SILVICULTURAL AND GENETIC INFLUENCES ON PLANTED CYPRESS PRODUCTIVITY

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Abstract—The potential for baldcypress (*Taxodium distichum* var. *distichum*) and pondcypress (*T. distichum* var. *imbricarium*) plantations has been further evaluated through two silvicultural and genetic studies in Florida. On a flatwoods site, initial bedding+compost, which resulted in better early growth and survival than just bedding, and in turn no bedding, enhanced soil properties and plantation productivity through 16 years with stand basal area averaging 179 square feet per acre at a 10- x 3-foot spacing and 136 square feet per acre at a 10- x 6-foot spacing and associated tree diameters at breast height (DBH) of 5.5 inches and 5.9 inches, respectively. The best progenies increased stand basal area up to 60 percent over these averages. Coppice growth initiated at ~7 years was similar to the original rotation growth, but 9-year-old coppice wood density was less than that of 16-year-old trees. On an irrigated and fertilized sandhills site after 19 years, pondcypress progenies were much smaller than three types of baldcypress (DBH of 6.8 inches versus 10.5, 11.4, and 11.9 inches, with associated stand basal areas of 73 square feet per acre versus 178, 146, and 237 square feet per acre). Seed orchard CO97 composed of 26 pondcypress progenies, 11 baldcypress provenances, 21 baldcypress progenies, and 7 baldcypress clones can annually produce 400,000 or more seed expected to be ~15 percent more productive than unimproved seed. Commercial cypress plantations on non-wetland sites have potential for producing mulchwood and/or sawtimber in multiple rotations of 10 to 25 years.

INTRODUCTION

While taxonomic relationships among three *Taxodium* varieties [*T. distichum* var. *distichum* (L.) Rich (baldcypress - **BC**), *T. distichum* var. *imbricarium* (Nutt.) Croom (pondcypress - **PC**), and *T. distichum* var. *mexicanum* Gordon (Montezuma cypress - **MC**)] remain a source of debate (Tsumura and others 1999), at least one source combines all three into one species with three botanical varieties (Arnold and Denny 2007). The ranges of **BC** and **PC** overlap in forested wetlands throughout the Southeast, and within Florida, they are the most common wetland tree species (Ewel 1990). Net annual harvest of cypress in Florida has often exceeded net annual growth, due largely to harvesting for cypress mulch (Brown 1995). From 1987 to 2013, cypress acreage decreased from 1.40 million acres to 0.96 million acres, and the number of cypress trees decreased from 808.02 million to 568.28 million (Brown and Nowak 2016). Although the associated decline in cypress volume seems to have stabilized recently, the sustainability of the natural cypress resource in Florida, and the industries that depend on it, is of concern.

Silviculture and genetic improvement have potential for significantly increasing productivity of cypress planted on non-wetland sites in Florida. At 1- x 1-m spacing on south Florida muck, a local **BC** source quickly suppressed competing vegetation, was 25.9 feet tall after 7 years, and coppiced consistently from 3 to 7 years of age (Rockwood and Geary 1991). Gaviria (1998) reported encouraging early results from studies of up to 30 seedlots and various cultures on a wide range of sites. In one of a series of genetic and silvicultural studies in Florida (Morse 2003, Rockwood and others 2001), five **BC** provenances planted on south Florida muck differed in tree size but not survival and wood density after 13 years. Individual trees were up to 42.6 feet in height and 7.9 inches in diameter at breast height (DBH) in 13 years, but tree growth rate slowed considerably after 10 years, very likely because of the shallow muck soil and dry climate. Across six studies, nine **BC** provenances and five **BC** checklots were, on average, similar in survival and height to 16 **PC** progenies after as many as

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4 years. 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 clay settling area in central Florida. Inconsistent topsoil redistribution hindered the growth of 21 **BC** progenies and two **PC** progenies planted on a reclaimed phosphate mine in northeast Florida in 1998. Bedding+compost (B+C) on a good flatwoods site significantly increased the growth of 30 **BC** and four **PC** progenies compared to bedding alone in studies established in 1999 and 2000. In another flatwoods study planted in 2000, B+C also resulted in better growth and survival than just bedding, which in turn was superior to no bedding. Performance of 13 seedlots in two progeny tests and two commercial plantings on central Florida clay settling areas highlighted the advantages of good site preparation and bedding. An intensively managed seed orchard with 12 **PC** progenies, 9 **BC** provenances, and 3 **BC** clones produced cones on 5-year-old trees.

This paper updates these findings and extends the assessment of silvicultural and genetic factors that are critical to cypress plantation establishment on non-wetland sites in Florida for the production of mulchwood and sawtimber.

MATERIALS AND METHODS

Two cypress studies in Florida (table 1) involving 65 accessions primarily from Florida (table 2) contribute to this paper. Study SRWC-86 was initially described by Rockwood and others (2001); its B+C treatment involved strip-applying ERTH compost (1.5-0.5-0.5 NPK, www.erthproducts.com) as fourteen ~4-foot-wide, 144-foot-long, 3-inch-high bands, which were subsequently incorporated into fourteen ~2-foot-high

Table 1—Location, planting date, number of BC and PC accessions, total trees, site type, and silvicultural treatments for two studies

Study	Florida location	Plant date	No. of accessions BC	No. of accessions PC	Total trees	Site type	Silvicultural treatments
CO97	Day	12/97	29	19	320	Sandhills; Otela-Penney complex	Fertilizer; irrigation
SRWC-86	Gainesville	2–3/00	13	1	448	Flatwoods; somewhat poorly drained Pomona soil	Bedding+compost; 10 x 3 feet, 10 x 6 feet

Table 2—Type and origin of BC and PC accessions in CO97 and SRWC-86

Type	Origin	CO97	SRWC-86
		BC	
Provenance bulk	Arkansas	B5	-
Provenance bulk	Illinois	B7	-
Provenance bulk	Louisiana	B1, B2	-
Provenance bulk	Northwest Florida	B8, B9	-
Provenance bulk	Northeast Florida	B3, B4	-
Provenance bulk	South Florida	B6	-
Individual tree	Northeast Florida	B10, B11, B12, B13, B14, B15, B16, B17, B18, B19, B20, B21, B22, B24, B25, B26, B27, B29, B30, B31	A, B, C, D, E, F, G, H, I, J, L, Ba, Lo
Clone	Various	Senator, Blountstown, Evergreen	-
		PC	
Individual tree	Northwest Florida	P1, P2, P3, P7, P8, P9	-
Individual tree	Northeast Florida	P4, P5, P6, P14, P15, P16, P17, P18, P19	K
Individual tree	Central Florida	P10, P11, P12, P13	-

beds before planting 448 trees of 14 accessions in early 2000 (Morse 2003). A ~2-inch-deep, 3-foot-wide top dressing of ERTH compost was applied in August 2001. Representative soil samples were taken from the unbedded (N), bedded only (B), and B+C treatments at planting in 2000 and from the B+C treatment in March 2016. At age 82 months, trees in one replication (seven beds) of the B+C treatment were felled to initiate a coppice rotation. In February 2016 (original age 192 months, coppice age 112 months), to update previous periodic measurements, both replications were remeasured for tree height, DBH, stem quality on a 0 to 5 scale (0 = straight stem, short horizontal branches; 5 = crooked stem, long angular branches, or forking), number of coppice stems equal to ½ of the largest stem (coppiced replication only), and survival and then thinned to the best trees. From a representative 10-tree subset of the felled trees, stem disks were removed at ¼-tree height to determine wood density and moisture content.

The genetic base population CO97 previously described by Rockwood and others (2001) is on sandhills (table 1) and was composed of a different set of diverse accessions, including 10 grafts of the Senator, the world's oldest and largest **BC** until 2012 (table 2), systematically assigned primarily to 24 single-tree plots in 12 replications (four rows of six trees) in a randomized complete block design arranged on eight rows of 40 trees at 15- x 10-foot spacing. In August 2016, CO97 had 32 **BC** accessions (9 provenances, 20 progenies, and 3 clones) and 19 individual **PC** accessions, of which four were systematically allocated to four positions at the ends of the eight rows. Based on August 2016 and previous tree height, DBH, quality, and survival measurements, CO97 was rogued in January 2017 to create a 65-tree orchard with **BC** and **PC** sections.

Stand basal area was also calculated in both studies. Appropriate analyses of variance were conducted on all variables to identify significant silvicultural and genetic factors. As appropriate, means were tested with Duncan's multiple range test.

RESULTS AND DISCUSSION

In SRWC-86, the early beneficial effects of B+C persisted through 16 years (table 3). After 9 months, B+C, involving a relatively low compost rate, was slightly superior to B for growth but not in survival (Rockwood and others 2001). The B treatment was in turn superior for height but not survival to N on this typical flatwoods site after one growing season with much below normal rainfall. However, after 3 years, tree growth and survival in the B and N treatments were so low that both treatments were abandoned. After 16 years, soil properties, especially organic matter and pH, in the B+C treatment were still very favorable, as was tree growth.

More compost may further increase cypress growth. McKinstry (2008), observing mature root growth in the B+C treatment into 12-inch-wide by 12-inch-deep holes filled with municipal solid waste compost mixed with phosphatic clay at 0-, 25-, 50-, 75-, and 100-percent rates, noted that as compost rates increased, soil bulk density significantly decreased and soil porosity increased. The 50-percent compost rate had the most root growth.

Spacing significantly affected tree size and stand development over 16 years (table 4). At 10 x 3 feet in both replications, trees were shorter and thinner at ~7 years than at 10 x 6 feet but had higher stand density. Based on the replication not felled, these differences continued though 16 years as trees at 10- x 6-foot spacing averaged nearly 36 feet tall and 6 inches in DBH, and the trees at 10- x 3-foot spacing had a stand density of nearly 180 square feet per acre. Differences among the 14 progenies for stand basal area, a strong indicator of biomass per acre, were large at both spacings and ages.

Coppice performance was good but also influenced by spacing (table 4). Allowing for the different ages (112 months for coppice versus 82 months for original growth), coppice rotation tree size and stand

Table 3—Soil nutrient levels, organic matter (OM), and pH due to three silvicultural treatments in cypress study SRWC-86 at 0 and/or 16 years

Trt[a]	NH_4-N *mg/kg*	NO_3-N *mg/kg*	OM *percent*	P *mg/kg*	K *mg/kg*	Ca *mg/kg*	Mg *mg/kg*	Zn *mg/kg*	Mn *mg/kg*	Cu *mg/kg*	pH
N_0	5.7	2.8	2.1	1.9	6.6	73.7	21.6	3.3	0.2	0.1	3.9
B_0	5.6	2.7	3.6	2.4	9.8	134.0	46.8	2.9	0.6	0.0	3.8
$B+C_0$	13	10.4	10.5	71.5	86.1	621.5	122.8	16.2	10.2	0.4	4.1
$B+C_{16}$	-	-	4.0	536	57	2968	135	89	6.6	13.3	6.6

[a] Treatments: N=none (unbedded); B=bedding only; B+C=bedding+compost.

Table 4—Tree and stand traits by spacing at two original ages and one coppice age for the SRWC-86 B+C treatment before and after thinning

Rotation	Trait	Before thinning		After thinning	
		10- x 3-foot spacing	10- x 6-foot spacing	10- x 3-foot spacing	10- x 6-foot spacing
Original at 82 months	Tree height (ft.) / DBH (in.)	19.7 / 2.8	22.3 / 3.7	-	-
	Trees per acre	1193	645	-	-
	Stand basal area (BA) (ft.^{2} per acre)	45	38	-	-
	Progeny low–high (BA per acre)	9–91	12–75	-	-
Original at 192 months	Tree height (ft.) / DBH (in.)	34.1 / 5.5	35.8 / 5.9	43.4 / 8.1	42.6 / 7.0
	Wood specific gravity	0.412	0.44	-	-
	Trees per acre	895	635	220	182
	Stand basal area (BA) (ft.^{2} per acre)	179	136	85	51
	Progeny low–high (BA per acre)	64–271	77–218	-	-
Coppice at 112 months	Tree height (ft.) / DBH (in.)	24.9 / 3.7	27.6 / 4.6	31.2 / 5.0	30.0 / 5.4
	Wood specific gravity	0.371	0.347	-	-
	Trees per acre	1089	311	298	117
	Stems per stool	1.6	1.6	-	-
	Stand basal area (ft.2 per acre)	91	39	42	19

development may actually have surpassed that of the original rotation, e.g., at 10 x 6 feet, tree DBH of 3.7 inches at 82 months versus coppice tree DBH of 4.6 inches at 112 months. As with the unfelled trees, coppice tree size was less at 10 x 3 feet than at 10 x 6 feet, but stand density was higher. The number of coppice stems per stool, 1.6, was favorable for both spacings.

Wood density trends with age appear to follow those of pines (*Pinus* spp.) (table 4). The densities of the older original trees were higher than those of the younger coppice trees at both spacings. Densities at both ages were higher than the average density of 0.330 noted for fast-growing 13-year-old **BC** on muck soil (Rockwood and others 2001) and less than the 0.470 reported by Panshin and others (1964).

In genetic base population CO97, many of the original **PC** and **BC** accessions grew well initially in response to irrigation and weed control on the sandhills site (Morse 2003, Rockwood and others 2001). Overall, **BC** provenances survived best and had the largest trees, while **PC** progenies had the best tree quality. **BC** clones had low survival and the worst tree quality. The range among progeny means was greater than among provenance means, suggesting that more genetic gain could be made by selecting among progenies instead of among provenances. Several **PC** progenies combined good survival with large tree size and desirable quality characteristics, and individual **BC** and **PC** trees were up to 17 feet tall in 4 years.

At age 19 years, taxa comparisons in the unrogued CO97 changed based on tree data and stand basal area (table 5). Although all four taxa were similar in height, **PC** was smaller in DBH, and **BC** progenies had the poorest quality trees. Seven **BC** provenances had the highest basal area, followed by three **BC** clones and 20 **BC** progenies. Overall, the 19 **PC** progenies were statistically worse than all three **BC** taxa. Still, these **BC** and **PC** comparisons, while updating previous taxa comparisons, are limited for concluding that **BC** outperforms **PC** because this is an atypical site for cypress and representation of **BC** and **PC** is unique.

These observed variations among **BC** and **PC** progenies, as had been noted for cypress elsewhere by Faulkner and Toliver (1983), suggests the potential for genetic gain in each taxon. Liu and others (1990) had noted that **BC** exhibited 95 percent of its genetic variability within populations.

Based on overall accession performances and individual tree attributes, the best 65 trees in CO97 were considerably better than the unrogued trees in three taxa (table 5). The selected trees in each taxon were generally taller, larger in DBH, and much improved in tree quality. The retained 21 **BC** progenies, 7 **BC** clones, and 26 **PC** progenies had 54, 19, and 60 percent, respectively, higher basal areas than their respective taxa averages before roguing. Due to removing many poorly formed, large trees, the 11 retained **BC** provenance trees actually had 9 percent less basal area. The retained **BC** provenances, **BC** progenies, and **BC** clones were similar in basal area, but the selected trees originating from **PC** progenies were still smaller than all **BC** taxa. Trees of all taxa were notably improved in tree quality, with **BC** progenies improving most to an average quality of 1.3 compared to 3.9 before roguing.

After roguing in January 2017, the distribution of the 65 trees retained across the 1.1-acre site resulted in CO97 having two sections (table 6, figure 1). CO97's "**BC**" section has 37 trees: 8 from 7 **BC** provenances, 16 from 10 **BC** progenies, 5 of 3 **BC** clones (3 Senators), and 8 from 8 **PC** progenies. The 28 trees in the "**PC**" section are 3 from 3 **BC** provenances, 5 from 4 **BC** progenies, 3 **BC** clones (two Senators), and 17 of 12 **PC** progenies. Collectively, the 36 diverse origins of the 65 CO97 trees are 7 **BC** provenances, 12 **BC** progenies, 3 **BC** clones, and 14 **PC** progenies. Two Senators were previously transplanted in 2013: one to replace the original Senator in Big Tree Park in Seminole County, FL (Babcock 2013) and another to Reiter Park in nearby Longwood, FL (Taylor 2013).

CO97 is now ready to produce commercial improved seed. While limited production of improved seed began with cones produced in Fall 2000 on 5-year-old trees, perhaps due to paclobutrazol treatment (Rockwood and others 2001), CO97's future production may exceed 400,000 seeds annually, making possible fast-growing, well-formed **BC** and **PC** for mulchwood and/or sawtimber plantations, restoration projects, and urban applications.

Although the estimated genetic gain from CO97 is ~15 percent for stand basal area, CO97 trees [identified by unique accession numbers from 59 to 339 (fig. 1)] will be progeny tested to confirm the realized gain, identify parents to favor in future collections, and even to rogue CO97 further. A comparison of E1 and E3 seedlots from the "**BC**" and "**PC**" sections of CO97 will document if the two sections influence seedling quality. Progeny tests will also include local, commonly planted **BC** and **PC** seedlots. There's also potential for vegetatively propagating and testing individual CO97 trees, as is commonly done with cypress elsewhere, particularly China (Creech and others 2011). For example, accession 190 has performed well in clonal trials in Texas (Zhou 2012).

CONCLUSION

These updated results continue to suggest potential for commercial cypress plantations on non-wetland sites in Florida for the production of mulchwood in initial rotations as short as 10 years and/or sawtimber in rotations perhaps as long as 25 years, followed by somewhat shorter coppice rotations. Silvicultural enhancements, notably good site preparation (bedding on flatwoods sites), vegetation control, and nutrition amendments such as compost when and where available, following selection of good quality sites, are essential. Initial spacing influences tree size and stand productivity over time, with close spacing such as 10 x 3 feet limiting tree size and increasing stand basal area without impacting coppice rate. Productivity can also be much further enhanced by using proven genetically superior seedlings from seed orchards and, when economically justified, well-tested clones. At present, **BC** appears more productive than **PC**. Future research includes progeny testing trees in CO97 and documenting response to thinning in SRWC-86.

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Table 5—Number of trees and mean tree height, DBH, quality (Q), and stand basal area by taxon in cypress orchard CO97 before and after roguing at age 228 months

	Before roguing					After roguing				
Taxon[a]	No.	Height *feet*	DBH *inches*	Q	Basal area *ft.² per acre*	No.	Height *feet*	DBH *inches*	Q	Basal area *ft.² per acre*
BC Provenances	72	48.3a	11.9a	2.1b	237a	11	51.5a	11.2a	1.7a	215a
BC progenies	134	53.6a	11.4a	3.9a	146b	21	54.9a	11.8a	1.3a	211a
BC clones	22	48.6a	10.5a	3.2ab	178b	7	52.7a	11.2a	1.8a	212a
PC progenies	60	52.0a	6.8b	2.6ab	73c	26	52.1a	8.4b	1.4a	109b
Total	288					65				

[a] Taxa means not sharing the same letter for the same trait differ at the 5-percent level.

Table 6—Number of BC and PC accessions retained in the BC and PC sections of cypress orchard CO97

Accession	Number of trees CO97 section BC	PC	Total by accession
BC			
B3	1	1	2
B4	1		1
B5	1		1
B6	2	1	3
B7	1	1	2
B8	1		1
B9	1		1
B11	1		1
B14	2		2
B16		1	1
B19	1		1
B20	2	2	4
B21		1	1
B25	1		1
B26	1	1	2
B27	1		1
B29	3		3
B30	3		3
B31	1		1
E1	3	2	25
E2	1		1
E3	1	1	2
BC Total	29	11	40
PC			
P2	1		1
P3	1	2	3
P4	1		1
P5	1	3	4
P7		1	1
P8		2	2
P9	1	1	2
P10	1	1	2
P11		1	1
P12	1	1	2
P14		1	1
P15		1	1
P16		2	2
P18	1	1	2
PC Total	8	17	25
CO97 Total	37	28	65

↓ N ... = Baldcypress = Pondcypress ... ↓ N

Trees @10'	Rows @ 15' Spacing 5	6	7	8	9	10	11	12
40		169 B30	206 P2					
39				226 B25	263 P4			
38					262 B19		332 B26	
37					261 B30			
36		167 B6					330 B14	61 E3
35	127 B3			224 B14				
34			202 B29					
33								
32				59 E1		293 B4		59 E1
31								
30	123 P18						325 B29	
29			198 B9					
28	121 P5			60 E2				
27				220 B20				
26	119 P3			59 E1			323 B20	
25		156 B11	194 B7				322 B30	
24		155 B6			249 B27	285 B29	321 B31	
23		154 P10						
22			191 P12			283 B5		
21		152 P9	190 B8					
20				59 E1	246 B20			
19				217 P14				343 B26
18	112 P18				244 B16			
17						278 P10		
16	110 P5						315 B21	
15								
14	108 P3			59 E1	240 B20			
13							312 B7	
12	106 P7			61 E3				
11				213 P16	237 B3			
10	104 P5		179 P12					
9						270 P9		339 P15
8					234 P3			
7								
6						268 B6		
5				209 P16				
4	99 P5							
3								
2							302 P11	
1		132 P8				264 P8		

Figure 1—Accession number and identification by row-tree location for 65 trees in CO97 after 2017 roguing.

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