable. Further consideration of the biomass market for Polk County requires (1) a more detailed assessment of the potential for the mulch industry to expand to accommodate greater supply, and (2) an analysis of the potential use of biomass as a feedstock for energy production, as an alternative market for both biomass crops from CSAs and current biomass waste resources.

The biomass market for energy generation, while speculative, is potentially very large. Power generation plants that are using or could use bioenergy include Ridge Generating Station in Auburndale; Lakeland Electric in Lakeland; Big Bend Power Plant near Apollo Beach; and Tampa Electric Polk Power station near Mulberry. Ridge Generating currently charges a tipping fee to receive biomass, ranging from \$8 green ton^{-1} for low ash biomass that is prechipped up to \$35 green ton^{-1} for high ash unprocessed biomass. Ridge might be able to accept SRWC biomass for free (i.e., no tipping fee) if it contains less than 6% ash (no roots and a minimum of soil) and were processed (i.e., chipped to <3"). They use 700 tons per day, and as such would need a sizeable supply (Tuohy 2006). If SRWC biomass is processed and delivered for free, additional economic incentives would be needed, as discussed below.

Lakeland Electric produces 2.8 million MW hours of electricity. As it recently raised rates, further rate increases for renewable energy are unlikely. However, if Lakeland had a 4% renewable portfolio standard (RPS) mandate, it would need to generate 12.5 MWs of renewable energy, equivalent to 9-15 tons of biomass per hour, or 59,000-98,000 dry tons (20% MC on green weight basis) and 94,000-158,000 green tons year^{-1}. Matt McArdle (2006) suggests starting at 70,000 green tons year^{-1} and using up to 140,000 green tons year^{-1} at a likely price of ~\$10 green ton^{-1} delivered.

The Big Bend Power Plant, another possible biomass buyer if an RPS is mandated, could consume up to 50,000 green tons year^{-1}. The Tampa Electric Polk Power Station, while a possible candidate, is more likely to use herbaceous biomass crops due to blocking of one of the flurry feed systems of the gasifier in a trial with woody biomass in 2001 (Curry 2004, McArdle 2004).

A developing market opportunity for SRWCs may be cellulosic ethanol as national, state, and private interests actively consider options including land availability and feedstock alternatives. Cottonwood may have advantages for fermentation-based conversion, and the eucalypts may be preferred for gasification-based systems.

Our first economic evaluation addresses purchasing CSAs for SRWC production. This economic optimization model estimated LEVs for reasonably wide ranges of stumpage prices, site preparation and planting costs, growth rates, NTBs, and interest rates (Langholtz 2005). The base case was 4% interest rate, \$1,800 ha^{-1} site preparation cost, \$1,200 ha^{-1} planting cost, no post-establishment weeding cost, and a carbon price of \$5 Mg^{-1} C. The three biomass stumpage prices assumed were \$10, \$20 and \$30 dry Mg^{-1}. Stumpage prices for eucalyptus may range from \$11-\$44 dry Mg^{-1} (\$5-\$20 green ton^{-1}, or \$10-\$40 dry ton^{-1} assuming 50% moisture content on a green weight basis).

LEVs increased with growth rate and biomass stumpage price (Table 28). Under all combinations of assumptions under a fixed C price of \$5 Mg^{-1} C, LEVs ranged from \$-2,789 to \$4,616 ha^{-1} and \$-224 to \$18,121 ha^{-1} assuming stumpage prices of \$10 and \$30 Mg^{-1}, respectively, comparable to LEVs of a SRWC system in the United Kingdom reported by Smart and Burgess (2000) of \$3,931, \$6,168 and \$14,814 ha^{-1} for market only, low NTB and high NTB model scenarios, respectively (stumpage price of \$31 dry

Mg^{-1}, establishment cost of \$1,538 ha^{-1} and an exchange rate of \$1.54 per £ in November 2000). Under these assumptions, marginal increases in LEV per dollar increment in stumpage price ranged from \$264-\$293 and \$588-\$629 under the low growth and high growth functions, respectively. Marginal benefits of increasing stumpage price were greater with the high growth function, as benefits of increased yield are magnified over multiple rotations.

Table 28. LEV (\$/ha), Optimum Number of Stages and Optimum Stage Length (Years) for Each Stage by C Benefit Scenario and Biomass Price Assuming a Base Scenario of 4% Interest Rate, \$1,800 ha^{-1} Site Preparation, \$1,200 ha^{-1} Planting, and No Post-Establishment Weeding Costs, and a Carbon Price of \$5 Mg^{-1} C.

		\$10 dry Mg^{-1}		\$20 dry Mg^{-1}		\$30 dry Mg^{-1}	
NTB	Growth	LEV	Stages	LEV	Stages	LEV	Stages
None	Low	-1,967	3.1, 3.1, 3.2, 3.3, 3.4	674	2.9, 2.9, 2.8, 2.6	3,722	2.8, 2.8, 2.6
C(M)	Low	-1,883	3.1, 3.1, 3.2, 3.2, 3.3	771	2.9, 2.9, 2.8, 2.6	3,828	2.8, 2.8, 2.6
C(B)	Low	-1,424	3.0, 3.1, 3.1, 3.1, 2.9	1,320	2.9, 2.9, 2.8, 2.6	4,448	2.8, 2.8, 2.6
None	High	619	3.4, 3.4, 3.3, 3.0	6,507	3.2, 3.1, 2.9	12,960	3.2, 3.0
C(M)	High	810	3.4, 3.4, 3.3, 3.0	6,715	3.2, 3.1, 2.9	13,140	3.2, 3.0
C(B)	High	1,832	3.4, 3.4, 3.3, 2.9	7,869	3.2, 3.1, 2.9	14,419	3.1, 3.0

The shortest optimal initial growth stage was 2.6 years under highest stumpage price and interest rate and lowest operational costs, and the longest optimal initial growth stage with a positive LEV was 3.5 years with high operational costs, low interest rate, and low stumpage prices (Langholtz 2005). Increasing stumpage price decreased optimum stage lengths and optimum stages per cycle, as the opportunity cost of the value of the stand increased. Incorporating the C incentive in the mulch product scenario increased optimum stage lengths, while applying the incentive in the biofuel scenario decreased optimum stage lengths due to reduced post-harvest emissions penalties, though differences in stage lengths were less than 0.1 year.

Raising incentives for C sequestration increased LEV (Langholtz 2005). Under the base scenario, increasing the price of C from \$0 to \$35 ha^{-1} increased LEVs from \$6,507 to \$7,965 and \$6,507 to \$16,422 ha^{-1} for the mulch and biofuel scenarios, respectively. The marginal increase in LEV per dollar increment in C price was a constant \$42 in the mulch scenario. Conversely, the marginal benefit in the biofuel scenario was both higher and more responsive to increases in C price, ranging from a marginal increase of \$272 to \$292 at \$5 and \$35 Mg^{-1} C, respectively. This reflects that the biofuel model is less penalized by post-harvest decay of sequestered C, thus increasing incentives for biofuel production rather than *in situ* sequestration.

The marginal LEV reduction per percent increase in capital cost from 4% to 7%, assuming a C price of \$5 Mg^{-1}, was -\$23 under the least profitable scenario and -\$2,928 under optimum assumptions (Langholtz 2005). For the base scenario, the marginal impact of increasing interest rates ranged from -\$192 to -\$2,581. Increases in interest rates from 4 to 7% and from 7 to 10% decreased optimum stage lengths by 0.1 year or less. At increases from 7 to 10%, the model selected for optimization with an additional growth stage, which is consistent with Smart and Burgess (2000), who observed that in SRWC biomass systems the opportunity cost of the standing biomass is low relative to the opportunity cost of the land, and thus increasing interest rate does not shorten rotations as it would with a conventional system, but rather LEVs are reduced, lowering the opportunity cost of the land relative to the marginal benefit of the stand growth, and stage lengths remain relatively unaffected, while the coppice cycle is extended to delay the cost of replanting.

Increases in operational costs decreased LEV (Table 29). Increases in site preparation, which are one-time up-front costs, reduced LEV dollar-for-dollar reduction. LEVs decreased \$3 per dollar increase in planting costs, with slightly higher marginal impacts at higher stumpage prices, reflecting shorter coppice cycles and increased planting frequency. Weed control may be needed to insure high yields, though the exact impact of weed control on growth is not known. LEV decreased \$8 for every dollar increase in weed control cost applied at the beginning of each growth stage. Marginal impacts were the same under the three NTB scenarios, except for the marginal impact of weeding increases from -\$8 to -\$9 in the biofuels scenario assuming \$30 Mg^{-1}, reflecting the shorter optimal stage lengths and more frequent weeding.

Table 29. LEVs and Marginal Impact on LEVs (\$ ha^{-1}) by Changes in Site Preparation, Planting and Weeding Costs (\$ ha^{-1}), Assuming a Base Scenario of C Price of \$5 Mg^{-1}, 4% Interest Rate, High Growth Function, No NTB, and High Site Prep, High Planting, and Low Weeding Costs.

		\$10 dry Mg^{-1}		\$20 dry Mg^{-1}		\$30 dry Mg^{-1}	
	Cost	LEV	? LEV	LEV	? LEV	LEV	? LEV
Site prep (low)	900	1519	-	7407	-	13860	-
Site prep (high)	1800	619	-1	6507	-1	12960	-1
Planting (low)	600	2354		8963		15754	
Planting (high)	1200	619	-3	6507	-4	12960	-5
Weeding (low)	0	619		6507		12960	
Weeding (high)	200	-937	-8	4831	-8	11261	-8

The value of below-ground C sequestration, exogenous in this model, was estimated separately (Langholtz 2005). The estimated value of SOC sequestration, comprising the majority of the below-ground carbon benefit, is influenced only by C price and interest rate. The value of C sequestration in roots is additionally influenced by the growth and yield function. The SOC model by Wullschleger and others (2004) yields 341 Mg ha^{-1} from 0-60 cm depth at 45 years, at a rate of 7.5 Mg SOC ha^{-1} $year^{-1}$,which is greater than 136.3 Mg SOC ha^{-1}, the average for longleaf-slash pine stands to 1m depth (Heath and others 2003). The rate of accumulation is 10 times that of tree plantations on agricultural lands (Garten 2002) but is closer to the 1-3 Mg SOC ha^{-1} $year^{-1}$ sequestration rate in the top 30 cm of reclaimed minesoils over 25 years in Ohio (Akala and Lal 2001), and might be influenced by the longer growing season and deeper measurement depth. Estimating carbon sequestered in roots as equivalent to 40% of the total biomass or 67% of the above ground biomass (based on Segrest 2007) yields 15 and 31 Mg C ha^{-1} after three years for the EA 3 and EA 4 growth curves, respectively. This is more than the 6.6 and 7.4 Mg ha^{-1} of below-ground organic matter after three years of sycamore (*Plantanus occidentalus*) in Tennessee and Mississippi, respectively (Tobert and others 2000), though higher rates of sequestration are expected with a longer growing season and faster growing *Eucalyptus* spp. Assuming a C price of \$5 Mg^{-1}, total estimated below-ground C benefits range from \$650 ha^{-1} (low growth function and 10% interest rate) to \$1,172 ha^{-1} (high growth function and 4% interest rate). Raising the C price to \$15 and \$25 Mg^{-1} approximately increases the below ground C benefit by 3 and 5 times, respectively.

To compare these findings with previously calculated production costs, our model was used to find minimum stumpage prices needed to achieve LEVs of \$1,235 ha^{-1} and \$2,470 ha^{-1}, representing LEVs of conventional forestry (Borders and Bailey 2001) and Florida agricultural land (Reynolds 2005), respectively. Stumpage prices of \$17 and \$21 dry Mg^{-1} generated LEVs of \$1,235 ha^{-1} and \$2,470 ha^{-1}, respectively, assuming site preparation costs of \$1,800 ha^{-1}, planting costs of \$1,200 ha^{-1} and averaging the EA 3 and EA 4 growth functions, equivalent to ~25 dry Mg ha^{-1} $year^{-1}$ and an interest rate of 5%. Rahmani and others (1997) report *Eucalyptus* spp. farm gate production costs for Florida of \$32-\$39 dry Mg^{-1}, slightly less than the \$39-\$43 dry Mg^{-1} farm gate costs estimated here assuming a harvest cost of \$22 dry Mg^{-1}. A higher cost of production is expected given the cost of site preparation on CSAs.

Because of relatively cheap conventional power generation fuels, utilities in central Florida currently pay from \$-35 to +\$10 ton^{-1} delivered for biomass. However, existing government incentives for renewable energy that could improve the profit margin of biomass for energy include the Renewable Energy Production Incentive (REPI, www.eere.energy.gov/wip/program/repi.html, 02-15-2005) and the Section 45 Tax Credit for utilities that pay federal income taxes. REPI is designed to increase the generation and utilization of electricity from renewable energy sources (U.S. Department of Energy 2005). REPI offers 1.76¢ kWh^{-1}, and the Section 45 Tax Credit offers a reduction in taxes of 2.76¢ kWh^{-1}. Assuming a heat rate of 11,500 BTUs kWh^{-1}, 4,238 BTUs lb^{-1}, and woody biomass at 50% MC on a green weight basis, REPI would be worth \$12.97 ton^{-1} or \$25.94 ton^{-1} delivered, and similarly the Section 45 Tax Credit would be worth \$40.69 ton^{-1} delivered. Consumers who chose to pay a premium for renewable energy might be willing to pay the equivalent of an additional \$22.00 green ton^{-1}, while the emerging market benefits of reduced CO_2 emissions from conventional energy or carbon stored in trees on CSAs could be worth \$2.00 green ton^{-1} or more. Because the accumulation of the economic incentives for environmental services could be worth more than standard price for the biomass (Steve Segrest, pers. com.), more work is needed to assess the potential impact of these incentives.

The influence of stumpage price, C sequestration benefit (CO_2 mitigation scenario or C price) or interest rate (from 4% to 10%) on optimum stage lengths is less than one year, and is probably operationally unimportant (Langholtz 2005). Increasing incentives for CO_2 mitigation can increase or decrease optimum stage lengths by about 0.1 year in the mulch and biofuels scenarios, respectively. Harvesting on CSAs would likely be scheduled during the months of December-February when sites are more accessible and coppice response to harvest is best, and practical application of this model is more likely in evaluating the economic viability of the system rather than projecting optimum harvest scheduling to sub-year accuracy. However, this model could be used to suggest the optimum number of stages per cycle and optimal harvest scheduling by identifying the winter closest to the optimum harvest age. Because of the short growth stages, penalties for post-harvest CO_2 emissions from product decay are discounted much less than those of conventional rotations of 20 or more years, countering benefits of *in situ* C sequestration, and underscoring the importance of recognizing the CO_2 mitigation benefit of displacing fossil fuels in the biofuel scenario.

These results emphasize both the potential for DFSSs on CSAs to mitigate atmospheric CO_2 and for CO_2 mitigation incentives to contribute to the profitability of SRWC production. Increases in LEV from CO_2 displacement benefits are on par with increases gained from SOC sequestration, and to a lesser degree, *in situ* sequestration in above- and below-ground biomass. It would probably be impractical to provide incentives and penalties for the sequestration and decay of C for SRWC systems on a per-harvest basis, given the frequent harvest rate *vis à vis* conventional forestry systems. However, this model might be used to assess the present value of CO_2 mitigation benefits over the life of the stand, providing the opportunity to offer incentives without monitoring of each biomass harvest. Though payment of C sequestration benefits independent of harvest monitoring could cause a divergence of private and socially optimum harvesting, these results suggest there is little difference in optimum harvest scheduling of private versus socially optimal SRWC production, and in fact both optimum stage lengths and stages per coppice cycle decrease in the biofuel production scenario, indicating that harvest monitoring might not be needed for a successful CO_2 mitigation program. In the biofuel production scenario, probably the easiest way to incorporate CO_2 mitigation benefits would be for utilities to pass on CO_2 emissions reductions incentives to producers by increasing stumpage price.

Under base case scenario assumptions, even assuming high establishment and planting costs (\$1,800 and \$1,200 ha^{-1}, respectively), a reasonable stumpage price (\$20 dry Mg^{-1}) and excluding C sequestration incentives in the DSS (Figure A-9), production of *E. amplifolia* on CSAs in central Florida is profitable (Table A-3), with LEVs, the amount that could be paid for bare land and still earn the discount rate, ranging from \$762 to \$6,507 ha^{-1} assuming interest rates of 10% and 4%, respectively. With the incorporation of a C sequestration benefit of \$5 Mg^{-1}, LEVs increase to \$946 and \$6,715 ha^{-1}, while recognizing the CO_2 mitigation benefits associated with the biofuel scenario increases LEVs to \$1,315 and \$7,869 ha^{-1} assuming interest rates of 10% and 4%, respectively. In addition, below-ground C sequestration (roots + SOC at \$5 Mg^{-1} C) is likely to be valued at \$1,081-\$1,172 ha^{-1} or \$815-\$900 ha^{-1} assuming discount rates of 4% and 7%, respectively.

Our second economic evaluation assumed that CSA land is already owned and SRWC production involves only establishment and management costs. Under these assumptions, the internal rates of return, the actual return on invested capital, are estimated to range from 4 to 32% (Table 30). As SRWC stumpage price is most likely to be \$10/green ton or higher, rates of return on investment are likely to exceed 12%.

Table 30. Rates of Return for *E. amplifolia* SRWCs Assuming Double Row Planting of 3,400 Trees/acre, \$40/acre Cost per Coppice, and \$10/acre Annual Costs.

Start-Up Costs	Costs per Rotation	Stumpage Price Assumptions (\$/Green Ton)		
\$/acre		\$5	\$10	\$15
\$365	\$243	10.9%	23.8%	31.9%
\$365	\$486	6.0%	17.0%	25.1%
\$730	\$243	7.0%	16.6%	23.8%
\$730	\$486	4.0%	12.4%	19.0%

In light of uncertainty associated with SRWCs, potential financiers might expect a high rate of return on their investment. These results suggest that SRWCs can be profitable at interest rates of 10%, assuming some combination of adequate yields, stumpage prices, NTB incentives, and/or operational costs is achieved.

In either the CSA purchase or CSA owned case, potential SRWC producers need to be aware of cash flows associated with SRWCs (Appendix A-10). Revenues from the first harvest may not offset initial costs. Typically, the second harvest (i.e., harvest of the first coppice at about six years after SRWC establishment) is expected to result in positive net revenue. Subsequent coppice harvests enhance net revenue.

ECOLOGICAL IMPACTS

Soils

SRWC impacts on soils were assessed at the Kent and PRP sites. Preliminary soil N and carbon levels of *E. grandis*-dominated portions of the Kent operational site were much higher than those of cogongrass-dominated sites (Table 31). These ten- and four-fold increases, respectively, suggested that *E. grandis* plantations can contribute significantly to restoring phosphate mined lands.

Table 31. Average Nitrogen and Carbon Levels (%) at Two Soil Depths (cm) in Cogongrass-Dominated and *E. grandis* (EG)-Dominated Portions of the Kent Operational Area (ex Wullschleger and others 2003).

Soil Depth	Soil Nitrogen		Soil Carbon	
	Cogongrass	**EG**	Cogongrass	**EG**
10 to 20	0.04	0.46	1.68	5.29
40 to 50	0.02	0.22	0.76	3.06

In subsequent sampling in the Kent operational area, soil parameters were variously influenced by cultures, plot locations and positions (Tamang 2005). TKN was significantly different in plots within cultures and the interaction between cultures and positions. K differed only in plots within culture and between the bed and interbed positions. Mg, SOM and pH differed significantly between cultures. In addition, SOM varied significantly between positions, pH between cultures and in plots within cultures.

TKN in Quadruple-EG was significantly lower than in other cultures (Table 32). P was highest in Double-EG and lowest in Double-PD. It was also highest in both bed and interbed positions in Double-EG. K decreased from southeast (Double-EG) to north (Single-EG) in eucalyptus cultures. However, Ca concentration increased in eucalyptus cultures from southeast to north and decreased to the lowest concentration of 10448 mg/kg in Double-PD.

Table 32. Average Total Kjeldahl N [TKN (%)], P, K, Ca, and Mg (mg/kg), SOM (%), pH, and BD (gm/cm^3) in Four Cultures in the Kent Operational Area.

Response	Culture (n=4)			
	Single-EG	Double-EG	Quadruple-EG	Double-PD
TKN	0.29^{a} (0.03)	0.32^{a} (0.04)	0.18^{b} (0.07)	0.35^{a} (0.05)
P	4098^{a} (198)	4210^{a} (83.5)	4126^{a} (156)	3778^{a} (794)
K	187.4^{a} (36.7)	234.8^{a} (52.9)	211.7^{a} (56.1)	210.5^{a} (99.8)
Ca	11049^{a} (198)	10821^{a} (1006)	10853^{a} (825)	10448^{a} (1688)
Mg	1257^{a} (79.6)	1169^{a} (55.1)	1277^{a} (86.0)	1109^{a} (35.0)
SOM	5.52^{a} (0.50)	5.65^{a} (1.60)	3.80^{b} (1.20)	6.50^{a} (1.14)
pH	7.8^{ab} (0.2)	7.3^{b} (0.3)	7.9^{a} (0.3)	7.5^{ab} (0.3)
BD (0 to 3 cm)	0.66^{a} (0.07)	0.67^{a} (0.11)	0.66^{a} (0.22)	0.77^{a} (0.13)
(3 to 6 cm)	0.71^{ab} (0.06)	0.67^{b} (0.12)	0.79^{a} (0.08)	0.71^{ab} (0.16)

Note: Standard deviation in parentheses; Means in the same row with the same letter are not significantly different at 5% level.

SOM was highest in Double-PD and lowest in Quadruple-EG. It was highest (6.70%) on the bed in Double-EG and lowest (2.85%) in interbed position in Quadruple-EG. pHs in Single-EG and Quadruple-EG were still quite high, and Double-EG had the lowest (7.3). Bulk density was slightly higher in subsurface (3 to 6 cm), except in Double-PD.

In SRWC-90 at the Kent site, TN was slightly higher in all *E. amplifolia* treatments except 5 (Tamang 2005). TN ranged from 0.28% in Treatment 3 in *E. grandis* to 0.39% in Treatment 4 in *E. amplifolia* and Treatment 5 in *E. grandis*. P ranged from 130.3 to 162.5 mg/kg in *E. grandis*. K was the lowest (81.9 mg/kg) in Treatment 3 in *E. grandis*.

E. amplifolia had both the highest (Treatment 1) and the lowest (Treatment 3) Ca, which was more or less similar in *E. grandis*. Mg ranged from 494.4 mg/kg in *E. grandis* (Treatment 2) to 646.4 mg/kg in *E. amplifolia* (Treatment 5). SOM ranged from 7.96% in Treatment 3 to 9.76% in Treatment 2 in *E. amplifolia*. In *E. grandis*, SOM ranged from 7.75% in Treatment 3 to 9.69% in Treatment 5.

In both eucalypts, pH was almost neutral, ranging from 6.8 to 7.3 in *E. amplifolia* and from 6.9 to 7.2 in *E. grandis*. Subsurface (3 to 6 cm) BD was slightly higher in *E. amplifolia*, except in Treatment 5. However, the surface (0 to 3 cm) BD was slightly higher in *E. grandis*, except in Treatment 1. None of the average soil responses were significantly different. However, surface BDs in *E. amplifolia* were significantly different between positions (Tamang 2005).

Across species, planting densities and ages, few soil properties were significantly different in the Kent studies. Similar results have been observed in different aged stands (Albert and Barnes 1987; Archer 2003; Gilliam and Turrill 1993). N and pH in both the operational area and SRWC-90 were higher than in sandy and loamy soil in 0-30-year-old pine stands (Archer 2003). P and Ca in this study were more than 6 and 1.5 times, respectively, than recorded by Stricker (2000). However, Mg and K were lower. Even the concentrations of N, Ca, Mg and K in the study area were greater than in the overburden of reclaimed phosphate-mined areas (Segal and others 2001).

There were no distinct trends in nutrient levels with planting age, density, or species in the operational area, except that P decreased from Double-EG to Double-PD. In SRWC-90, there were no differences between fertilized and nonfertilized treatments (Tamang 2005). In *E. grandis*, Mg increased considerably from Treatment 2 to 5. P, K, Ca and Mg in SRWC-90, however, were far less than in the operational area.

The extracting solutions used (Mehlich 3 for the operational area and water for SRWC-90 due to high carbonate content) may had an influence. Mehlich 3 extracts more nutrients such as K, Mg, Ca, and P than other methods (Woods and others 2005; Mehlich 1984; Monterroso and others 1999). $CaCO_3$ in calcareous soil reduces the amount of soluble P (Torbert and others 2002), which can reduce the amount in water extraction.

The northern section of Kent had lower nutrient concentrations. Nutrients in study SRWC-89 were less (P = 1028.9, K = 175.1, Ca = 4663 and Mg = 1001.3 mg/kg) (Morse 2003) than in the operational area, but higher than in the nearby SRWC-90. The northern section was comparatively lower, and portions remain under water most of the year, which may lead to nutrient leaching.

SOM in the operational area, as high as 6.50% in Double-PD, was almost similar to that of mineral soil (Table 32). In SRWC-90, SOM was higher in all treatments than in mineral soil. However, both the operational area and SRWC-90 had lower SOM than SRWC-89 (Morse 2003). SOM in this study was 130% more than reported by Wullschleger and others (2004). Leaf litter is the main source of SOM.

Though pH in the operational area was higher, pH in SRWC-90 was similar to SRWC-89 (Morse 2003). Soil pH depends on the presence of SOM. Accumulated SOM acidifies soil and forms soluble complexes with nutrients such as Ca and Mg, leading to their loss through leaching (Brady and Weil 2002). This partly explains lower nutrient concentration and pH in the northern section of the Kent site. The 8 to 8.2 pH before trees were planted appears to have decreased as trees grew.

BD is related to soil texture and SOM. However, BD in this study was far less than that of mineral soil. In SRWC-90, BD of surface soil increased slightly from Treatment 1 to 5, while there was no specific trend in the operational area. Due to the expanding and shrinking nature of clay (Brady and Weil 2002), large cracks developed on the surface during dry periods, filled with water in the beginning of a wet period, and then closed due to swelling. Therefore, BD of montmorillonite soil undergoes periodic changes with the amount of water available. The expansion of the clay may be the reason behind the low BD in the study area.

Due to plantation age and limited translocation of SOM, SOM was mostly confined to the top 15cm. Because SOM was trapped in soil cracks, translocation of SOM in the lower soil profile in CSAs was possible. In some instances, SOM was limited to <15cm, with only the clay content below it. This was observed in the Philippines where SOM was distinct only in the surface soil in cogongrass grasslands and decreased rapidly with depth (Snelder 2001). Similar observations were made in the initial years of bioenergy crop production in areas converted from traditional agriculture where SOM was confined to the top 10cm (Tolbert and others 2002).

SRWC impacts on soils at three PRP sites (SRWC-107, NA, and CM) were evaluated starting in 2005 (Maehr 2006). SOM initially ranged from 7.34% for SRWC-107 to 5.37% for the CM site. Soils high in clay are generally higher in SOM than sandy soils (Brady and Weil 2002), which were more common in NA. Finer textured soils amass more SOM because (1) they typically produce more plant biomass, (2) the soils are less well aerated and lose less SOM, and (3) more of the SOM is shielded from decomposition because it is bound by clay-humus complexes (Brady and Weil 2002).

pH and NO_3-N differed significantly between the PRP sites, but Ca and Mg did not. NA had the lowest pH, CM the highest. SRWC-107 had the most NO_3-N, CM the least. There was a high frequency of legumes in the first vegetation sampling date, mainly hairy indigo in SRWC-107. NA had the highest P, CM the least. SRWC-107 had the greatest K and CM had the least.

Surface BD was less than subsurface BD for all PRP sites. BDs taken deeper in the soil profile are typically greater due to various reasons: lower SOM, less aggregation, fewer roots and other soil organisms, and compaction due to the weight of the overlying layers (Brady and Weil 2002). There was no difference between sites for surface BD ($p = .3928$) or subsurface BD ($p = .6691$).

SOM differed significantly between sampling dates. The greatest SOM occurred for the cottonwood planted in February 2005. After 10 months, SOM dropped to 5.4%. In February 2005, the soil had recently been disked, incorporating much vegetation into the soil for an ample SOM. Similar trends have been seen with SOM dropping as mineralization and tree growth occur in eucalyptus stands (Loumeto and Bernhard-Reversat 2001). pH, P, Ca, and Mg did not change significantly between sampling dates, but K did, averaging 339 mg/kg in February 2005 and 158mg/kg 10 months later.

In SRWC-107, SOM was significantly different with slope. SOM was lowest at the top, 1.7%, where sand was most prevalent. Typically, less SOM is found in sandy soils (Brady and Weil 2002). Likewise, pH, NO_3-N, P, and Ca were also lowest at the top. pH also differed significantly with slope and between species. Surface and subsurface BDs differed significantly with slope, being highest at the top. BD is typically higher in sandier soils than clay soils because solid particles of the fine-textured soils are structured in porous granules, especially when SOM is high. These aggregated soils have pores between and within granules (Brady and Weil 2002). Still, the lowest SOM was observed in the mulch culture, perhaps because the breakdown of mulch is a gradual process and little mulch had decomposed into SOM. Eventually, greater SOM might be the outcome of a longer breakdown period. pH was greatest in the control treatment and lowest in the shrub treatment. Typical CSA pHs range from 7 to 8.3 (Stricker 2000) and analyses revealed a much lower soil pH. This could be attributed to the SOM contributed from the SRWC foliage and from the thick canopy of herbaceous species that dominated the area in September 2005.

The shrub treatment had the most NO_3-N, and the mulch treatment the lowest, but the difference was not significantly different. The wood mulch likely took N from the soil. Shrubs had the lowest P, K, Ca, Mg, BD, and pH. The herbicide treatment had the greatest P, Ca, and Mg.

SOM was greatest (8%) in cypress, which was at the bottom of the slope. Cypress was similar to cottonwood and *E. amplifolia* for SOM but differed from *E. grandis* and slash pine. This could be attributed to the fact that slash pine and *E. grandis* were mainly planted in the sandier, more elevated portions of the PRP site. Cypress and cottonwood also had the highest pHs and NO_3-N. Slash pine had the overall greatest BD, and cypress and cottonwood had the lowest, again due to their location.

Some variables were correlated in SRWC-107 (Maehr 2006). For *E. grandis*, height at 11 months was positively correlated to pH. For cypress, vigor at 11 months was positively correlated to NO_3 and K. For all trees combined, SOM and pH were positively correlated to height. Height was also positively correlated with survival at eleven months. Height was negatively correlated with surface and subsurface BD.

Soil macronutrients were highly correlated. P-Ca, P-Mg, and P-K were positively correlated for each species but cypress. The same macronutrient trends existed for all the trees combined. P was positively correlated with K, Ca, and Mg, K was positively correlated with Ca and Mg, and Ca was positively correlated with Mg. Average pH of SRWC-107 was 6.4; a pH value of 5.5 to 7 usually provides optimal conditions for plant nutrient levels. If P is readily available at a pH of 6.4, the other plant nutrients, if present in ample amounts, will be satisfactorily available for most plants (Brady and Weil 2002).

pH was correlated with SOM in the eucalypts. SOM was also positively correlated with NO_3. Most soil N occurs as part of organic molecules (Brady and Weil 2002). P-K, P-Ca, P-Mg, Ca-K, K-Mg, and Ca-Mg had significant correlations.

Soil analyses conducted by Wallace Laboratories for the Kent and PRP sites were in general agreement with the above results (Tables 32 and 33). P, K, Fe, Zn, Cu, Ca, and Mg levels were high or very high. B and pH were moderate. A liberal application of gypsum (e.g., 2.5 tons per acre) is recommended because the ratio of Mg to Ca is too high for most crops, Zn, Cu, etc., are highly available, and the soils will be easier to manage; however, microbes will reduce gypsum to toxic H_2S in saturated soil (Wallace 2006).

Wallace Laboratories also provided recommendations for the use of polyacrylamide (PAM) for creating good soil aeration (Wallace 2006). In CSAs, 150-300 pounds per acre has produced some excellent soil but only 10-30 pounds per acre may be required for minimal soil preparation. Without gypsum, the need for PAM is much higher (Table 34). The higher recommendation for the Kent interbed soils reflects that, to date, tree derived SOM has only improved soil conditions on the beds where the trees were growing. An additional recommendation is to apply some Micronized PAM and modest amounts of gypsum simultaneously to slurry entering CSAs so that the clay would settle faster and be much easier to handle in the future; smaller clay particles (0.25-0.5") respond best.

Table 33. Soil Analyses by Wallace Laboratories for PRP and Kent Sites.

Element	Site - Sample			
	PRP EG #3		Kent EG #4 Interbed	
	mg/kg Soil	Level	mg/kg Soil	Level
Phosphorus	85.80	*****	14.35	****
Potassium	269.37	*****	121.98	****
Iron	93.06	*****	32.05	*****
Manganese	9.47	****	0.64	***
Zinc	10.15	*****	9.59	****
Copper	4.53	*****	3.37	*****
Boron	0.24	***	0.42	***
Calcium	714.62	*****	518.11	****
Magnesium	736.59	*****	794.81	*****
Sodium	21.28	*	11.84	*
Sulfur	29.42	**	18.71	*
Molybdenum	n d	*	n d	*
Aluminum	n d	*	n d	*
Arsenic	n d	*	n d	*
Barium	n d	*	n d	*
Cadmium	0.88	*	2.22	**
Chromium	n d	*	0.03	*
Cobalt	0.21	*	0.10	*
Lead	0.95	*	1.06	**
Lithium	0.21	*	0.17	*
Mercury	n d	*	n d	*
Nickel	2.36	**	1.11	**
Selenium	n d	*	0.21	*
Silver	n d	*	n d	*
Strontium	0.44	*	0.56	*
Tin	n d	*	n d	*
Vanadium	1.22	**	2.06	***
Saturation Extract				
pH	6.63	***	7.07	***
ECe (milli-mho/cm)	0.46	**	0.15	*
		millieq/l		millieq/l
Calcium	49.1	2.5	25.7	1.3
Magnesium	20.8	1.7	6.2	0.5
Sodium	13.3	0.6	11.7	0.5
Potassium	13.6	0.3	2.7	0.1
Cation Sum		5.1		2.4
Chloride	9	0.2	7	0.2
Nitrate as N	0	0.0	0	0.0
Phosphorus as P	3.7	0.1	6.6	0.2
Sulfate as S	13.3	0.8	5.3	0.3
Anion Sum		1.2		0.7
Boron as B	0.08	*	n d	*
SAR	0.4	*	0.5	*
Gypsum Req. (Lbs/A)	6,660		7,374	

Note: Relative Level - *very low,**low,***moderate, * * * *high,* * * * *very high.

Table 34. Polyacrylamide (PAM) Application Rate (for Top 6" of Soil) Recommendations and Expected Responses for Four Soil Samples from the Kent and PRP Sites (Wallace 2006).

Soil	PAM (Lbs per Acre) Required		Response to		Other Rates
	With Gypsum	Without Gypsum	15 lb/Acre	30 lb/Acre	
Kent					
EG3 Bed	24	72+	Fair	Good	
EG3 Interbed	42	120	Fair	Better- could be better	
EG4 Bed	18	90	Poor	Fairly good	
EG4 Interbed	66	91	Poor	Fair only	75 Very good; more is better
PRP					
EG3	36	70	Good	Very good	150 Excellent
PD1	15	60	Good	Good	150 Excellent
PD2	18	80	Good	Very good	
EA1	15	50	Good	Good	

Vegetation

Vegetation analyses at the Kent and PRP sites indicated dramatic SRWC effects on the types and amounts of understory plants. A total of 57 herbaceous species (40 native, eight introduced, nine unknown) were recorded at the Kent site. A total of 54 species were recorded in the operational area: 33, 35, 26 and 27 for Single-EG, Double-EG, Quadruple-EG and Double-PD, respectively (Table 35, Tamang 2005).

Table 35. Number and Nativity of Herbaceous and Shrub/Subshrub Species in the Kent Operational Area by Culture.

Nativity	Single-EG	Double-EG	Quadruple-EG	Double-PD
Herbaceous:				
Native	25	25	20	22
Introduced	4	4	3	4
Unidentified	4	6	3	1
Total	33	35	26	27
Shrub/subshrub:				
Native	7	17	6	7
Introduced	4	3	2	2
Unidentified	0	3	0	0
Total	11	23	8	9

A total of 26 shrubs/subshrubs (19 native, 4 introduced, 3 unknown) were observed in the Kent operational area. Double-EG had the highest species richness followed by Single-EG (Table 35, Tamang 2005). Quadruple-EG and Double-PD had 8 and 9 species, respectively. The number of introduced species was the highest in Single-EG followed by Double-EG and Quadruple-EG and Double-PD.

In SRWC-90 at Kent, Treatments 1, 2, and 3 were highly dominated by cogongrass, where IVI was as high as 300 (Tamang 2005). Treatments 2 and 5 were identical to Treatment 4 except that the latter had the fertilizer treatment. In Treatments 4 and 5, cogongrass IVIs were 201.7 and 53.4, respectively. Tree size in Treatment 4, while larger, was not significantly different from Treatment 5. Tree responses in Treatments 4 and 5 suggest that cogongrass hinders tree growth, regardless of the treatment.

In SRWC-90, 20 herbaceous species were recorded; 15 were native while the rest were introduced. The highest number of species was found in Treatment 5, with the lowest both in Treatments 2 and 3. Treatments 2 and 3 did not have any other herbaceous species except cogongrass. Within SRWC-90, *E. amplifolia* in Treatment 5 had the highest number of native species (Table 36, Tamang 2005).

Table 36. Number and Nativity of Herbaceous and Shrub/Subshrub Species in SRWC-90 by Treatment and *E. grandis* (*EG*) and *E. amplifolia* (*EA*).

Nativity	Treat. 1		Treat. 2		Treat. 3		Treat. 4		Treat. 5	
	EG	*EA*	*EG*	*EA*	*EG*	*EA*	*EG*	*EA*	*EG*	*EA*
Herbaceous:										
Native	1	0	0	0	0	0	7	4	6	12
Introduced	2	1	1	1	1	1	4	3	5	4
Unidentified	0	0	0	0	0	0	0	0	0	0
Subtotal	3	1	1	1	1	1	11	7	11	16
Total	3		1		1		13		17	
Shrub/subshrub:										
Native	3	1	0	0	0	0	7	6	10	8
Introduced	0	0	0	0	0	0	0	1	1	1
Unidentified	0	0	0	0	0	0	0	0	0	0
Subtotal	3	1	0	0	0	0	7	7	11	9
Total	4		0		0		9		13	

Compared to *E. grandis* plots, *E. amplifolia* plots had more species with significantly different percent cover and frequency in plots within treatments. Even the frequency of six species was significantly different between treatments as compared to only two in *E. grandis*. Percent cover and frequency of *I. cylindrica* were significantly different between treatments and plots within treatments in both *E. grandis* and *E. amplifolia* plots. Species composition was also significantly different in plots within the treatments in both the species plots. However, its species composition was significantly different between treatments only in *E. amplifolia* plots. Position did not have any significant effect on percent cover, frequency and species composition of *I. cylindrica* in both *E. grandis* and *E. amplifolia* plots (Tamang 2005).

Thirteen shrubs/subshrubs were recorded in SRWC-90 (Table 36). Treatment 5 had the highest (13) species richness. Treatments 2 and 3 did not have any shrubs/subshrubs. Only one introduced species, *S. terebinthifolius,* was recorded from SRWC-90.

General characteristics of both disturbed sites and new plantations were obvious at the Kent site. Disturbed site species such as *B. alba, P. americana, S. diphyllum, E. capillifolium, E. serotinum* and *A. artemisiifolia* (Taylor 1992) occurred frequently. Species such as *C. diffusa, S. diphyllum, A. artemisiifolia, C. canadensis, B. halimifolia* and *S. canadensis* are characteristic of moist habitat and new plantations (Miller and Miller 1999). Clay soils are widely known for retaining more water. The Kent CSA seems to be suitable habitat for such species due to nutrient rich and moist soil. Wind and animals play major roles in transporting seeds of these species.

Treatments 1, 2 and 3 in SRWC-90 reflect cogongrass dominated grasslands in terms of species richness. Native species are hardly present in cogongrass grasslands. Regeneration of native species is slow or almost prohibited due to fire and intensive competition, lack of soil seed bank and adverse growing conditions for seedling establishment (Otsamo 2000b).

Multiple disking in this study gave variable results in controlling cogongrass. All planted sites were treated with herbicide and double disked prior to planting. A small area between Double-EG and Quadruple-EG was disked thrice and abandoned (Steve Segrest, pers. comm.) without planting trees. However, cogongrass is completely absent in the area. Similar types of intensive site preparation were done to restore cogongrass dominated grasslands in Indonesia. Sites were disked twice and harrowed with a rotavator before planting (Otsamo and others 1995). Disking cuts underground rhizomes into smaller pieces and exposes them to direct sunlight, which ultimately kills the rhizomes. Rigorous site preparation, weeding (first 2 years) and early canopy closure suppresses cogongrass, but doesn't necessarily eliminate it (Otsamo 2000b).

Rather than planting density, stand age and proximity of Double-EG to a natural area at Kent had significant effect in species richness. Higher numbers of herbs and shrubs were found in Double-EG, which was a year older than Quadruple-EG and Double-PD. Because Double-EG is adjacent to the natural area, there was higher potential for native species to seed into Double-EG. Single-EG was also planted at the same time with Double-EG. Its distance from the natural area might have slowed species recruitment.

Similarly in Indonesia, 4-year-old *A. mangium*, *Paraserianthes falcataria* and *G. arborea* stands in cogongrass grasslands had fewer species regenerate (Otsamo 2000b). Even in SRWC-90, treatments with high density planting (Treatments 4 and 5) both had higher number of herbaceous species and shrubs. Regardless of high density planting, Treatment 2, however, had only one herbaceous species and no shrub/subshrub, probably due to the effect of cogongrass.

Communities at the Kent site were less diverse compared to native communities (Tamang 2005). This might be due to young stand age and the competition of native species with cogongrass. Allelopathy of eucalyptus also might have affected species recruitment. None of the cultures in the operational area were similar. Though herbaceous species diversity in Treatments 2 and 3 in SRWC-90 was zero, they however had the highest community similarity (1.0) indicating the two treatments were similar.

Regardless of species, plantations of equal age had the same community in India (Pande and others 1988). Different understory species composition in plantations compared to that of nearby forest has also been observed elsewhere (Bernhard-Reversat and Huttel 2001), leading to difference in communities.

In the Kent operational area, average IVI ranged from 0.2 for *Eupatorium capillifolium* in Double-PD to 75.2 for cogongrass in Single-EG for herbaceous species (Tamang 2005). The second highest was also for cogongrass in Double-PD followed by 52.7 for *C. dactylon* in Double-EG. In SRWC-90, cogongrass was the dominant herbaceous species and had the highest IVI in all treatments except Treatment 5, in which the IVI was 2.8 in *E. amplifolia*. It had the highest possible IVI in Treatments 2 and 3 in *E. grandis* and Treatment 1 in *E. amplifolia*. Its IVI was almost 300 in Treatments 2 and 3 in *E. amplifolia*. There were no other herbaceous species in Treatments 2 and 3, both in *E. grandis* and *E. amplifolia*.

E. grandis was better than cottonwood in suppressing cogongrass in individual plots in the Kent operational area. Cogongrass was absent in Plot 1 in Single-EG and three plots each in Double-EG and Quadruple-EG. However, it was present in all eight plots in Double-PD. Stands with good growth and early canopy closures are necessary for suppressing cogongrass and to enhance secondary succession. In uneven stands, cogongrass will dominate and will slow secondary succession (Otsamo 2000b).

However, cogongrass IVI varied among plots in the Single-EG culture. While cogongrass was absent in Plot 1, Plots 3, 4 and 7 had the highest tree densities of 1075, 1003 and 1003 trees/ha, respectively. Total basal area was also highest in the culture with 15.3 m^2/ha, 17.9 m^2/ha and 15.4 m^2/ha in Plots 3, 4 and 7, respectively. In Plot 1, the density was 681 trees/ha with total basal area of 11.0 m^2/ha. Despite low density and basal area, cogongrass was well suppressed in Plot 1.

In Double-EG, cogongrass was well controlled in Plots 1, 4 and 5. Plot 1 had the highest density (1477 trees/ha) and total basal area (10.6 m^2/ha) followed by Plot 4. Though Plot 5 had the lowest density (612 trees/ha); its total basal area (7.9 m^2/ha) was higher than that of Plots 2 and 3. Plot 2 had higher density (792 trees/ha), but its total basal area was smaller than that of Plot 3. Cogongrass IVI in Plot 2 (66.8) was less than in Plot 3 (173.6). Tree dominance expressed either as basal area or density seems to be effective. A similar conclusion can be made in the Quadruple-EG culture, where cogongrass was present only in Plot 4 which had the least density (1430 trees/ha).

In Double-PD, stand basal area decreased considerably from Plot 1 (13.2 m^2/ha) to 6 (6.0 m^2/ha) and increased slightly in Plot 7 (6.6 m^2/ha). It, however, decreased again in Plot 8 (5.4 m^2/ha). Tree density did not show any particular trend. However, Cogongrass IVI was considerably lower in plots with higher basal area, except in Plot 8, which had the lowest IVI (3.3) but also the lowest basal area and density (2054 trees/ha). Double-PD also had decreasing cogongrass IVI with increasing basal area.

Total basal area and cogongrass IVI in the Kent operational area were not correlated for three *E. grandis* cultures and for the Double-PD culture (Figure 5, Tamang 2005). This may however, be due to nonlinear data and small sample size (n = 16). *C. dactylon, C. virginiana,* and *C. diffusa* had significant negative associations with cogongrass. *Thelypteris kunthii* was positively correlated (r = 0.51, p = 0.0420), and *B. alba* negatively correlated (r = -0.58, p = 0.0177), with stand basal area.

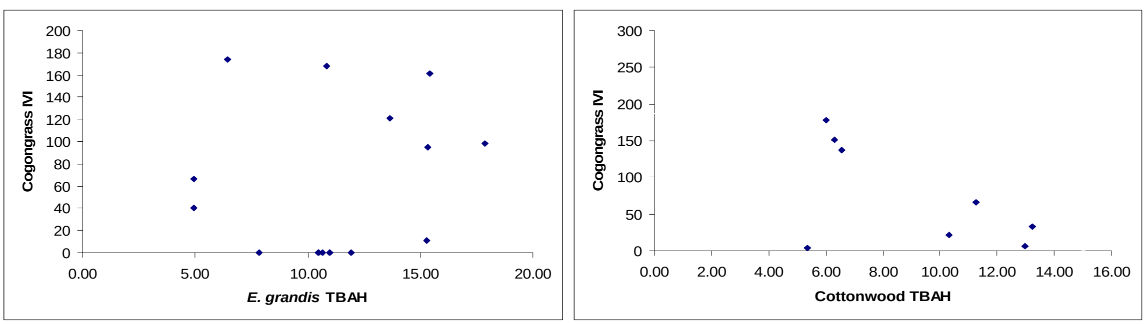

Figure 5. Cogongrass IVI and Total Basal Area Relationships for *E. grandis* (Left) and Cottonwood (Right) in the Kent Operational Area.

In SRWC-90, cogongrass IVI was as high as 300 in both *E. grandis* and *E. amplifolia* in Treatments 1, 2 and 3 (Tamang 2005). IVI decreased with increasing tree basal area only in the case of *E. amplifolia* in Treatment 4. However, there was a considerable decrease in average IVI in Treatments 4 and 5 compared to the first three treatments. Treatments 4 and 5 had comparatively higher total basal area (Table 24). One of the main reasons for cogongrass dominance in SRWC-90 was edge effect. Because of a 7.1m gap between each treatment, originally designed for watering the trees, cogongrass moved into the stands.

However, cogongrass IVI was negatively correlated with both *E. grandis* (r = -0.91, p < 0.0001) and *E. amplifolia* (r = -0.73, p = 0.0028) basal area in SRWC-90 (Figure 6). It was similarly correlated with both eucalyptus species combined across the operational area and SRWC-90 at Kent (r = -0.52, p = 0.0004) (Figure 6). Eucalypts species are apparently superior to cottonwood in suppressing cogongrass. *E. grandis* seems to perform better than *E. amplifolia*.

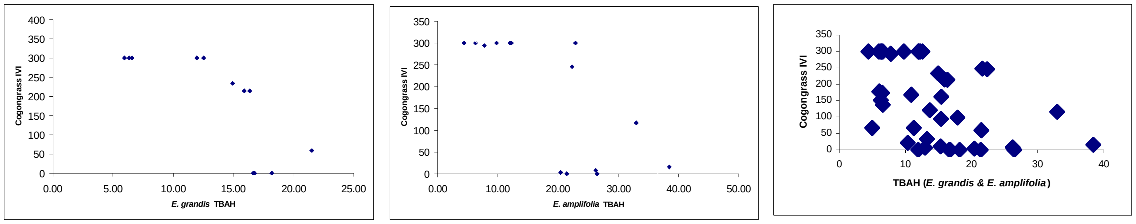

Figure 6. Cogongrass IVI vs. Total Basal Area per Hectare at the Kent site: *E grandis* (Left) and *E. amplifolia* (Middle) in SRWC-90, *E. grandis* and *E amplifolia* (Right) Combined Across SRWC-90 and the Operational Area.

Removing overstory canopy may not have significant effect on cogongrass regrowth in controlled areas. During soil sampling, cogongrass rhizomes were not observed where cogongrass was controlled, indicating less chance of reinvasion from rhizomes. Wind-borne seeds and spread from current patches are the only potential sources. However, seeds are less likely to germinate if the groundcover remains intact. In a fast-growing *A. mangium* plantation in Indonesia, canopy removal to enhance the growth of underplanted *Anisoptera marginata* did not result in cogongrass regrowth in the gaps (Otsamo 1998b). Similar result was found in the gaps created in another *A. mangium* plantation in cogongrass grassland (Otsamo 2000a).

These positive results from Kent have some limitations. Seasonal vegetation and soil quality evaluations were limited since sampling was done only once due to stand damage by hurricanes. The small study area limited the sampling design and subsequent analyses. Problems with metal extraction in SRWC-90 soil samples limited the comparison of soil nutrients between the operational area and SRWC-90.

SRWC impacts on vegetation at three PRP sites (SRWC-107, NA, and CM) were also evaluated starting in 2005 (Maehr 2006). The PRP vegetation study tallied 69 species in the three sites. Five species were common to SRWC-107 and the NA (*Crotolaria spectabilis, Eupatorium capillifolium, Boehmaria cylindrica, Oxalis corniculata,* and *Ptilimnium capillaceum*). All species at the CM site were in SRWC-107, and two species at the NA were observed in the CM site (*Eupatorium capillifolium* and *Oxalis corniculata*). In the NA, 32 herbaceous species (only three introduced) were observed. The CM treatment appears best for preventing vegetation growth.

There were 42 species in SRWC-107. Within all three growing seasons, hairy indigo was observed in 140 plots of 160 plots (88%) but was only growing in Fall 2005. It is a N fixer and alters soil conditions to make the soil more suitable for other vegetation species. N deficiency is a common barrier to plant growth on mine spoils (Bradshaw and Chadwick 1980). The development of a stable ecosystem on mine spoils depends on colonization by N fixing species (Roberts and others 1981), and hairy indigo facilitates the establishment of future plants. Hairy indigo was typically growing with only one other plant species; its highest IVI was 197. Cogongrass was growing in all cultures, most prolifically in the native shrub and tree cultures; it average IVI was 125.

SOM was not an important variable in determining whether cogongrass or hairy indigo was present (Figure 7). Hairy indigo, the primary vegetation in September 2005, did not exist in March or May 2006; dominant species then included sow thistle (*Sonchus asper)* and Mexican clover (*Richardia brasiliensis)*. Cypress had no cogongrass present, and *E. grandis* had minimal cogongrass.

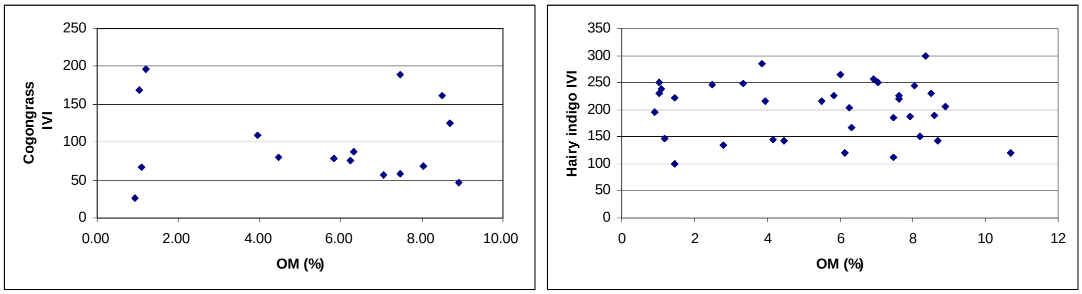

Figure 7. Relationships between Cogongrass (Left) and Hairy Indigo (Right) IVI and SOM in SRWC-107.

The absence in SRWC-107 of many species found in the NA was due in part to stressful conditions and poor dispersal of the native herbaceous species. It might also be attributed to the lack of canopy cover. Also, it is more difficult for native species to compete with introduced species.

A total of 34 shrub species (three exotic) were observed in the three sites (Maehr 2006). Only three were observed in SRWC-107. Saltbush was found at all three sites, and it was the only shrub in the CM area. However, all the saltbush found in the CM and SRWC areas were seedlings. Those in the NA were much vegetatively developed. The top five species for TSC were all found in the NA, except for one that was found only once in SRWC-107 and thrice in the NA. IVI was highest for Saltbush, 271, because it was the most prevalent shrub species in the SRWC.

The NA had 32 shrubs, of which only four were introduced. TSC and IVI differed among species. IVI was greatest for *Ulmus americana* at 126, followed by *Serenoa repens* with 108, *Itea virginica* at 98, Saltbush with 91, and *Urena lobata* at 87. Only three shrub species were observed in SRWC-107. The only shrub present in the CM, saltbush, was in 3 of the 12 plots (25%).

SRWC-107 and CM were much less diverse than NA, perhaps due to young stand age and cogongrass competition, and to allelopathy of eucalyptus and cottonwood in SRWC-107. Shannon-Wiener diversity index for herbs in SRWC-107 was .69, 1.13 for the NA (not typical of most natural forests), and 0.5 for the CM. This could be attributed to too small a sample to get accurate representation of all herbaceous species.

For shrubs, the NA had the greatest Shannon-Wiener index at 1.29. SRWC-107 had a very low .086 since only three shrub species were present. CM had 0 because only one shrub species frequented the site. Only the NA had trees present as part of the vegetation surveys and they had a Shannon-Wiener index of .9.

None of the sites were similar. SRWC-107 was in a very early stage of succession, and number of shrubs will increase. Trees were only found in the NA. A total of 148 trees of 13 species were observed. Height differed significantly among transects (16.3m for transect 1, 13.2m for transect 2) and among species. DBH was also greater for transect 1, 24.7cm vs. 15.8 cm. Baldcypress was tallest at 24m and was the most frequent with 40 observations.

SRWC plantations, particularly *E. grandis* and cottonwood, have the potential to suppress cogongrass on CSAs in central Florida. Though cottonwood forms dense canopy as early as *E. grandis*, its deciduous nature may give cogongrass an opportunity to come back in the understory. In contrast, *E. grandis* forms permanent canopy. Similar observations have been made in Asia using fast-growing trees (Awang and Taylor 1993; Otsamo and others 1997). However, initial intensive management is necessary to suppress cogongrass (Otsamo and others 1995), before the trees can establish in the plantation. Both planting fast-growing trees and intensive site preparation reduce cogongrass rhizomes (Brook 1989; Soerjani 1970).

CONCLUSIONS AND RECOMMENDATIONS

In general, this project has identified that commercial SRWC establishment on CSAs is possible under strict implementation of the following cultural options:

- Herbiciding/disking – for cogongrass control,
- Bedding – for weed control, aeration, and drainage on flat CSAs,
- Watering/packing seedlings – for high tree survival,
- Fertilization with ammonium nitrate – for rapid tree growth,
- High planting density – for early and continuing weed control and high yields,
- Planting eucalypts - *E. grandis* and *E. amplifolia* can dominate cogongrass**.**

Cottonwood cultural requirements of thorough site preparation (herbiciding, disking, bedding), double row planting, fertilization with ammonium nitrate at planting and annually thereafter as feasible, post-planting weed control measures such as mulching to suppress herbaceous competition, and harvesting by the end of February so that coppice regeneration suppresses weeds exceed those of the eucalypts. *E. amplifolia* can have high survival on well prepared, bedded CSAs, respond favorably to fertilization, tolerate high stand densities, and coppice reliably. *E. grandis* has the potential to be the most productive species with thorough site preparation and fertilization and properly timed harvesting. *E. grandis* is best suited for immediate commercialization because of its ample availability of seed, while seed of *E. amplifolia* is limited.

While *E. grandis*, *E. amplifolia*, and cottonwood growth potential on CSAs is quite high, SRWC cost competitiveness is very dependent on establishment success, yield improvements, harvesting costs, and identifying/using incentives (tax, mining reclamation, etc.). Strong collaboration among public and private partners is essential for commercializing SRWCs.

The most likely SRWC products on CSAs are (1) mulchwood, an existing multimillion dollar market in Polk County annually, (2) energywood for electricity generation, a prospective market with much potential for expansion if renewable energy incentives develop, and (3) biofuels. Mulchwood stumpage prices, annual production, and land requirement estimates range from \$11-14 green ton^{-1}, 25,000-260,000 green tons year^{-1}, and 1,600-17,500 acres of plantations, assuming a growth rate of 15 green tons acre^{-1} year^{-1}. The hurricane-damaged 3- to 4-year-old *E. grandis* and *E. amplifolia* at Kent sold for mulch at \$8 ton^{-1} in 2005, but cottonwood was not marketable.

A decision support system spreadsheet, based on an economic optimization model, estimated that stumpage prices of \$15 and \$19 dry ton^{-1} are needed to achieve the conventional forest and agricultural LEVs of \$500 and \$1,000 acre^{-1}, respectively, in Florida, assuming high site preparation and planting costs, average *E. amplifolia* growth, and an interest rate of 5%. Under these same site prep and planting cost assumptions, a reasonable stumpage price, and interest rates of 10% and 4%, production of *E. amplifolia* on CSAs in central Florida is profitable, with LEVs ranging from \$308 and \$2,633 acre^{-1}, respectively. Adding a carbon sequestration benefit increases LEVs to $383 and $2,718 acre^{-1}, respectively, while recognizing the CO_2 mitigation benefits of a biofuel scenario increases LEVs to $532 and $3,185 acre^{-1}, respectively. In addition, the societal value of below-ground carbon sequestration is likely to be $437-475 acre^{-1} or $330-364 acre^{-1}, assuming discount rates of 4% and 7%, respectively. When SRWC production involves only establishment and management costs, the internal rates of return, the actual return on invested capital, are estimated to range from 4 to 32%. As SRWC stumpage price is likely to be at least $10/green ton, rates of return on investment are likely to exceed 12%.

The shortest optimal initial growth stage was 2.6 years under conditions of highest stumpage price and interest rate and lowest operational costs, and the longest with a positive LEV was 3.5 years with high operational costs, low interest rate and low stumpage price. Aboveground yields of *E. grandis* and *E. amplifolia* under five treatments increased rapidly through 3.5 years of age. Under the base scenario presented above, increasing the carbon price from $0 to 14 acre^{-1} increased LEVs from $2,633 to $3,223 and $2,633 to $6,646 acre^{-1} for mulch and biofuel scenarios, respectively. Estimated below-ground carbon benefits range from $263 acre^{-1} to $474 acre^{-1}.

Cogongrass was well controlled in all *E. grandis* cultures in the Kent operational area through hurricane damage in 2004 and harvest in Spring 2005, except where tree survival was very low. Caesar's weed was the dominant understory shrub, whereas creeping dayflower and Spanish needle were the dominant herbs. Other common species included oak, red maple, saltbush, pepper vine, lantana, elderberry, southern shield fern, virgin's bower, dogfennel, passion flower and various grasses. Exotic and introduced species such as Peruvian primrosewillow, twoleaf nightshade, and Chinese tallow were also present. Cottonwood seems to control cogongrass less than *E. grandis*.

In contrast to the operational area, most of SRWC-90 was dominated by cogongrass. A few native species such as southern shield fern, red maple, Virginia creeper, and climbing aster occurred in double row unfertilized and double row fertilized cultures. Fertilized *E. grandis* and *E. amplifolia* performed well compared to unfertilized both in single and double row plantings. Average height and DBH of cottonwood in the double fertilized culture was slightly higher than the double unfertilized and much higher than both single row cultures.

SRWCs seem to be soil-builders that can improve soil N and C status and properties. SRWCs thus may serve as "bridge crops" to restore cogongrass-infested CSAs to native forest or productive agricultural lands. SRWC systems, e.g., agroforestry systems using SRWCs as riparian buffers, may meet societal needs such as renewable energy, carbon sequestration, and remediation of mined lands.

Our preliminary analyses of CSA restoration by SRWCs need to be considerably extended to document the scope of significant changes and to provide guidelines for wide-scale implementation. The most immediate need is for a better understanding of growth response to management options. With such information, particularly with regards to below-ground C sequestration, growth functions and coppice growth, our

Decision Support System spreadsheet can be used to make case-specific evaluations. A better understanding of long-term impacts of SRWC production on CSAs and eligibility for mined-land reclamation incentives would be beneficial, as would assessments of economic multiplier effects on communities in Polk County. In light of the 2004 hurricane season, a feasibility analysis incorporating risk assessment could be useful in assessing potential advantages of SRWCs to reduce the probability of hurricane damage.

All existing plantings should be remeasured, ideally semiannually, for tree size and survival through 2009, and new plantings should be installed on "new" CSAs. Recommendations on genotypes for commercial use should be based on growth, survival, tree quality characteristics, and coppicing success and growth through a full rotation. The 16 *E. grandis* plots harvested in SRWC-90 at Kent in 2004 should be monitored so that coppice productivity can be included in growth and yield modeling and that second-rotation management strategies can be examined. All 24 permanent plots at Kent, SRWC-90, and SRWC-107 could also provide cover, frequency, and composition values for different understory species including cogongrass. Continued monitoring especially of the species-culture study SRWC-107 would apply, extend, and demonstrate results to date concerning the influence of superior genotypes of cottonwood, slash pine, cypress, *E. amplifolia*, and *E. grandis* growing in response to herbicide, mulch, and native interplant treatments on the potential of fast growing trees for restoration of mined lands to improve soil conditions, control invasive species, sequester carbon, and provide a transition to natives.

Ongoing changes in soil quality (nutrients, organic matter, pH), occurrence of cogongrass rhizomes, and performance of the trees (heights, DBH, density) should be documented. Natural succession may require several SRWC cycles. As regeneration of native species largely depends on seed supply, interplanting native species that quickly produce seed with SRWCs might shorten the rate of native species recruitment. Through installation of monitoring wells, SRWC groundwater levels could be compared to those in cogongrass dominated areas.

Eucalyptus species have been criticized throughout the world due to possible allelopathy. Though *E. amplifolia* and *E. grandis* are not known to be invasive, this needs to be firmly documented on CSAs. SRWC success in controlling cogongrass largely depends on permanent canopy coverage, including coppice rotations after harvests. Close spacing is very important. Dense planting can reduce edge effect.

Price variability for energywood, mulchwood, pulpwood, and sawtimber could be further assessed by continuing to interview individuals and firms that are active in the Polk County area. Production cost information could also be collected. Economic evaluation should use several economic indicators, including (1) LEV, (2) EAE, and (3) IRR. A simulation-based risk analysis could be conducted using a range of real discount rates and varying price and cost assumptions using specialized spreadsheet software. Climatic risks can also be included in the modeling. Optimal economic and biological rotation ages under all cases can be determined. The decision analysis spreadsheet for growing commercial *E. amplifolia* should be updated and expanded to other species.

Verification that SRWCs improve SOC and N in CSA soils will substantiate (1) the use of SRWCs for CSA restoration, making CSAs conducive to sustainable agricultural or forest production and (2) soil physical changes promoted by SRWC systems. If SRWCs increase the stability of SOC and sequester significant quantities of SOC, then further study will provide the basis for marketing carbon credits in developing carbon markets. More study will also confirm SRWC systems with potential economic benefit and formulate species-specific guidelines for CSA restoration.

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Appendix A

FIGURES AND TABLES DESCRIBING PROJECT RESEARCH

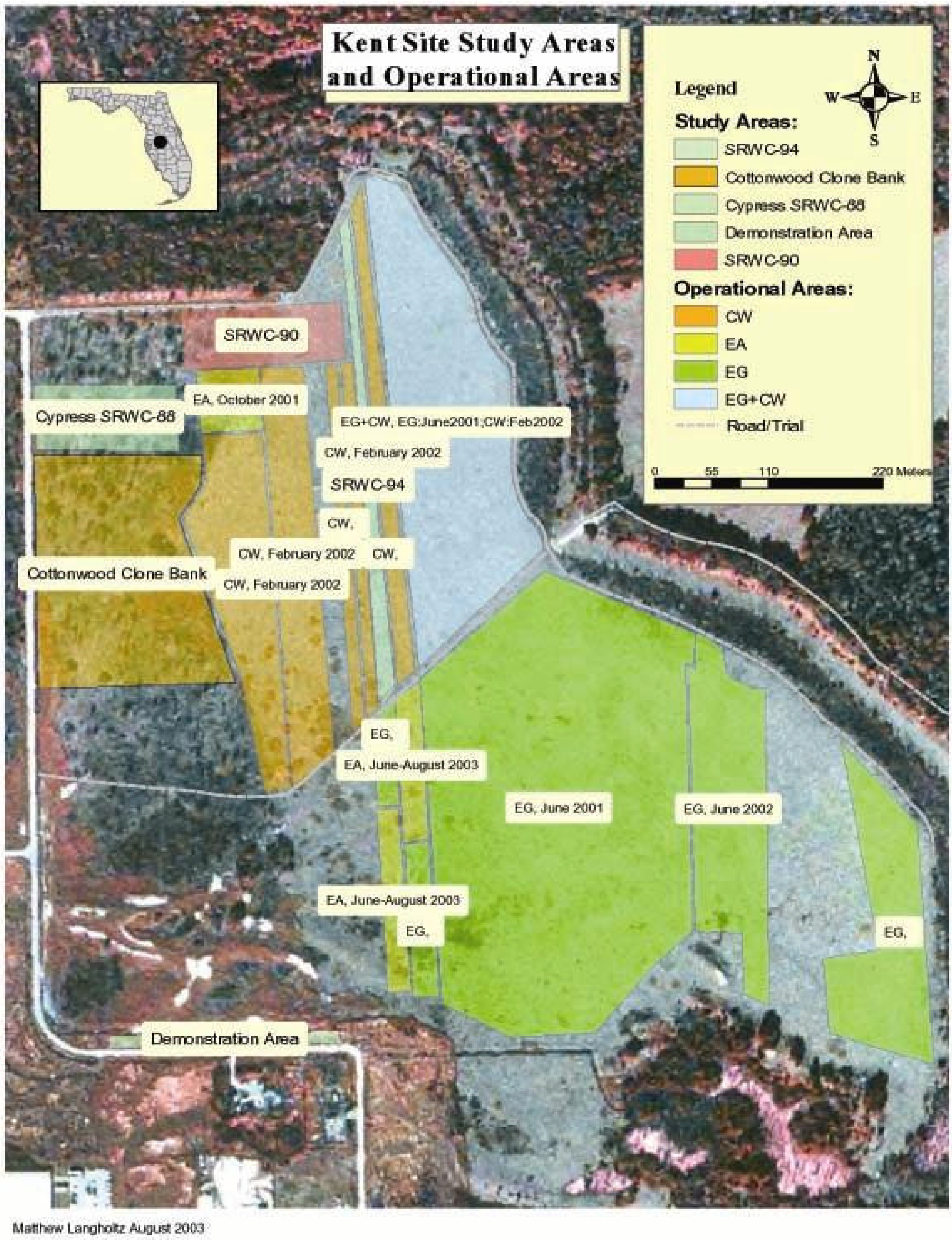


Figure A-1. Map of Kent Site Study and Operational Areas.

Figure A-2. Cypress Seedlings and Seed Orchard: 4-Month-Old Bareroot Cypress Seedlings Growing at CFL&T for 2001 Plantings (Top Left), Potted Cypress Seedlings from CFL&T for June 2001 Plantings (Top Right), Cypress Seedings for SRWC-89 at Cargill CSA (Bottom Left), Heavy Cone Crop on 4-Year-Old PC in CO97 Seed Orchard at CFL&T (Bottom Right).

Table A-1. ID, QFRI or UF Pedigree, Growth Breeding Values of FE and QE Taxa Seedlots, and Allocation of Seedlots to Two Slash Pine Studies.

	Seedlot	UF\QFRI		Growth Breeding Value		Study SRWC-	
Taxon	ID	Dam	Sire	Dam	Sire	92	94
FE	FE1	270-56	35-60	22	41	X	X
FE	FE2	35-60	49-57	41	32	X	X
FE	FE3	270-56	49-57	22	32	X	X
FE	FE4	179-55		27		X	X
FE	FE5	245-55		14			
FE	FE6	89-57		24		X	
FE	FE7	158-58		15		X	X
FE	FE8	52-56		22		X	X
FE	FE9	41-62		18		X	
FE	FE10	164-57		17		X	X
FE	FE11	166-57		13		X	X
FE	FE12	249-55		11		X	
QE	QE1	1ee1-142				X	
QE	QE2	1ee3-027				X	
QE	QE3	2ee1-149				X	
QE	QE4	2ee1-170				X	
QE	QE5	2ee1-188				X	X
QE	QE6	1ee1-144				X	X
QE	QE7	1ee2-066				X	X
QE	QE8	1ee1-130				X	X
QE	QE9	2ee1-107				X	X
QE	QE10	2ee1-108				X	X
QE	QE11	1ee1-161				X	X
QE	QE12	1ee2-012				X	X

Figure A-3. Chronological Development of *E. grandis* Operational Area at Kent Site: Top-Left) Aerial View of Site ~1995, Top-Middle) Cogongrass on Site in 2000, Top-Right) Herbicided Cogongrass, Middle-Left) "Wide" Bed, Middle-Middle) *E. grandis* at 2.5 Years, Middle-Right) Native Understory at 2.5 Years, Bottom-Left) Aerial View of Site at 2.5 Years Showing Areas with and without SRWC Dominance, Bottom-Middle) EG After 2004 Hurricanes, Bottom-Right) Commercially Harvested EG in March 2005.

Figure A-4. Cargill LP9 Overburden Site for 2002 Slash Pine and Cypress Study SRWC-92.

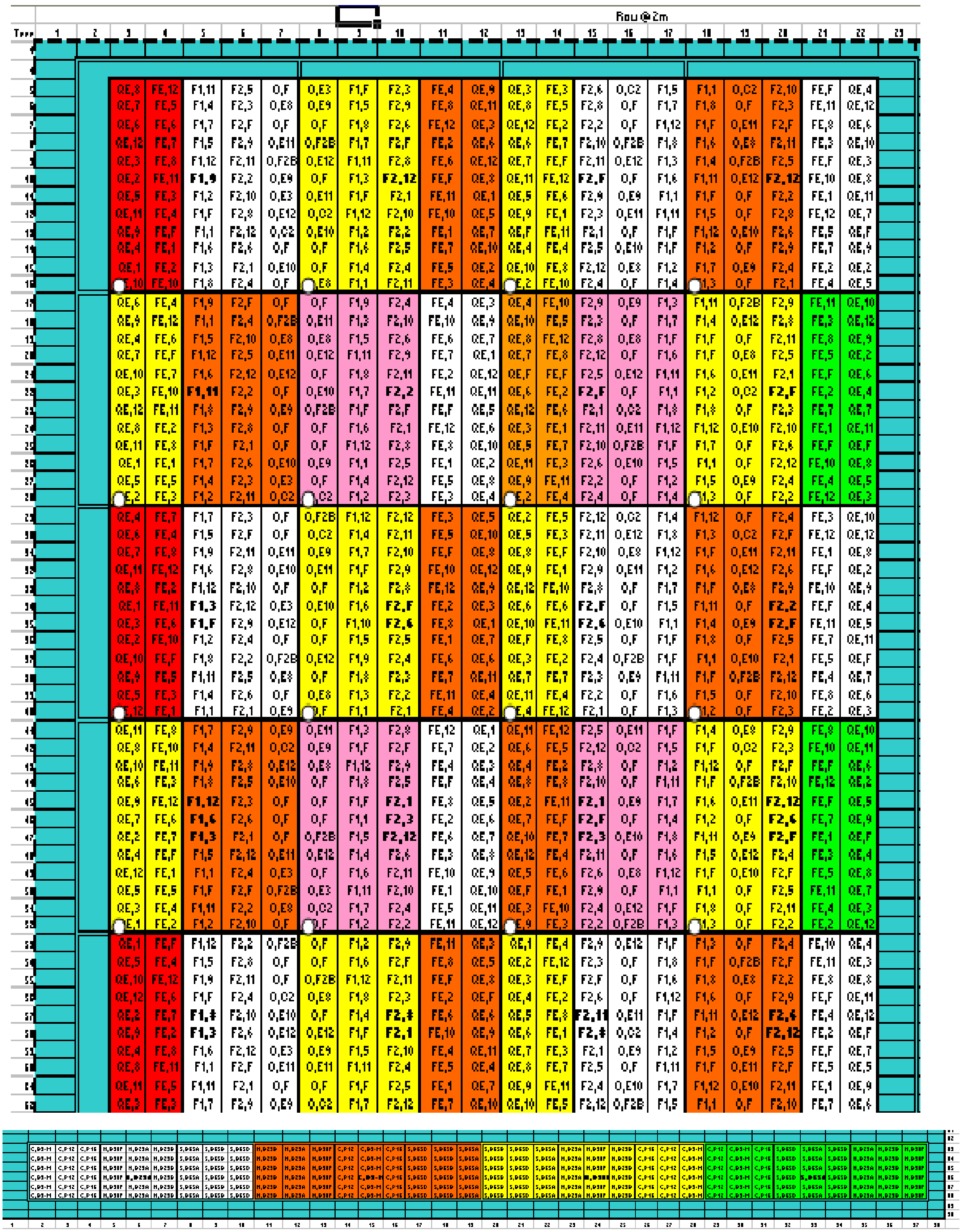


Figure A-5. Slash Pine (Top) and Cypress (Bottom) Components of SRWC-92 on Mosaic LP9 Overburden Site.

Figure A-6. Research Sites East of Homeland, FL: IMC-Agrico Peace River Park (North of CR 640 with SRWC-107 to the Left and Natural Area to the Right) and Cogonmash Site to the Bottom Right off Photo.

Table A-2. Number of Clones and Seedlots of Five Slash Pine Taxa in SRWC-107 at Homeland.

Taxon	Clones	Seedlots
F_1	64	1
F_2	12	1
BCH	10	
BCE	13	
PEE		8
Total	99	10

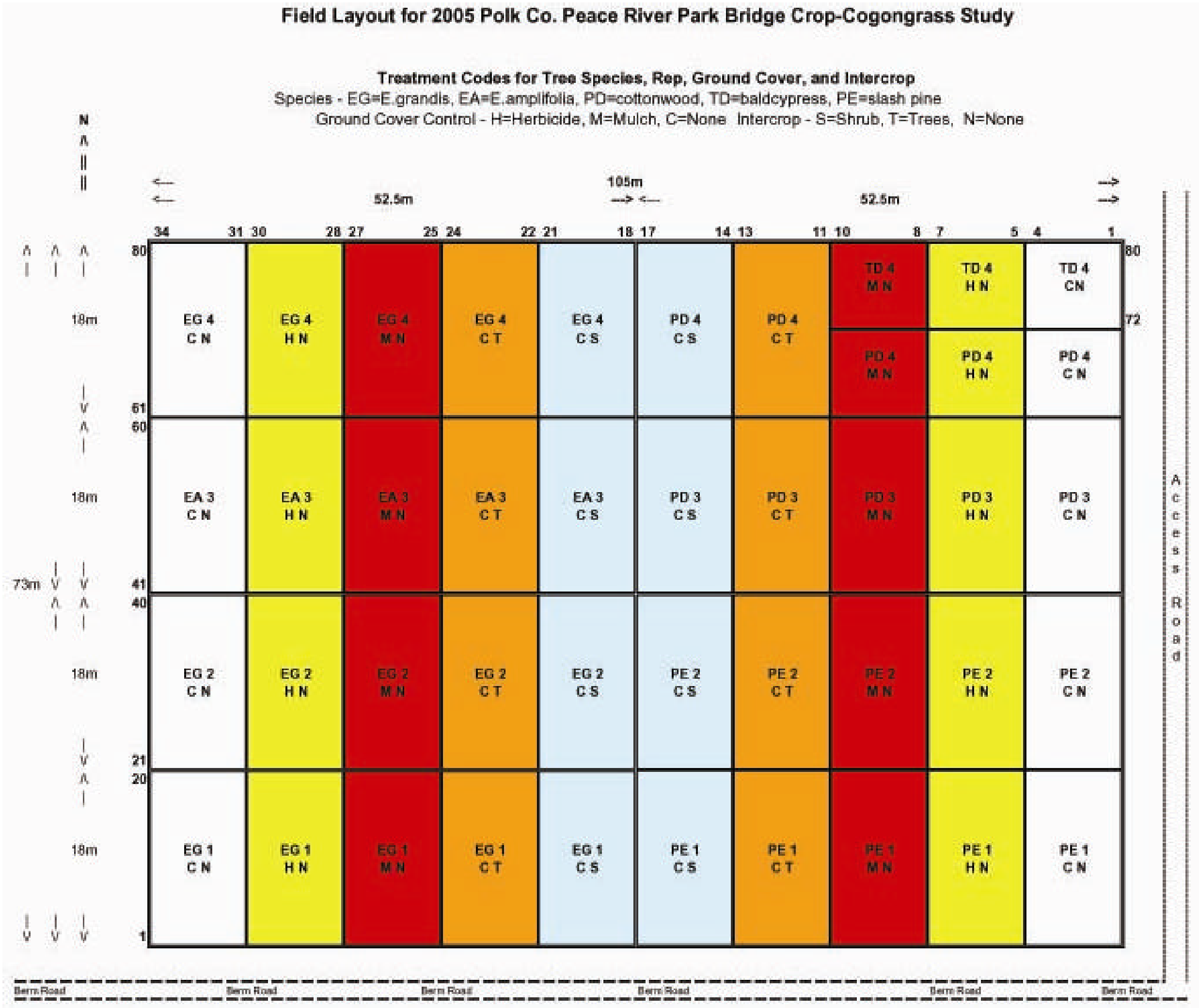


Figure A-7. Cottonwood, Slash Pine*, E. amplifolia, E. grandis,* and Cypress Components of SRWC-107 at the IMC-Agrico Peace River Park.

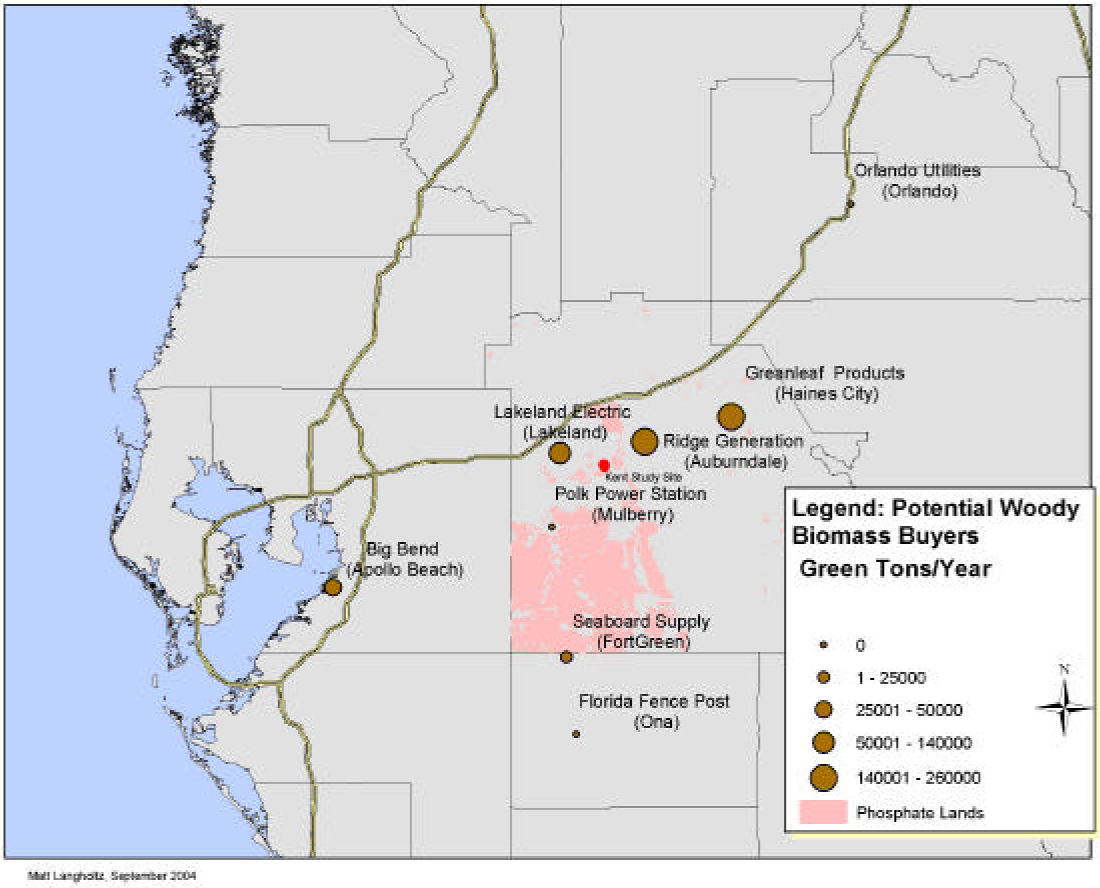
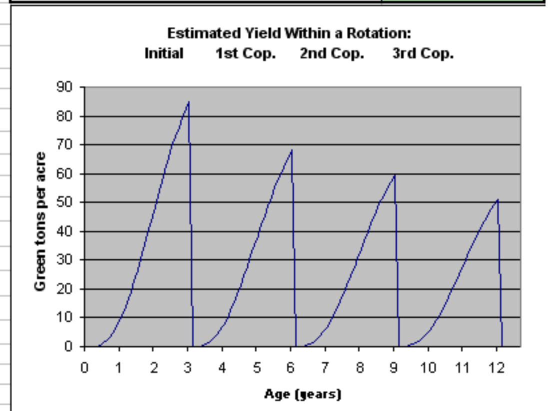


Figure A-8. Location of Potential SRWC Markets.

SRWC Decision Support System:
Land Expectation Value (LEV), Equal Annual Equivalent (EAE), Internal Rate of Return (IRR), and Net Present Value (NPV) Calculator

INPUTS	
Stumpage Price, Incentives, Capital Cost	
Stumpage price (\$ green ton^{-1})	$10
Renweable Energy Porfolio Incentive (\$ green ton^{-1})	
Other Incentives (\$ green ton^{-1})	
Total stumpage value (\$ green ton^{-1})	$10
Capital cost (annual interest rate)	5.0%
Start-up Costs	
Herbicide (\$ acre^{-1})	$200
Site Prep (\$ acre^{-1})	$50
Disk (\$ acre^{-1})	$90
Bed (\$ acre^{-1})	$200
Total:	**$540**
Costs at the Beginning of Each Rotation	
Fertilize (\$ acre^{-1})	$40
Propagule price (per tree)	$0.11
Trees per acre (1,700-3,400)	3,400
Cost of Trees (\$ acre^{-1})	$374
Planting cost (\$ acre^{-1})	$150
Total	**$564**
Costs at the Beginning of Each Coppice	
Weed control (\$ acre^{-1})	$40
Annual Costs	
Annual maintenance/administration (\$ acre^{-1})	$10
General Parameters	
Inside bark or total above-ground biomass	Total above-ground biomass
Expansion factor for branches and leaves	1.7
Number of coppices per rotation	4
Age of first harvest	3.0
Harvest age of first coppice	3.0
Harvest age of second coppice	3.0
Harvest age of third coppice	3.0
Total Rotation Length	12.0
Initial harvest yield (as % of first harvest)	100%
First coppice yield (as % of first harvest)	80%
Second coppice yield (as % of first harvest)	70%
Third harvest yield (as % of first harvest)	60%

OUTPUTS	
LEV (\$ acre^{-1})	**$2,011**
EAE (\$ acre^{-1})	**$101**
IRR	**14.0%**
NPV benefits (\$ acre^{-1})	$4,205
NPV costs (\$ acre^{-1})	$2,194
Benefit/cost ratio	**1.92**
NPV after 1st Rotation (\$ acre^{-1})	**$615**
NPV after 2nd Rotation (\$ acre^{-1})	**$1,271**
NPV after 3rd Rotation (\$ acre^{-1})	**$1,631**
NPV after 4th Rotation (\$ acre^{-1})	**$1,828**
NPV after 5th Rotation (\$ acre^{-1})	**$1,936**



Yields (green tons acre^{-1}) by harvest age within a rotation	
Initial harvest at 3 years of age	85.1
First coppice at 3 years of age	68.1
Second coppice at 3 years of age	59.6
Third coppice at 3 years of age	51.1

Figure A-9. SRWC Decision Support System Spreadsheet

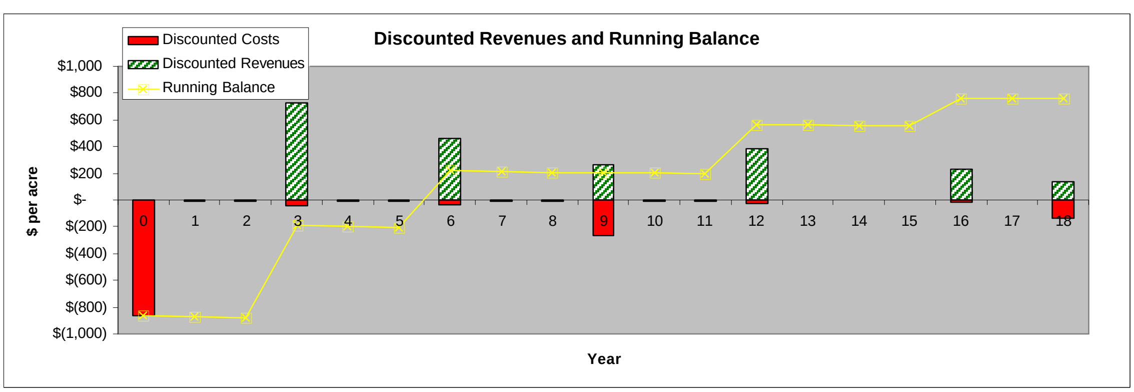


Figure A-10. Representative Discounted Revenues and Running Balance for SRWCs Based on the Decision Support System Spreadsheet in Figure A-9.

Table A-3. Land Expectation Value (LEV, \$ Acre^{-1}), Equal Annual Equivalent (EAE, \$ Acre^{-1}), and Internal Rate of Return (IRR, %) for Three Discount Rates (%) and Three Stumpage Prices (\$ Green Ton^{-1}) Assuming \$728 Acre^{-1} Site Preparation Cost and \$486 Acre^{-1} Planting Cost.

	Discount Rate	Stumpage Price		
		$4.54	$9.07	$13.61
LEV[1]	4	$251	$2,633	$5,245
	7	-$323	$977	$2,373
	10	-$556	$308	$1,237
EAE[2]	4	$10	$105	$210
	7	-$23	$68	$166
	10	-$56	$31	$124
IRR[3]	4	5.0%	12.4%	18.3%
	7	5.0%	12.4%	18.3%
	10	5.0%	12.4%	18.3%

[1]LEV is a measure of profit in present value terms, net of land costs, and can be interpreted as the amount that could be paid for bare land and still earn the discount rate.
[2]EAE is the annualized form of LEV, or annual profit (also net of land costs).
[3]IRR is the rate of return actually earned on invested capital.

Appendix B

PROJECT-RELATED PUBLICATIONS AND PRESENTATIONS

Project results were disseminated through 58 publications/presentations and two websites. The "Tree Crops for Phosphate Mined Lands" website (http://trees.ifas.ufl.edu) provides information about the project, project personnel, and project reports. Contact information for the project leaders is available through links to existing pages at the University of Florida. Links are provided for five related sites. The Treepower website (www.treepower.org) maintained by the Common Purpose Institute documents many project activities at the Kent site.

Of the following 27 publications, five are theses or dissertations:

- Stricker JA, Rockwood DL, Segrest SA, Alker GR, Prine GR, Carter DR. 2000. Short rotation woody crops for Florida. In: Proc. 3rd Biennial Short Rotation Woody Crops Operations Working Group Conference; 2000 Oct 10-13; Syracuse, NY. p 15-23.

- Rockwood DL. 2001. Performance of Queensland produced slash x Caribbean pine hybrids in peninsular Florida. In: Cooperative Forest Genetics Research Program 43rd Prog. Rpt. p. 4-6.

- Rockwood DL, Alker GR, Cardellino RW. 2001. Forest trees for land reclamation and remediation. Abstract of poster presentation. In: Abstract book and program, Natural Resources Forum: Watershed science, policy, planning, and management: can we make it work in Florida?; 2001 Jun 19-21; Tampa, FL. p 57-8.

- Rockwood DL, Morse DM, Gaviria LT. 2001. Genetic and silvicultural factors affecting productivity of planted cypress in Florida. In: Dean JFD, editor. Proc. 26th South. For. Tree Imp. Conf.; 2001 Jun 26-29; Athens, GA. p 74-83. Also available online at: http://www.rngr.net/Publications/sftic/2001

- Land SB, Jr., Stine M, Ma X, Rockwood DL, Warwell MV, Alker GR. 2001. A tree improvement program for eastern cottonwood in the southeastern United States. In: Dean JFD, editor. Proc. 26th South. For. Tree Imp. Conf.; 2001 Jun 26-29; Athens, GA. p 84-93. Also available online at: http://www.rngr.net/Publications/sftic/2001

- Segrest SA, Rockwood DL, Stricker JA, Alker GR. 2001. Partnering to cofire woody biomass in central Florida. In: Abstracts 5th Biomass Conference of the Americas. 2p. Available online at: http://www.brdisolutions.com/pdfs/bcota/abstracts/4/z280.pdf

- Rockwood DL, Carter DR, Alker GR, Morse DM. 2002. Compost utilization for forest crops in Florida. In: Proc. Recycle Organics '02, Composting in the Southeast Conf. and Exposition; 2002 Oct 6-9; Palm Harbor, FL. CD-ROM.

- Rahmani M, Rockwood DL, Carter DR, Smith WH. 2003. Co-utilization potential for biomass in Florida. In: Proc. International Conference on Co-utilization of Domestic Fuels; 2003 Feb 5-6; Gainesville, FL. CD-ROM.

- Morse DM. 2003. Genetic and silvicultural factors affecting productivity of planted cypress in Florida [MS thesis]. Gainesville (FL): University of Florida.

- Proctor PA, Rockwood DL, Mathey JA. 2003. Slash and loblolly pine productivity on reclaimed titanium mined lands in northeast Florida. In: Proc. 27th South. For. Tree Imp. Conf.; 2003 Jun 24-27; Stillwater, OK. p 162-170. Also available online at: http://digital.library.okstate.edu/forestry/sf27p162.pdf

- Adams MD. 2003. Assessing the awareness of Florida homeowners about the use of biomass for electricity production [MS thesis]. Gainesville (FL): University of Florida. Available online at http://etd.fcla.edu/UF/UFE0001483/adams_m.pdf

- Langholtz M, Carter DR, Rockwood DL, Alavalapati JRR, Green A. 2005. Effect of dendroremediation incentives on the profitability of short-rotation woody cropping of *Eucalyptus grandis*. Forest Policy and Economics 7(5): 806-17.

- Segrest SA, Rockwood DL, Carter DR, Smith WH, Green AES, Stricker JA. 2004. Short rotation woody crops for cofiring in central Florida. In: Proc. 29th International Technical Conference on Coal Utilization & Fuel Systems; 2004 Apr 18-22; Clearwater, FL. Paper 12. Available on CD only.

- Rockwood DL, Naidu CV, Carter DR, Rahmani M, Spriggs T, Lin C, Alker GR, Isebrands JG, Segrest SA. 2004. Short-rotation woody crops and phytoremediation: opportunities for agroforestry? In: Nair PKR, Rao MR, Buck LE, editors. New vistas in agroforestry: a compendium for the 1st World Congress of Agroforestry 2004. Dordrecht (The Netherlands): Kluwer Academic Publishers. p 51-63.

- Wullschleger SD, Segrest SA, Rockwood DL, Garten CT Jr. 2004. Enhancing soil carbon sequestration on phosphate mine land in Florida by planting short-rotation bioenergy crops. In: Third Annual Conference on Carbon Capture and Sequestration; 2004 May 3-6; Alexandria, VA.

- Tamang B, Langholtz M, Becker B, Segrest S, Rockwood D, Richardson S, Stricker J. 2004. Fast growing tree bridge crops for ecological restoration of phosphate mined lands. In: Proc. First National Conference on Ecosystem Restoration; 2004 Dec 6-10; Lake Buena Vista, FL. p. 425. Abstract available online at: http://conference.ifas.ufl.edu/ecosystem/abstracts.pdf

- Tamang B. 2005. Vegetation and soil quality changes associated with reclaiming phosphate-mine clay settling areas with fast growing trees [MS thesis]. Gainesville (FL): University of Florida. Available at: http://etd.fcla.edu/UF/UFE0011871/tamang_b.pdf

- Rockwood DL, Peter GF, Langholtz MH, Becker B, Clark A III, Bryan J. 2005. Genetically improved eucalypts for novel applications and sites in Florida. In:

Proc. 28th South. For. Tree Imp. Conf.; 2005 Jun 20-23; Raleigh, NC. p 162-70. Available online at: http://www.rngr.net/Publications/sftic/2005

- Langholtz MH. 2005. An economic and environmental analysis of tree crops on marginal lands in Florida [DPhil dissertation]. Gainesville (FL): University of Florida. Available online at: http://etd.fcla.edu/UF/UFE0012141/langholtz_m.pdf

- Tamang B, Rockwood D, Langholtz M, Becker B, Maehr E. 2005. Changes in vegetation and soil quality in reclaiming phosphate-mined clay settling areas with fast growing trees. In: Proc. 32nd Annual Conference on Ecosystem Restoration and Creation; 2005 Oct 27-28; Tampa, FL. p 126-40.

- Rockwood DL, Carter DR, Langholtz MH, Stricker JA. 2006. Eucalyptus and populus short rotation woody crops for phosphate mined lands in Florida USA. Biomass and Bioenergy 30(8-9): 728-34.

- Maehr E, Tamang B, Rockwood D. 2006. Influence of fast growing trees on ecological restoration of clay settling areas in Polk County, Florida. In: Proc. Florida Academy of Sciences; 2006 Mar 11-12; Melbourne, FL. Abstract AGR-8.

- Maehr EN. 2006. Preliminary evaluation of using fast growing trees and cultures for cogongrass control on phosphate mined lands [MS thesis]. Gainesville (FL): University of Florida. Available online at: http://etd.fcla.edu/UF/UFE0015737/maehr_e.pdf

- Langholtz M, Carter DR, Rockwood DL, Alavalapati JRR. 2006. Effect of CO_2 mitigation incentives on the profitability of short-rotation woody cropping of *Eucalyptus amplifolia* on clay settling areas in Florida. In: Sustainable Forest Management with Fast Growing Plantations, 2006 IUFRO Forest Plantations Meeting; 2006 Oct 10-13; Charleston, SC. 3 p. Available online at: http://www.ces.ncsu.edu/nreos/forest/feop/Agenda2006/iufro_plantations/proceedings/F04x-Langholtz.pdf

- Langholtz M, Carter DR, Rockwood DL, Alavalapati JRR. 2007. The economic feasibility of reclaiming phosphate mined lands with short-rotation woody crops in Florida. J. For. Econ. 12(4): 237-49.

- Langholtz M, Carter DR, Rockwood DL. 2007. Assessing the economic feasibility of short-rotation woody crops in Florida. Florida Cooperative Extension Service Circular 1516. 4p. Available at: http://edis.ifas.ufl.edu/FR169

- Tamang B, Rockwood DL, Langholtz M, Becker B, Maehr E, Segrest S. (forthcoming) Fast-growing trees for cogongrass (Imperata cylindrica) suppression and enhanced colonization of understory plant species on a phosphate-mine clay settling area. Ecological Engineering.

Project results were also disseminated through 25 presentations that included four tours of the Kent site:

- Stricker JA, Rockwood DL, Segrest SA, Alker GR, Prine GR, Carter DR. 2000. Short rotation woody crops for Florida. In: Proc. 3rd Biennial Short Rotation Woody Crops Operations Working Group Conference; 2000 Oct 10-13; Syracuse, NY. p 15-23.

- Alker GR, Rockwood DL, Ma LQ, Green AES. 2000a. Phytoremediation and bioenergy production systems in Florida using fast growing tree species. In: Proc. Florida Remediation Conference; 2000 Nov 15-19; Orlando, FL.

- Rockwood DL, Alker GR, Cardellino RW. 2001. Forest trees for land reclamation and remediation. Abstract of poster presentation. In: Abstract book and program, Natural Resources Forum: Watershed science, policy, planning, and management: Can we make it work in Florida?; 2001 Jun 19-21; Tampa, FL. p 57-8.

- Morse DM. 2001. Genetic and silvicultural factors affecting productivity of planted cypress in Florida. In: Proc. 26th South. For. Tree Improvement Conf.; 2001 Jun 26-29; Athens, GA.

- Rockwood DL. 2002. Florida energywood potential: energywood plantations. In: Florida Public Service Commission Staff Workshop – Florida Renewable Technologies Assessment; 2002 Jul 2; Tallahassee, FL.

- Rockwood DL, Carter DR, Alker GR, Morse DM. 2002. Compost utilization for forest crops in Florida. In: Proc. Recycle Organics ’02, Composting in the Southeast Conf. and Exposition; 2002 Oct 6-9; Palm Harbor, FL.

- Rahmani M, Rockwood DL, Carter DR, Smith WH. 2003. Co-utilization potential for biomass in Florida. In: Proc. International Conference on Co-utilization of Domestic Fuels; 2003 Feb 5-6; Gainesville, FL.

- Morse DM. 2003. Genetic and silvicultural factors affecting productivity of planted cypress in Florida. Presentation at SFRC Seminar; 2003 Nov 6; University of Florida, Gainesville, FL.

- Langholtz M. 2004. Effect of dendroremediation incentives on the profitability of short-rotation woody crops. Presentation at Wildland-Urban Interface: Forum on Economics and Policy; 2004 Mar 14; St. Augustine, FL.

- Rockwood DL. 2004. Assessing the awareness of Florida homeowners about the use of biomass for electricity production. Presentation at SNRE Seminar; 2004 Apr 20; University of Florida, Gainesville, FL.

- Smith W, Rockwood D, Carter D, Post D, Langholtz M, Cunilio T. 2004. Woody biomass - green energy for Florida. In: Proc. 2004 Florida SAF-SFRC Spring Symposium; 2004 Apr 21-22; Gainesville, FL.

- Stricker JA. 2004. Short rotation woody crops for cofiring in central Florida. Presentation at 29th International Technical Conference on Coal Utilization & Fuel Systems; 2004 Apr 18-22; Clearwater, FL.

- Rockwood DL, Segrest SA. 2004. Short rotation woody crops for cofiring in central Florida. Presentation at 29th International Technical Conference on Coal Utilization & Fuel Systems Field Tour; 2004 Apr 23; Lakeland, FL.

- Segrest SA, DL Rockwood, and JA Stricker. 2004. Presentation at Hardee County tour of Common Purpose / University of Florida SRWC Energy Farm; 2004 Apr 23; Lakeland, FL.

- Rockwood DL, Stricker JA, Segrest SA, Becker B, Langholtz M. 2004. Short rotation woody crops (SRWC). Presentation at 1st World Congress of Agroforestry Field Trip; 2004 Jun 30; Lakeland, FL.

- Rockwood DL, Segrest SA. 2004. Eucalyptus tour. Presentation at Short Rotation Woody Crops Operating Group Meeting Preconference Tour; 2004 Nov 4; Lakeland, FL.

- Tamang B. 2004. Fast growing tree bridge crops for ecological restoration of phosphate mined lands. Presentation at First National Conference on Ecosystem Restoration; 2004 Dec 9; Lake Buena Vista, FL.

- Smith W. 2004. Woody biomass - green energy for Florida. Florida Forestry Association Annual Meeting, December 15, 2004, Sandestin, FL.

- Wullschleger SD. 2004. Enhancing soil carbon sequestration on phosphate mined lands in Florida by planting short-rotation bioenergy crops. Presentation at Third Annual Conference on Carbon Capture and Sequestration; 2004 May 3-6; Alexandria, VA.

- Rockwood DL. 2005. Restoration of clay settling areas by commercial tree "bridge crops." Presentation at 20th Annual Regional Phosphate Conference; 2005 Oct 13; Lakeland, FL.

- Tamang B. 2005. Changes in vegetation and soil quality in reclaiming phosphate-mined clay settling areas with fast growing trees. Presentation at 32nd Annual Conference on Ecosystem Restoration and Creation; 2005 Oct 28; Tampa, FL.

- Maehr E. 2006. Influence of fast growing trees on ecological restoration of clay settling areas in Polk County, Florida. Presentation at meeting of Florida Academy of Sciences; 2006 Mar 12; Melbourne, FL.

- O'Leary J. 2006. Changes in vegetation and soil quality in reclaiming phosphate-mined clay settling areas with fast growing trees. Presentation at FIPR Teacher Education Workshop; 2006 Jun 14; Bartow, FL.

- Langholtz M. 2006. Effect of CO_2 mitigation incentives on the profitability of short-rotation woody cropping of Eucalyptus amplifolia on clay settling areas in Florida. Presentation at Sustainable Forest Management with Fast Growing Plantations, 2006 IUFRO Forest Plantations Meeting; 2006 Oct 13; Charleston, SC.

- O'Leary JE. 2006. Encouraging industry and agency involvement in environmental education. Presentation at 35th Annual NAAEE Conference; 2006 Oct 15; Minneapolis, MN.

Appendix C

EUCALYPTUS INVASIVENESS STATUS

Status of E. grandis and E. amplifolia per Alison Fox E-mail, September 26, 2006:

Don,
Thank you for your email.

I will respond in two parts:

1) as the Chair of the Florida Exotic Plant Pest Council (FLEPPC) concerning the position of FLEPPC to your request and

2) as the UF/IFAS faculty member supervising the IFAS Assessment of the Status of Non-Native Plants in Florida's Natural Areas.

1) Currently, FLEPPC has no protocol to endorse the use of any particular non-native plant species, although we are currently in the process of developing a list of alternative plants that might be used in the place of species that the FLEPPC has determined to be invasive. An example of such an alternatives list that focuses on native species has been developed for south Florida http://www.fleppc.org/Misc/AlterNative2.pdf but our expectation is that the state-wide list will include non-invasive non-native species also.

The Eucalyptus species that you mention are not currently listed on the 2005 FLEPPC Category I or II Lists of Invasive Species http://www.fleppc.org/list/list.htm.

You may consider those lists to be the current official statement, on the assumption that these species would have been included had there been concerns about their current distribution and impacts.

As you have indicated, since the sad and untimely passing of Kathy Burks, we have had a change in personnel dealing with the invasive plant lists for FLEPPC. Keith Bradley (copied on this message) is the new Chair of the FLEPPC Plant List Committee. He has recruited new members to this committee and they are reviewing the process by which the biennial lists are developed. I would recommend that you contact Keith if you wish to discuss the likelihood that these eucalypt species might change status and appear on the FLEPPC lists.

If the FIPR Board of Directors still wishes to request a statement from FLEPPC, this would have to be discussed at our next FLEPPC BOD meeting which will not be until late January.

2) These species have not yet been evaluated using the IFAS Assessment of the Status of Non-Native Plants in Florida's Natural Areas http://plants.ifas.ufl.edu/assessment.html as indicated by their absence from the list of Conclusions for species that have been assessed http://plants.ifas.ufl.edu/concl_genus.pdf

Currently, we do not plan to assess E. grandis and E. amplifolia this year but we do have

E. camaldulensis, E. robusta and E. torelliana on our list of species to do. Crysta Gantz, the staff member running the assessment program is away until Thursday, but we will let you know later this week if we can add E. grandis and E. amplifolia to our work plan for this year and when those assessments might be completed.

Since E. grandis and E. amplifolia have not yet been assessed, they can be recommended for use in any IFAS Extension documents (as per http://plants.ifas.ufl.edu/useassessjun05.pdf and item 9 under: http://plants.ifas.ufl.edu/webexamplesjun05.pdf).

I hope that this information will be of assistance to you. Please let me know if you have other questions.

Best wishes,
Alison Fox
Associate Professor - Agronomy Dept.
392-1811 ext 207

Status of E. grandis and E. amplifolia per Alison Fox E-mail, February 3, 2007:

Don,

Thank you for your follow-up enquiry.

The position with FLEPPC has not changed. Neither of these species have been added to the 2007 FLEPPC lists of Invasive Plants so you can continue to cite that as evidence that they are not currently invasive in Florida according to FLEPPC.

Keith Bradley the Chair of the FLEPPC Plant List Committee intends to discuss the possibilities of developing a criteria-based ranking system for the FLEPPC lists at the next committee meeting in June so you can assume that no change in decision-making on these species is likely for a while.

The IFAS Assessments however, have just about been completed. Crysta Gantz Assessment Team (AquaOPS@ifas.ufl.edu) can provide you with further details if needed but the results are:

E. amplifolia - Not considered an invasive species at this time throughout Florida.
The only herbarium samples found in Florida were cultivated specimens, the species is not new to the state (i.e., not introduced within the last 20 years), and it does not have a record of causing problems in other regions with similar habitats and climate to Florida.

E. grandis - Not considered an invasive species at this time in Florida but a predictive assessment should be applied.

Although herbarium specimens were found for natural areas in central and southern Florida, they were only found in areas disturbed by human activities and the species is not known to persist if the natural disturbance regime is restored. Although the species is not new to the state (not within the last 20 years), it does have a record of causing problems in other regions with similar habitats and climate to Florida and this results in the recommendation to use a predictive tool. It is regarded as clearly invasive in riverine habitats in South Africa (Forsyth and others 2004 South African Journal of Science 100: 75-77) and it received a high risk score of 11 in the Weed Risk Assessments for Hawaii and Pacific Islands (a score of 6 is needed for a prediction of high risk).

http://www.botany.hawaii.edu/faculty/daehler/WRA/full_table.asp.
http://www.hear.org/pier/wra/pacific/eucalyptus_grandis_htmlwra.htm

If we conducted a predictive Weed Risk Assessment here in Florida, there is no reason to believe that the resulting score and outcome of "high risk" would be any different given that the species is already here and so is likely to have a good climate match between its native range and Florida.

Thus, this species can currently be recommended for use in Florida by IFAS faculty based on its current status in Florida, but the evidence and prediction that it can become invasive should be noted. (Currently, IFAS has no policy based on predictions of invasiveness.)

Best wishes,
Alison

GREAT SEAL OF THE STATE OF FLORIDA

IN GOD WE TRUST