Evaluation of Slash Pine (*Pinus elliottii* Englem.) Hybrids in the Western Gulf Region

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ABSTRACT

While slash pine (*Pinus elliottii* Engelm.) hybrids have shown improvements in growth rate and wood quality in other parts of the world, they have not been used extensively in the southern United States. This study was designed to examine the suitability of slash pine hybrids for the Western Gulf Region, USA by studying survival, growth, and fusiform rust incidence. Fifteen slash x loblolly pine (*P. taeda* L.), 18-19 slash x Caribbean pine (*P. caribaea* Morelet var. *bahamensis* Barret *et*. Golfari), and 7 slash x (slash x Caribbean pine var. *hondurensis* Barret *et*. Golfari) hybrid families were compared with 8 improved slash pine families and one unimproved commercial bulk at five sites in the Western Gulf Region. At age 5, hybrids had lower survival, and slower growth rates than did the improved and unimproved slash pine across all sites. Improved slash pine outperformed the hybrids by 13 to 83% in volume growth and had 15% higher volume than the unimproved slash pine. Despite this, it was possible to find some slash x loblolly pine families with exceptional performance. Of the top 20% of fast growing families, half were improved slash pine and half were slash x loblolly pine hybrids. Rust incidence was high among the fast growing slash x loblolly hybrids and in general, hybrids had over 3 times as much rust as the improved slash. Hybrids also had a higher rust incidence than unimproved slash pine, which had twice the rust incidence of improved slash pine. Among hybrids, slash x Caribbean pine (var. *bahamensis*) hybrids had the highest rust incidence. Though further assessments are required to understand hybrid performance at maturity, these results suggest that slash hybrids are not well adapted to the Western Gulf Region.

Key words: *Pinus elliottii*, hybrids, survival, growth, fusiform rust incidence.

INTRODUCTION

Slash pine (*Pinus elliottii* Engelm.) is a conifer species of major economic importance in the southern USA. In south Florida, it is the most important timber species and regionally, it is the second most important commercial timber species after loblolly pine (*P. taeda* L.). Genetic improvement of slash pine began in the 1950's with selections made initially from natural stands and plantations (Zobel and Talbert 1984, pp.4-5). Thereafter, well-designed progeny tests were established to evaluate parental performance and to provide material for advanced generations.

As of yet, genetic improvement through hybridization with other species has not seen much application in the USA. The first artificial interspecific hybrid of pine species in the USA was developed in 1929, between slash pine and longleaf pine (*P. palustris* P. Mill.) (Dorman 1976, p.295). Early pine hybrids were created for two reasons: 1) to test crossability between various species, and 2) to combine traits of economic importance such as growth, disease resistance, cold resistance and wood density. To date, pine hybrids tested in the USA, including slash pine hybrids, have failed to show much positive hybrid vigor. Instead, they have tended to be intermediate to their parental species in traits of interest (Dorman 1976, pp.300-323; Schmitt 1968; Wells 1978). For example, longleaf pine x slash pine and shortleaf pine (*P. echinata* P. Mill.) x slash pine hybrids tend to be more resistant to fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*) than the less rust resistant parent, pure slash pine, but less resistant than the more rust resistant parents, pure longleaf and pure shortleaf pine (Schmitt 1968; Wells 1978). Both hybrids also tend to have lower growth rates than their faster growing parent, pure slash pine.

Performance of slash pine hybrids has been impressive in other parts of the world. In Australia, the slash pine x Caribbean pine (*P. caribaea* Morelet) hybrid outperforms pure species on specific sites due to a combination of desirable traits from each of the parents (Dieters 1996). The higher wood density, better stem straightness, better tolerance to poorly drained sites, and wind firmness of slash pine are combined with the higher growth rate of Caribbean pine (Dieters 1996). In South Africa, a hybrid of slash pine and *P. caribaea* var. *hondurensis* Barret *et*. Golfari at age 13 years had 250% more volume production than the pure slash pine that is commonly planted in the area (Van der Sijde and Roelofsen 1986). The hybrid had similar pulp properties to pure slash pine, showing no decrease in wood quality with the increased volume growth. In Zimbabwe, the volume growth of the same slash x Caribbean pine hybrid was 300% greater than that of the commonly planted pure slash pine varieties at 5 years (Gwaze 1999).

The excellent results of slash pine hybrids, in particular that of slash pine x *P. caribaea* var. *hondurensis*, around the world inspired the Cooperative Forest Genetics Research Program (CFGRP) at the University of Florida to evaluate the potential of F_1 slash pine x loblolly and slash x Caribbean pine hybrids as well as advanced generation hybrids (backcrosses) for planting in the southern USA. This paper reports on hybrid performance in the Western Gulf Region of the southern USA. Performance of the same slash pine hybrids planted in the lower Coastal Plain of the southeastern USA was reported by López-Upton et al. (1999).

The objective of this study was to examine the suitability of slash pine hybrids for planting in the Western Gulf Region by comparing the survival, fusiform rust incidence, and growth of the hybrids with those of improved and unimproved slash pine. The hybrids included in this study were *P. elliottii* x *P. caribaea* var. *bahamensis* Barret *et*. Golfari, *P. elliottii* x *P. taeda* and *P. elliottii* backcrossed to *P. elliottii* x *P. caribaea* var. *hondurensis.*

MATERIALS AND METHODS

Slash pine hybrid tests were established at five field sites in the Western Gulf Region of the southern USA. Each test included five taxa: three hybrids, one improved pure slash pine taxon and one unimproved pure slash pine taxon. The three hybrid taxa were *P. elliottii* x *P. taeda* (PEE x PTA), *P. elliottii* x *P. caribaea* var. *bahamensis* (PEE x PCB) and *P. elliottii* x (*P. elliottii* x *P. caribaea* var. *hondurensis*) (PEE x F1). Hybrids were developed by the Cooperative Forest Genetics Research Program (CFGRP) through crosses between 30 outstanding female slash pine parents from the CFGRP and 25-30 male PCB, F1 and PTA parent polymixes from Queensland Forest Research Institute in Australia. Detailed descriptions of hybrid development can be found in López-Upton et al. (1999). A subset of the CFGRP hybrids was obtained by the Western Gulf Forest Tree Improvement Program (WGFTIP) and established in the five tests discussed in this paper. Each Western Gulf test contained 15 PEE x PTA families, 18 to 19 PEE x PCB families, and 7 PEE x F1 families. Additionally, each test included 8 improved slash pine (PEEI) families and one unimproved slash pine (PEEU) bulk as control taxa. The improved slash pine families were all first-generation selections from the WGFTIP slash pine breeding program. The unimproved slash pine was a commercial bulk collection from South Mississippi and was intended to represent slash pine as it existed prior to tree improvement efforts. This bulk has also been used as a control in all WGFTIP slash pine progeny tests. Pure loblolly pine was not included in the Western Gulf tests.

All five tests were established between November 1994 and March 1995. Temple-Inland Forest (TIF) established a test in Hardin County, Texas, Boise Cascade Company (BCC) and the Louisiana Department of Agriculture and Forestry (LDAF) each established a test in Beauregard Parish, Louisiana and the USDA Forest Service established tests in Grant Parish, Louisiana (USFS1) and in Harrison County, Mississippi (USFS2). Each test consisted of three replications of either 48 or 49 families representing the five taxa. The tests established by Boise Cascade Company, Temple-Inland Forest and Louisiana Department of Agriculture and Forestry each included 18 PEE x F1 backcross families, while the USDA Forest Service tests included only 17 PEE x F1 backcross families. In addition, the test located in Grant Parish also included one family from a sixth taxon, rust-resistant slash pine. This taxon was dropped from the analysis because it was planted at only one location. Families were planted in five-tree row plots with tree spacing varying by location from 6 ft x 8 ft (1.8 m x 2.4 m) to 6 ft x 10 ft (1.8 m x 3.0 m).

Survival, height, diameter at breast height (dbh), and fusiform rust incidence were measured in each test between 1999 and 2000. Rust incidence was assessed on a 0 (absent), 1 (1-2 small limb galls present), 2 (many small - a few large limb galls present), 3 (1 or more stem galls present), 4 (rust-associated mortality) scale. The BCC, LDAF, and TIF tests were measured at 5 years, while the USFS1 and USFS2 tests were measured at 5.5 and 6 years, respectively. For simplicity, all measurements will hereafter be referred to as occurring at 5 years.

Volume growth was calculated using the following formula:

$$\text{Volume growth} = \text{height} \times \text{dbh}^2 \times 0.0261 \qquad \textbf{[1]}$$

Mean volumes per planted tree (in dm^3/planted tree) were then obtained for each family and each taxon at each location. Mean values were also computed for survival (%), height (m), dbh (cm), and rust incidence (%).

Using the SAS PROC GLM procedure (SAS Institute, 1989), analyses of variance (ANOVAs) were used to test for significant differences among families, taxa, and replications. The interaction between replication and taxon was also tested. The following linear model was used for the individual site analysis:

$$Y_{ijkl} = \mu + R_i + T_j + F_{k(j)} + RT_{ij} + e_{ijkl} \qquad \textbf{[2]}$$

where

Y_{ijkl} is the observation on the l^{th} tree of the k^{th} family of the j^{th} taxon in the i^{th} replication,

μ is the population mean,

R_i is the random variable for replication,

T_j is the fixed effect of taxon,

$F_{k(j)}$ is the random variable for family nested within taxon,
RT_{ij} is the random interaction replication by taxon,
and e_{ijkl} is the error term.

The data from all locations were then pooled and ANOVAs were used to test for significant differences among families, taxa, replications and locations. The interactions between location and taxa and between location and family were also tested. The following linear model was used for the pooled analysis:

$$Y_{ijklm} = \mu + L_i + R_{j(i)} + T_k + F_{l(k)} + LT_{ik} + LF_{il(k)} + e_{ijklm} \quad \textbf{[3]}$$

where
Y_{ijklm} is the observation on the m^{th} tree of the l^{th} family of the k^{th} taxon in the j^{th} replication in the i^{th} site,
μ is the population mean, L_i is the random variable for location,
$R_{j(i)}$ is the random variable for replication nested within location,
T_j is the fixed effect of taxon,
$F_{l(k)}$ is the random variable for family nested within taxon,
LT_{ik} is the random interaction location by taxon,
$LF_{il(k)}$ is the random interaction location by family nested within taxon,
and e_{ijkl} is the error term.

Where significant differences were detected among taxa and among locations in the pooled data, Duncan's Multiple Range Test was used to compare means.

RESULTS AND DISCUSSION

Taxa comparison

Significant differences among taxa were detected in all traits ($P < 0.05$) (Table 1). High coefficients of variation indicate that each taxon had substantial variation in the 5 traits measured (Table 2).

Hybrid survival ranged from 73% to 82% and was approximately 23% lower than that of pure slash pine (93-95%, Table 2). Slash pine x loblolly pine hybrids had the lowest survival at all the sites, except at TIF and USFS1 where slash x Caribbean pine hybrids had the lowest survival (Table 3). Survival was similar for improved and unimproved slash pine at all sites.

Rust incidence was higher in the hybrids (37-56%) than in pure slash pine (13–28%, Table 2). Average hybrid rust incidence across all sites was over 3 times greater than that of improved slash pine. Of the five taxa, the slash x PCB pine hybrid had the highest rust incidence at all sites (Table 3). These results are consistent with those of López-Upton et al. (1999) who found that the slash x Caribbean pine (var. *bahamensis*) hybrids were more susceptible to rust infection than both improved and unimproved pure slash in Florida. In this study, the slash x Caribbean pine hybrid had twice the rust incidence of the unimproved slash pine and four times the rust incidence of the improved slash pine across all sites (Table 2). Differences in rust susceptibility may in part result from the conditions in the Western Gulf Region, which tend to be more drought-prone than those in Florida and Queensland. Selection may also be a factor. Neither the slash nor the Caribbean parents were native to the Western Gulf region and neither

Table 1. Analysis of 5-year data pooled across sites for survival, rust incidence, height, diameter and volume per planted tree.

Source	DF	F-values				
		Survival	**Rust Incidence**	**Height**	**Diameter**	**Volume**
Site	4	13.4**	18.5**	140.6**	63.2**	58.7**
Rep (Site)	10	2.5**	1.3ns	2.9**	3.8**	5.1**
Taxa	4	6.9**	11.0**	7.3**	5.4**	3.8*
Family (Taxa)	44	1.1ns	2.6**	1.7**	1.7*	1.4ns
Site x Taxa	16	3.0**	1.6ns	4.4**	5.8**	6.0**
Site x Family (Taxa)	174	1.6**	1.4**	1.2ns	1.2ns	1.6**
Error	476[+]					

ns, *, ** = Not significant, Significant at 5% and 1 % levels, respectively.
[+] Error degrees of freedom are 476 for survival and volume, 474 for rust incidence and 473 for height and diameter.

Table 2. Mean survival, rust infection, height, diameter and volume (with coefficients of variation) at 5 years of age for improved *P. elliottii* (PEEI), unimproved *P. elliottii* (PEEU), and the hybrids: *P. elliottii* x *P. taeda* (PEE x PTA), *P. elliottii* x *P. caribaea* var. *bahamensis* (PEE x PCB), and PEE x (PEE x *P. caribaea* var. *hondurensis*) (PEE x F1)[1]. Data is pooled across sites.

Taxon	**Survival** (%)	**Rust Infection** (%)	**Height** (m)	**Diameter** (cm)	**Volume** ($dm^3.tree^{-1}$)
PEEI	93^{a} (26)	13^{c} (285)	4.87^{a} (21)	7.1^{a} (25)	6.73^{a} (70)
PEEU	95^{a} (24)	28^{bc} (164)	4.55^{ab} (21)	6.7^{ab} (26)	5.82^{ab} (72)
PEE x PTA	73^{b} (62)	37^{ab} (152)	4.91^{a} (31)	6.9^{a} (35)	5.93^{ab} (115)
PEE x PCB	74^{b} (60)	56^{a} (120)	4.19^{b} (31)	5.5^{b} (37)	3.68^{b} (115)
PEE x F1	82^{ab} (48)	41^{ab} (139)	4.49^{ab} (28)	6.5^{ab} (33)	5.09^{ab} (99)

[1] Means within a column with different superscripts differ at the 5% level of significance on a Duncan's Multiple Range Test.

Table 3. Taxon means for survival, rust infection, height, diameter and volume at 5 years of age for individual sites (from West to East)[1].

Trait	Taxon	TIF[+]	BCC	LDAF	USFS1	USFS2
Survival (%)	PEEI	92.5^{a}	95.4^{a}	95.4^{a}	97.9^{a}	97.0^{a}
	PEEU	93.3^{a}	95.0^{a}	91.7^{ab}	97.1^{a}	96.2^{a}
	PEE x PTA	66.7^{b}	66.7^{c}	73.8^{b}	72.0^{b}	84.8^{a}
	PEE x PCB	43.8^{b}	78.1^{bc}	91.4^{ab}	71.4^{b}	85.0^{a}
	PEE x F1	66.7^{b}	89.3^{ab}	85.9^{ab}	75.3^{b}	90.6^{a}
Rust (%)	PEEI	27.4^{a}	8.5^{a}	4.2^{a}	9.7^{a}	16.4^{a}
	PEEU	57.6^{b}	23.6^{ab}	10.9^{a}	13.7^{a}	34.3^{ab}
	PEE x PTA	48.8^{ab}	31.4^{abc}	50.0^{b}	24.7^{ab}	31.2^{ab}
	PEE x PCB	73.9^{b}	54.6^{c}	57.9^{b}	46.5^{b}	46.3^{b}
	PEE x F1	66.5^{b}	38.4^{bc}	38.3^{a}	27.7^{ab}	32.2^{ab}
Height (m)	PEEI	5.1^{ab}	4.2^{a}	6.2^{a}	4.7^{a}	4.0^{a}
	PEEU	4.8^{b}	4.1^{a}	5.8^{a}	4.3^{a}	3.8^{a}
	PEE x PTA	5.5^{a}	4.2^{a}	6.3^{a}	4.7^{a}	3.8^{a}
	PEE x PCB	3.9^{c}	3.9^{ab}	5.9^{a}	4.1^{a}	3.2^{a}
	PEE x F1	4.7^{b}	3.7^{b}	6.1^{a}	4.1^{a}	3.8^{a}
DBH (cm)	PEEI	8.3^{ab}	5.7^{a}	8.7^{a}	6.9^{a}	5.9^{a}
	PEEU	7.5^{ab}	5.6^{a}	8.4^{ab}	6.3^{ab}	5.4^{ab}
	PEE x PTA	8.6^{a}	5.4^{ab}	8.4^{ab}	6.8^{a}	5.2^{ab}
	PEE x PCB	5.1^{c}	4.9^{b}	7.7^{b}	5.5^{b}	4.4^{b}
	PEE x F1	7.3^{b}	4.9^{b}	8.5^{ab}	6.0^{ab}	5.8^{ab}
Volume (dm^3)	PEEI	9.5^{a}	3.6^{a}	12.1^{a}	6.1^{a}	4.0^{a}
	PEEU	7.6^{ab}	3.5^{ab}	10.1^{a}	4.8^{ab}	3.1^{ab}
	PEE x PTA	8.9^{a}	2.6^{ab}	9.6^{a}	5.2^{ab}	3.3^{ab}
	PEE x PCB	1.9^{c}	2.6^{b}	8.8^{a}	2.9^{b}	2.3^{b}
	PEE x F1	5.4^{b}	2.5^{b}	10.6^{a}	3.4^{b}	3.5^{ab}

[1] Trait means within a column with different superscripts differ at 5% level of significance on a Duncan's Multiple Range Test.

[+] TIF = Temple Inland Forest, BCC = Boise Cascade Company, LDAF = Louisiana Department of Agriculture and Forestry, USFS1 = USDA Forest Service test located in Louisiana, USFS2 = USDA Forest Service test located in Mississippi.

was selected or developed in the area. Furthermore, neither the slash nor Caribbean pine parents had been exposed to the rust genotypes in the Western Gulf region prior to this study so their levels of resistance are unknown.

Rust incidence in the PEE x PTA hybrids in this study was greater than in the pure slash taxa, indicating possible negative hybrid vigor for the trait. Slash tends to be the more susceptible parental species. However, we have no loblolly data from these tests to compare. In Florida, López-Upton et al. (1999) found that rust incidence in PEE x PTA hybrids was intermediate to the parental species, being less than in improved slash but greater than in pure loblolly. Intermediate values like those from Florida are commonly found in hybrids in the USA (Dorman 1976, pp. 300-323; Schmitt 1968; Wells, 1978).

In terms of diameter and volume per planted tree, PEEI outperformed all of the hybrids across all sites. However, PEEI growth rates were only significantly greater than those of the slash x PCB hybrid (Table 2). Slash x loblolly pine hybrids were almost always the best hybrids, having height, dbh, and volume means statistically equal to those of the improved and unimproved slash pine. There were no pure loblolly data for comparison. In Florida, PEE x PTA hybrids also had excellent growth, but the high rust incidence on the hybrids was a cause for concern (López-Upton et al. 1999, Rockwood and Nikles 2000). In this study, PEE x PTA hybrids had three times the rust incidence of improved slash pine. Since the impact of rust incidence is likely to increase over time, the relatively small differences observed between the growth rates of slash x loblolly hybrids and those of improved slash may be expected to increase as the hybrids succumb to increased rust incidence and rust related mortality.

The poorest performing taxa at all sites (expect BCC) was the slash x Caribbean pine (var. *bahamensis*) hybrid (Table 3). Survival was approximately 20% lower in the PEE x PCB hybrid than in PEEU and PEEI and rust-incidence was much greater in the hybrid. On average, it produced only 55% as much volume as the improved slash pine, and 63% as much volume as unimproved slash (Table 2). The high rust incidence along with the environmental stresses associated with transferring seed long distances probably contributed to the slow volume production of the slash x Caribbean pine hybrids.

Site comparison

Highly significant differences between sites were detected in all traits (Table 1).

Average survival within each site was moderate (82-89%), except in TIF where survival was significantly lower (68%) (Table 4). The low survival at TIF is attributed to low survival in the hybrids (44-67%) (Table 3). Slash x Caribbean hybrids suffered the greatest mortality. Hybrid survival was highest at LDAF and USFS2 (74-91%), followed by BCC (67-89%) and USFS1 (71-75%). Rank changes in survival across sites caused the site x taxa interaction for survival to be significant ($P < 0.05$). An example of the rank changes is PEE x PCB, which had the lowest survival at TIF but was ranked third in survival at LDAF (Table 3).

TIF had significantly higher rust incidence (55%) than the other sites (31-39 %) (Table 4). Rust incidence in the improved (27%) and unimproved (58%) slash pine was also highest at this site. The low survival at TIF appears to be associated with the high rust incidence at that site.

Height, diameter and volume growth were highest at LDAF, followed by TIF (Table 4). Volume production at LDAF was over three times that at BCC and USFS2 and over twice that at USFS1. In general, the hybrids performed fair at the different test sites. However, in most cases, their performance was less than that of improved slash. Site x taxa interactions for all growth traits were significant ($P < 0.05$), indicating rank changes in these traits across sites. An example is PEE x F1 backcross, which had the lowest volume at BCC, yet was ranked second in volume at LDAF (Table 3).

Table 4. Site means for survival, rust infection, height, diameter and volume at 5 years of age across all taxa[1].

Site	Survival (%)	Rust (%)	Height (m)	Diameter (cm)	Volume (dm³/tree)
TIF	68 [c]	55 [a]	4.9 [b]	7.6 [b]	6.7 [b]
BCC	82 [ab]	33 [bc]	4.0 [d]	5.2 [d]	2.8 [d]
LDAF	85 [ab]	38 [b]	6.1 [a]	8.4 [a]	10.3 [a]
USFS1	78 [b]	26 [c]	4.4 [c]	6.3 [c]	4.3 [c]
USFS2	89 [a]	31 [bc]	3.8 [d]	5.4 [d]	3.3 [cd]

[1] Means within a row with different superscripts differ at 5% level of significance on a Duncan's Multiple Range Test.

Family variation

Across all sites, families within taxa were significantly different in height, diameter and rust incidence (Table 1). Within individual sites, families differed significantly in volume as well as height, diameter, and rust incidence (data not shown). This variation suggests that genetic improvement in all traits can be made by selecting families within each taxon.

While hybrids on average produced less volume growth than the improved slash taxon, it was possible to identify some hybrid families with exceptional performance in the Western Gulf Region. Of the top 10% of the families based on volume growth across all sites, 60% of the selected families were slash x loblolly hybrids. Of the top 20%, 50% of the families were slash x loblolly and 50 % were improved slash pine. Pure loblolly was not planted. The top two families in volume growth overall were slash x loblolly hybrid families. These results are promising. However, the outstanding families identified above had more than twice the rust incidence than did the improved slash pine. Therefore, the outstanding hybrid families will need to be monitored overtime to determine the impact of rust incidence on their performance. If the hybrid families follow the pattern observed in standard slash pine progeny tests, families with increased rust incidence will succumb to more rust related mortality over time. We expect that the hybrid families will begin to suffer from the increased impact of rust infection, which will lead to poor growth and poor survival for these families at older ages.

Caribbean pine hybrids, the most rust susceptible in this study, already show this trend. Of the bottom 20% of families, 90% involve a Caribbean pine species ancestor (either parent or grandparent). Sixty percent are slash x Caribbean pine (var. *bahamensis*) families, and 30% are PEE x F1 backcross families. The remaining 10% are slash x loblolly hybrids.

CONCLUSION

This study has shown that slash pine hybrids are poorly adapted to the Western Gulf Region of southern USA. Compared to pure slash pine, all hybrids demonstrated poor growth and high levels of fusiform rust infection. Hybrids involving Caribbean pine were the most susceptible of all taxa to rust infection. There were large family variations within taxa and some slash x loblolly pine hybrid families even had outstanding growth rates. However, those PEE x PTA families had more than twice the rust incidence of improved slash and as a result, may begin to suffer decreased growth and increased mortality as time goes by. Results reported here are at the young age of 5 years, and it is recommended that further assessment be carried out at 10 years to better understand the potential of these slash hybrids at maturity. The future role of hybrids in the Western Gulf Region is not clear, but based on early results from this study, slash hybrids are not likely to be of much value because they have higher rust incidence and poorer growth than pure slash pine.

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