IS THERE HOPE FOR HYBRID POPLARS IN THE SOUTHERN UNITED STATES?

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ABSTRACT

Early-age results of hybrid poplars showed promise with higher survival rates than eastern cottonwood and rapid growth rates that rivaled that of eastern cottonwood (*Populus. deltoides* Bartr. ex Marsh.) when grown on the newly developing and highly fertile soils of the Lower Mississippi Alluvial Valley (LMAV). But as the tests aged so did the susceptibility to the fungus (*Sphaerulina musiva*) which resulted in mortality. This fungus is both a leaf disease as well as a canker disease that manifests itself on both stem and limbs of hybrid poplars. Although eastern cottonwood is not resistant to the leaf spot disease of the fungus, it is resistant to the canker formation. Between 2010 and 2013, a total of four test sites was established by Mississippi State University with two in the LMAV and two on Upland sites in Mississippi. This document examines only the common varietals included for all four sites. Comparison between the LMAV and Upland sites revealed patterns that were unexpected for both eastern cottonwood and hybrid poplar varietals.

INTRODUCTION

The term "hybrid" always catches one's interest, with forest researchers and landowners being no different. The term is taken to mean that a hybrid will be superior to the native species because it conveys a dramatic improvement in growth or other characteristic over whatever species is common to that specific environment. In agriculture, hybrids are planted widely, and farmers rely on new genotypes to increase crop yields. In forestry, most tree improvement programs employ a recurrent selection system focused primarily on general combining ability where repeated cycles of mating, testing, and selection within each generation provides genetic gain (Isik and McKeand 2019). However, in *Populus* emphasis is placed on inter-specific matings to produce hybrid vigor, which is then followed by vegetative propagation to take advantage of the full potential of genetic gain.

Populus hybridization work which began in the Northern United States has involved numerous species and has seen varying success across poplar-growing regions. In the Midwest, there has also been considerable hybridization work including the mating of *P. deltoides* x *P. nigra* (DN) and *P. deltoides* x *P. maximowiczii* (DM). In the Pacific Northwest, work at the University of Washington and Washington State University in the late 1970s and early 1980s led to the development of *P.* x *generosa* which results from matings of *P. trichocarpa* x *P. deltoides* (TD). In the 1990s and 2000s, GreenWood Resources began a large inter-specific breeding program that produced a variety of *Populus* taxa for their landholdings in Oregon and Washington (Berguson and others 2010).

In the 1960s through the mid-1980s, the *Populus* program in the South centered around eastern cottonwood (*P. deltoides* Bartr. ex Marsh.) (CTW) and was designed by the U.S. Department of Agriculture Forest Service Laboratory located at Stoneville, MS. Pulp and paper companies operating along the Mississippi River quickly added CTW plantations on alluvial soils both inside and outside the levee system from Cairo, IL to Baton Rouge, LA. The Stoneville Laboratory provided information on a variety of disciplines including tree improvement, silviculture, biometrics, pathology, and entomology. While little breeding was done during this period, the groundwork was well laid to build a significant population for immediate and future use. The Stoneville Laboratory examined a limited number of hybrid poplars (HYB) but found them unsuitable for use in the Lower Mississippi Alluvial Valley (LMAV) (Maisenhelder 1970). It was not until mid-1980 that the Westvaco central region, located just south of the confluence of the Mississippi and Ohio Rivers, would venture from the norm, and examine newly developed HYB in the LMAV. In a series of trials that spanned from 1987 to 1989, various HYB varietals within the TD taxon were tested on batture sites along the Mississippi River, south of the confluence of the two rivers. Varietals of *P.* x *generosa* were provided by Dr. Reinhard Stettler, (Geneticist, University of Washington) and included in varietal trials with selected CTW in 1987, 1988, and 1989. It was obvious from these tests that the HYB varietals rooted

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better and exhibited excellent first-year height growth. However, by age 2 growth rates slowed and disease in the form of stem and limb cankers, identified as resulting from *Septoria musiva* (now known as *Sphaerulina musiva*), became prominent. By age 3, the hybrids were riddled with cankers resulting in excessive mortality and by age 5 not a single hybrid ramet remained alive. It was unclear if the mortality was due to disease, annual flooding, or a combination of both factors. Regardless, further work with HYB varietals in the LMAV was discontinued (Westvaco Central Region 1991).

From mid-1990 to about 2005, there was a resurgence of research among a few industrial programs (e.g., James River and Westvaco) aiming to develop new and faster growing intra-specific CTW varietals for use in the LMAV and testing of inter-specific HYBs for upland sites in the South. Concurrently, short rotation woody crops (SRWCs), including poplar, were garnering more interest as feedstock for biofuels and bioenergy. Hybrid poplars were envisioned as the answer for rapid growth, thin bark, good coppice regeneration, and the ability to perform well across a wide range of sites.

This study focuses on the Department of Energy (DOE)—SunGrant Regional Biomass Feedstock Partnership entitled "Consolidated Populus Feedstock Trials" where the goal was to test the most current *Populus* material available from tests in different geographic areas to determine what species or taxa and varietals would perform best. This document covers only trials established by Mississippi State University (MSU).

PROCEDURES

The Consolidated *Populus* Feedstock testing began in 2010 and included the University of Minnesota (UMN), MSU, ArborGen (AG), and GreenWood Resources (GWR), each of which provided 20 varietals. Varietals from the UMN and GWR were HYBs while most of the material provided by AG and MSU were CTW genotypes (table 1). A total of four trials was established between 2010 and 2013 by MSU. The original design called for two trials in 2010 and 2011, with one trial each year placed in the LMAV and the other to be placed on an Upland site in Mississippi. The 2010 trials were established as expected with one trial established on an Upland site of the Upper Gulf Coastal Plain near Pontotoc, MS and the other in the LMAV near New Madrid, MO. In 2011, only the Upland site was established because flooding along the Mississippi River, which reached historic levels, prevented establishment. The LMAV test site was selected because a cooperative study between Westvaco and the University of Kentucky identified a number of races of cottonwood leaf rust (*Melampsora medusae* THÜM), some of which were very aggressive in this area (Prakash and Heather 1986, Prakash and Thielges 1987). The spring of 2013 was the earliest that the second LMAV trial could be established on this site.

As per the Consolidated Populus Feedstock study, the trials were designed as varietal screening trials where minimum copies (ramets) were tested per varietal. This allows screening of many varietals, but selections should be further tested. The design consisted of a compact varietal block design (i.e., split-plot) consisting of three blocks, with each block having four sub-blocks, consisting of 20 varietals per sub-block, arranged in two tree-row plots, and planted at a spacing of 6 x 9 feet. The summer prior to the respective planting sites was disked and sub-soiled in two perpendicular directions to a depth of 16 inches. Cutting length varied depending on the contributor, with HYB cuttings between 9 to 12 inches and CTW cuttings between 16 to 18 inches. In 2010, both sites were planted during April and immediately treated with a broadcast application of Goal 2XL (Oxyfluorfen) at a 64 ounce per acre rate. When the herbicide lost effectiveness, the sites were mechanically disked and, if needed, hoed around the trees. Disking was maintained, as needed, during the first summer and once at the start of the second growing season. Insect control was conducted on an as-needed basis during biweekly checks. Any infestation of cottonwood leaf beetles (*Chrysomela scripta* F.) or Japanese beetles (*Popillia japonica* Newman) was treated with Admire® Pro (Imidacloprid). Total height (THT) and diameter at breast height (DBH) were measured at ages 1, 3, 5, and 10 for the 2010 trials, ages 1, 3, and 5 for the 2011 Trial and ages 1, 5, and 8 for the 2013 Trial.

The 2011 Upland test site was planted in April, but as previously noted the companion LMAV site was not planted until March of 2013. Varietal material intended for the 2011 LMAV site was placed into a stoolbed and held until the spring of 2013. This LMAV Trial is located in Mississippi County, Missouri and like the 2010 LMAV Trial, the test site is just outside of the Mississippi River levee system. Unfortunately, the 2013 LMAV Trial did not include all the HYB varietals that were included in the 2011 Upland Trial. Eleven HYB varietals were not included because they exhibited disease in the stoolbed. The 11 varietals excluded from the 2013 Trial included five HYB varietals (6320, 6329, 99007115, 1428, and 12804) that were part of the 21 common clones to be placed in each trial (table 1).

Our analysis focused on measurements taken at ages 1, 3, and 5 for all sites except the 2013 LMAV Trial that was not measured at age 3. These measurements included:

2010 LMAV Trial	Age 1 THT, Ages 3, 5, and 10 DBH and THT
2010 Upland Trial	Age 1 THT, Ages 3, 5, and 10 DBH and THT
2011 Upland Trial	Age 1 THT, Ages 3 and 5 DBH and THT
2013 LMAV Trial	Age 1 THT, Ages 1, 5, and 8 DBH and THT

Table 1—Varietal identification, taxa, agency of varietal, test location and age of the 21 common genotypes planted in the four SunGrant Consolidated Populus Feedstock trials established by Mississippi State University

Varietal ID	Taxa	Agency	Trial locations
110412	DD	MSU[b]	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
110804	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
111234	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG414	DD	AG[c]	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG437	DD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
S7C1	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
ST66	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
ST244	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
1428[a]	TD	GWR[d]	2010 LMAV, 2010 Upland, 2011 Upland
6018	TD	GWR	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
6198	DT	GWR	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
6320[a]	DM	GWR	2010 LMAV, 2010 Upland, 2011 Upland
6329[a]	DM	GWR	2010 LMAV, 2010 Upland, 2011 Upland
9732-31	DN	UMN[e]	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
12804[a]	TD	GWR	2010 LMAV, 2010 Upland, 2011 Upland
22021048	DN	UMN	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
99007115[a]	DN	UMN	2010 LMAV, 2010 Upland, 2011 Upland
AG187	TD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG188	TD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG229	TD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
DN5	DN	UMN	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV

[a]Varietals omitted from the 2013 LMAV Trial.
[b]MSU varietals provided by Mississippi State University.
[c]AG varietals provided by ArborGen.
[d]GWR varietals provided by GreenWood Resources.
[e]UMN varietals provided by the University of Minnesota.

When possible, individual tree volume calculations were derived for ages 3, 5, 8, and 10 using an equation developed for small CTW plantation grown trees (Mohn and Krinard 1971):

Total volume outside bark $= 0.21099 + (0.00221(DBH^2 \times THT)$

where

$D = DBH$

$THT =$ *Total height.*

Though disease was not measured, it was noted when mortality appeared to be specific to a known disease.

The data were analyzed using Proc MIXED and Proc GLIMMIX model procedures in SAS Proprietary Software 9.4 (TS1M6) (SAS Institute 2016). Blocks and varietals within species and taxa were considered random. We conducted a combined analysis of all four sites and separate analyses combining like and different geographic areas. Additionally, each test site was subjected to Proc GLIMMIX producing Pearson correlations to identify trait and age relationships for making effective selections.

RESULTS

Survival

Patterns of survival emerged for varietal groups (CTW versus HYB) when analyzed across all test sites, as well as when analyzed between LMAV and Upland sites. When combining all four test locations, the HYB group exhibited higher age 1 survival (92.9 percent) as compared to the CTW group (89.6 percent). This trend continued to age 3, when survival of the HYB and CTW groups were 84.6 percent and 80.5 percent, respectively. By age 5, survival of the HYB group dropped to 56.0 percent, while survival of the CTW group held at 80.2 percent (table 2). Although not shown in table 2, age 10 survival for the CTW group on the 2010 LMAV site was 72.9 percent, while the HYB group was zero. However, age 10

Table 2—Mean survival for the eastern cottonwood (CTW) and the hybrid poplar (HYB) groups at ages 1, 3, and 5 and least square means for total height, diameter at breast height (DBH), and volume at ages 1, 3, and 5

	Mean survival			Total height			DBH		Volume	
	percent			*feet*			*inches*		*cubic feet*	
All trials combined[a]:										
Type	**Age 1**	**Age 3**	**Age 5**	**Age 1**	**Age 3**	**Age 5**	**Age 3**	**Age 5**	**Age 3**	**Age 5**
CTW	89.6	80.5	80.2	8.5a	20.4a	36.8a	2.4a	4.3a	0.6185a	2.2474a
HYB	92.9	84.6	56.0	7.7a	16.4b	27.0b	1.7b	3.0b	0.3774b	1.2218b
2010 LMAV Trial[b]:										
Type	**Age 1**	**Age 3**	**Age 5**	**Age 1**	**Age 3**	**Age 5**	**Age 3**	**Age 5**	**Age 3**	**Age 5**
CTW	83.3	83.3	83.3	14.3a[d]	28.6a	44.1a	3.8a	5.6a	1.1855a	3.4307a
HYB	87.2	74.4	16.7	11.3b	19.7b	30.4b	2.4b	3.7b	0.4845b	1.3026b
2010 Upland Trial[b]:										
Type	**Age 1**	**Age 3**	**Age 5**	**Age 1**	**Age 3**	**Age 5**	**Age 3**	**Age 5**	**Age 3**	**Age 5**
CTW	89.6	85.4	83.3	4.9b	17.2a	28.6a	1.6a	3.1a	0.3704a	1.0069a
HYB	93.6	93.6	91.0	6.4a	16.9a	22.8b	1.5a	2.5a	0.3390a	0.6577b
2011 Upland Trial[b]:										
Type	**Age 1**	**Age 3**	**Age 5**	**Age 1**	**Age 3**	**Age 5**	**Age 3**	**Age 5**	**Age 3**	**Age 5**
CTW	91.7	72.9	60.4	6.0a	15.7a	23.7a	1.7a	3.0a	0.3340a	0.7749a
HYB	93.6	85.9	65.4	6.0a	13.1a	17.6b	1.3a	2.0b	0.2867a	0.4647b
2013 LMAV Trial[b]:										
Type	**Age 1**	**Age 3**	**Age 5**	**Age 1**	**Age 3**	**Age 5**	**Age 3**	**Age 5**	**Age 3**	**Age 5**
CTW	93.8	N/A[c]	93.8	8.9a	N/A	49.1a	N/A	5.4a	N/A	3.6355a
HYB	100.0	N/A	47.9	6.9b	N/A	32.0b	N/A	3.3b	N/A	1.1342b

[a]Combined analyses included all four trials between the various varietals grouped into either the CTW or HYB group and shown under the first heading of all four trials combined.

[b]Individual analyses represents only the data from the specific trial shown.

[c]Age 3 data were not available for the 2013 LMAV Trial.

[d]Total height, DBH, and volume at specific ages with the same letter are not significantly different at P < 0.05 level.

survival for the CTW group on the 2010 Upland site was 79.2 percent, while the HYB group was 56.4 percent.

When combining the LMAV trials of 2010 and 2013, age 1 survival for the HYB group was 92.1 percent, while the CTW group was 88.5 percent. At age 3 the 2010 LMAV site and age 5 for the 2010 and 2013 LMAV sites, survival between the two groups began to diverge with the HYB group showing 74.3 percent at age 3 and 28.5 percent at age 5, while survival of the CTW group remained near constant from ages 1 to 5. Age 1 survival for 4 of the 13 HYB varietals exhibited no mortality in the 2010 and 2013 LMAV sites. By age 5, no single HYB varietal exhibited 100-percent survival over both sites, but varietal 6198 (DT) ranked as the highest surviving genotype at 83.3 percent (table 3). Later age survival (ages 8 and 10) revealed little difference after age 5. The CTW varietals particularly 110412, 111234, AG414, and S7C1 showed a loss of no more than one or two ramets.

Analysis of the combined 2010 and 2011 Upland sites revealed a different survival pattern between the two groups. Age 1 survival for the HYB group was similar to the previous combinations (93.6 percent), but survival of the CTW group (90.6 percent) was higher than expected. Survival for both groups fell at ages 3 and 5, with the HYB group being 89.7 and 78.2 percent, respectively, while the CTW group was 79.2 and 71.9 percent, respectively.

Survival of individual varietals shows the extent of variability among the groups (table 3). Varietal 12804 suffered extensive mortality and was the main contributor to the 3.8-percent drop in survival of the HYB group between ages 1 and 3. A 9-percent drop in the HYB group survival occurred between ages 3 and 5 due to varietals 6320, DN5, and 12804. Thus, age 5 survival ranged from 100 percent (Varietals 6329 and AG229) to 33.3 percent (Varietal 12804). Similarly, the CTW group showed a drop of approximately 10 percent between ages 3 and 5 driven by mortality of varietals 110804 and S7C1. By age 5, only one CTW varietal, AG414, maintained 100-percent survival. Age 10 measurements were only taken

Table 3—Mean survival of 21 common varietals at ages 1, 3, 5, and 10 for the 2010 LMAV and Upland sites, at ages 1, 3, and 5 for the 2011 Upland site, and ages 1, 5, and 8 for the 2013 LMAV site

2010 LMAV site Eastern cottonwood					2010 Upland site Eastern cottonwood				
	Percent survival					Percent survival			
Varietal ID	1	3	5	10	Varietal ID	1	3	5	10
110412 (DD)	100.0	100.0	100.0	100.0	110412 (DD)	100.0	100.0	100.0	100.0
110804 (DD)	83.3	83.3	83.3	50.0	110804 (DD)	100.0	100.0	100.0	100.0
111234 (DD)	100.0	100.0	100.0	100.0	111234 (DD)	100.0	83.3	83.3	83.3
AG414 (DD)	100.0	100.0	100.0	83.3	AG414 (DD)	100.0	100.0	100.0	66.7
AG437 (DD)	33.3	33.3	33.3	16.7	AG437 (DD)	50.0	33.3	33.3	33.3
S7C1 (DD)	100.0	100.0	100.0	100.0	S7C1 (DD)	100.0	100.0	83.3	83.3
ST66 (DD)	83.3	83.3	83.3	83.3	ST66 (DD)	83.3	83.3	83.3	83.3
ST244 (DD)	50.0	50.0	50.0	50.0	ST244 (DD)	83.3	83.3	83.3	83.3
Hybrid Poplars:					Hybrid Poplars:				
1428 (TD)	83.3	83.3	00.0	00.0	1428 (TD)	100.0	100.0	100.0	100.0
6018 (TD)	50.0	50.0	00.0	00.0	6018 (TD)	66.7	66.7	66.7	33.3
6198 (DT)	83.3	66.7	66.7	00.0	6198 (DT)	100.0	100.0	100.0	66.7
6320 (DM)	83.3	50.0	00.0	00.0	6320 (DM)	100.0	100.0	66.7	00.0
6329 (DM)	83.3	66.7	66.7	00.0	6329 (DM)	100.0	100.0	100.0	83.3
12804 (DT)	100.0	66.7	16.7	00.0	12804 (DT)	66.7	66.7	66.7	33.3
9732-31 (DN)	100.0	83.3	50.0	00.0	9732-31 (DN)	100.0	100.0	100.0	66.7
22021048 (DN)	100.0	66.7	00.0	00.0	22021048 (DN)	100.0	100.0	100.0	00.0
99007115 (DN)	100.0	100.0	00.0	00.0	99007115 (DN)	100.0	100.0	100.0	83.3
AG187 (TD)	100.0	100.0	16.7	00.0	AG187 (TD)	100.0	100.0	100.0	50.0
AG188 (TD)	66.7	66.7	00.0	00.0	AG188 (TD)	83.3	83.3	83.3	83.3
AG229 (TD)	83.3	83.3	00.0	00.0	AG229 (TD)	100.0	100.0	100.0	100.0
DN5 (DN)	100.0	83.3	00.0	00.0	DN5 (DN)	100.0	100.0	100.0	00.0

continued

on the 2010 Upland Trial revealing that AG414 lost two trees between ages 5 and 10, both due to mechanical injury.

Growth Traits

The LMAV sites showed better growth than the Upland sites for all traits examined between ages 1 and 5 (table 2). Analysis of the four sites combined revealed site differences for all traits when sites were grouped by geographic areas, the differences were no longer apparent. The combined analysis of the sites indicated location differences for all age 3 traits (DBH, THT, and volume) with the 2010 LMAV site performing better than the 2010 and 2011 Upland sites (table 2).

Age 1 height of the 2010 site was significantly taller (12.5 feet) than the 2013 LMAV Trial (7.9 feet) (table 4). Age 1 heights for the 2010 and 2011 Upland sites were significantly shorter than the LMAV sites but did not differ significantly from each other at 6.0 and 5.7 feet. Age 3 volume of the 2010 LMAV site was greater than twice the volume produced by the 2010 Upland site and 2.5 times greater than the 2011 Upland site. DBH followed the trend seen for volume with the LMAV site being about double the DBH of each of the Upland sites. Age 3 THT of the 2010 LMAV site was 23.1 feet versus 16.5 feet and 14.1 feet for the 2010 Upland and 2011 Upland sites, respectively. Analysis indicated highly significant effects site, site by type, varietal within type, and site by varietals of the age 5 traits of DBH, THT, and volume. Age 5 volume of the 2010 LMAV site was the highest at 2.5608 cubic feet and the 2013 LMAV site at 2.5505 cubic feet. Age 5 volume of the 2010 and 2011 Upland sites were much lower at 0.7979 cubic feet and 0.5338 cubic feet, respectively.

The combined site analysis of the CTW versus HYB groups indicated that these groups differed for all traits except age 1 height (table 3). But analysis of each site indicated a somewhat different pattern for DBH, total height, and volume. Results of the 2010 and 2013 LMAV sites followed

Table 3—Mean survival of 21 common varietals at ages 1, 3, 5, and 10 for the 2010 LMAV and Upland sites, at ages 1, 3, and 5 for the 2011 Upland site, and ages 1, 5, and 8 for the 2013 LMAV site (continued)

2013 LMAV site Eastern cottonwood				2011 Upland site Eastern cottonwood			
	Percent survival				Percent survival		
Varietal ID	1	5	8	Varietal ID	1	3	5
110412 (DD)	83.3	83.3	66.7	**110412 (DD)**	83.3	50.0	50.0
110804 (DD)	100.0	100.0	66.7	**110804 (DD)**	100.0	33.3	33.3
111234 (DD)	100.0	100.0	83.3	**111234 (DD)**	83.3	33.3	33.3
AG414 (DD)	100.0	100.0	66.7	**AG414 (DD)**	100.0	100.0	100.0
AG437 (DD)	100.0	100.0	100.0	**AG437 (DD)**	100.0	100.0	100.0
S7C1 (DD)	100.0	100.0	83.3	**S7C1 (DD)**	83.3	83.3	50.0
ST66 (DD)	100.0	100.0	33.3	**ST66 (DD)**	83.3	83.3	83.3
ST244 (DD)	66.7	66.7	33.3	**ST244 (DD)**	100.0	100.0	66.7
Hybrid Poplars:				**Hybrid Poplars:**			
1428 (TD)		*Not planted*		**1428 (TD)**	100.0	100.0	83.3
6018 (TD)	100.0	16.7	00.0	**6018 (TD)**	100.0	83.3	83.3
6198 (DT)	100.0	100.0	00.0	**6198 (DT)**	83.3	66.7	66.7
6320 (DM)		*Not planted*		**6320 (DM)**	100.0	100.0	66.7
6329 (DM)		*Not planted*		**6329 (DM)**	100.0	100.0	100.0
12804 (DT)		*Not planted*		**12804 (DT)**	66.7	33.3	00.0
9732-31 (DN)	100.0	83.3	00.0	**9732-31 (DN)**	100.0	100.0	83.3
22021048 (DN)	100.0	50.0	00.0	**22021048 (DN)**	100.0	50.0	16.7
99007115 (DN)		*Not planted*		**99007115 (DN)**	100.0	66.7	50.0
AG187 (TD)	100.0	00.0	00.0	**AG187 (TD)**	83.3	83.3	83.3
AG188 (TD)	100.0	00.0	00.0	**AG188**	83.3	83.3	83.3
AG229 (TD)	100.0	83.3	00.0	**AG229**	100.0	100.0	100.0
DN5 (DN)	100.0	50.0	00.0	**DN5**	100.0	100.0	33.3

Table 4—Mean height, diameter at breast height (DBH), and volume by site location at ages 1, 3, and 5 for the four SunGrant test sites established by Mississippi State University

	Total height			DBH		Volume	
Location	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
	------------------*feet*		------------------	------- *inches* -------		------ *cubic feet* ------	
2010 LMAV	12.5a[a]	23.1a	36.7b	3.0a	4.6a	0.7528a	2.5608a
2010 Upland	5.9c	16.5b	25.0c	1.5b	2.7b	0.3484b	0.7979b
2011 Upland	6.0c	14.1c	20.0d	1.4b	2.3b	0.3002bc	0.5338bc
2013 LMAV	7.9b	N/A	40.9a	N/A	4.4a	N/A	2.5505a

[a]Total height, DBH, and volume means at specific ages with the same letter are not significantly different at $P < 0.05$ level.

a pattern similar to that of the combined four site analysis, but the 2010 and 2011 Upland sites showed the CTW group differed from the HYB group until age 5, though trends leading to these differences were obvious at age 3. By age 5, the CTW group averaged approximately 6 feet taller, an inch larger in diameter, and 1.5 times greater in volume than the HYB group. No site by varietal interactions were found when sites of similar geographic area were combined. However, site by varietal interactions was found when combining locations of different geographic areas (i.e., LMAV vs. Upland).

Though CTW varietals exhibited the highest volume production on the 2010 LMAV site at ages 3 and 5 as well as age 5 on the 2013 LMAV site, there was considerable variation in this trait among the CTW varietals. Volume of the CTW varietals continued to increase based on the later age measurements of 8 and 10 years. Examination of the two Upland sites where volume for CTW varietals was approximately less than one-half of what was observed on the LMAV sites, reveals a different picture than described above. There was a considerable lack of variability in age 3 volume among the eight CTW and the 13 HYB varietals as compared to the findings on the LMAV site. Additionally, some varietals, such as AG437 (DD), showed puzzling volume yields in the Upland sites with poor volume production in the 2010 site and good volume in the 2011 site (table 2).

To determine performance differences, the common varietals were compared to the entire varietal test populations at each test site. Selecting the top 20 percent of the test population for volume at ages 3 and 5 gives an indication of potential gains via varietal selection. The top 16 volume producing varietals for the 2010 LMAV site at ages 3 and 5 consisted of 15 CTW varietals and a single HYB varietal 13317 (TN). Performance of the CTW varietals were in the upper one-half of the test population whereas HYB varietals were in the bottom half of the test population. For age 3 volume, six of the common varietals (all CTW varietals) 110412, 110804, 111234, AG414, ST66, and ST244 were among the top 16. Age 5 results were nearly identical with 110804 and 111234 dropping out and only five common CTW varietals 110412, AG414, S7C1, ST66, and ST244. For the 2010 Upland site, the top performing varietals at age 3 were a mixture of HYB and CTW varietals, seven of which were HYB varietals, six were DM varietals of which two (6320 and 6329) are common varietals. The nine CTW varietals included two common varietals, AG414 and 110412. The HYB varietal 8019 was the top volume performer at ages 3 and 5. Age 5 volume included three HYB varietals in the top 20 percent of the entire test population and two common CTW varietals, AG414 and 110412, are among the best performing varietals. The 2010 and 2011 Upland sites showed a similar trend as age increased, fewer HYB varietals remained in the top 20 percent of the test population. The top 20 percent of the 2011 Upland site for age 3 volume included eight CTW varietals and eight HYB varietals, of which AG414 was a common CTW varietal. The common HYB varietals were 6198, 6329, and AG229. Age 5 top volume producers included 5 HYB and 11 CTW varietals of which AG414 and S7C1 were common CTW varietals. Varietal rankings for age 5 volume of the 2013 LMAV site was similar to the 2010 LMAV site in that the upper half of the test population was comprised primarily of CTW varietals and AG414 was the only common varietal in the top 20 percent of the test population.

Age 1 height was poorly correlated with age 3 ($r = 0.51$) and age 5 height ($r = 0.23$). Age 3 height was strongly correlated with age 5 height and volume at 0.90 and 0.87, respectively.

DISCUSSION

The genus *Populus* is well known for possessing some of the fastest growing tree species in the world and its ease of vegetative propagation, thus allowing for varietal use to capture total genetic gains. This document focused partially on survival primarily for three reasons:

1. Variability in early survival when using dormant unrooted stock is often associated with rooting. Can selection for enhanced rooting, especially among CTW varietals lead to improved overall survival during the establishment phase?
2. Disease limits advancement of improved HYB *Populus* varietals. Selection for disease resistance that conveys long-term survival plays a foundational role in defining the landscape conducive for *Populus* species and hybrids in the Southeastern United States.
3. Yield is maximized when high survival is combined with exceptional growth. Effective selections combine these field performance traits to maximize area-basis yields.

Although marginal agriculture sites are often suggested as likely areas for biomass production with SRWCs, the 2016 Billion Ton update does not actually state marginal but rather the use of cropland (Langholtz and others 2016). A marginal agriculture site would be an area limited by either accessibility or by capability of supporting a suitable return from agriculture. In the case of the LMAV, this is often in the batture where flooding impairs agricultural crops, or soil types are unsuited for agriculture. In uplands of the South, soils are typically limiting to agriculture due to inherently low nutrient status. The LMAV sites, in general, possess the inherent soil fertility as shown by the mean volume production of the 2010 and 2013 LMAV sites and could play a major role in biomass production. Currently, a limitation centers around the inability to use inter-specific hybrids due to disease.

In respect to uplands, poor soil fertility does not limit age 1 survival of either CTW or HYB varietals but greatly affects volume production. Thus, it is imperative that specific varietal selections must be found that are capable of not only high survival and disease resistance, but capable of capturing specific inputs to maximize volume production. This study provides some insight into these possibilities, but increased effort must be devoted to the Southeastern United States to make this a possibility.

Survival and growth variables of the 21 common clones included in this study indicated that all three of the previously mentioned reasons certainly were borne out for the LMAV and the nearby lands of Arkansas, Kentucky, Louisiana, Missouri, and Tennessee. One of most critical issues is disease resistance and especially *Sphaerulina musiva* (Peck) Quaedv., Verkley and Crous (Syn. *Septoria musiva* (Peck) limb, and stem-canker resistance (Newcombe and Ostry 2001, Ostry and McNabb 1985). The necessary resistance to this disease cannot be overstated especially for the use of HYB varietals in a wide geographic area of the LMAV. The 2010 and 2013 LMAV sites clearly demonstrate that HYB varietals of any taxa should not be used in this region. This does not come as a complete surprise as Maisenhelder (1970) alluded to the same finding in 1970. It appears possible that the amount and perhaps virulence level from the array of strains or races of *Sphaerulina* in the LMAV overwhelms the low HYB varietal resistance. A typical case in point is the 2013 site. In this trial, the common HYB varietals exhibited 100-percent survival at the end of the first growing season, confirming their excellent rooting ability. However, by age 5 the disease impacted the HYB population such that only three varietals remained at a survival rate suitable for further examination. This was not to be because not a single HYB ramet remained alive at age 8. The LMAV is certainly still an area unsuitable for current HYB varietals.

Upland sites have been recommended as areas where biomass could be produced given suitable production rates. The 2010 and 2011 Upland sites show that *Populus* will certainly grow on these sites, but the resulting volume production was far less than the volume production shown on LMAV sites. A good performance of some CTW varietals on Upland sites was unexpected. It was also unexpected to observe *Sphaerulina* in the Upland sites, thus suggesting that HYB varietals must be thoroughly screened prior to deployment. A previous study conducted by Rousseau and others (2013), on an upland site some 65 miles east of the Mississippi River showed that *Sphaerulina* limb and stem cankers resulted in extensive mortality to varietals of TD, TDxD, TM, TMxM, and TN taxa at age 9, even though age 2 data indicated no incidence of cankers. In that study survival dropped from 92.4 percent at age 2 to 23.9 percent at age 9, considerably lower than the 56.4 percent at age 10 recorded for 2010 Upland site of the current study. Both studies indicated the negative effect on growth by *Sphaerulina*. However, the current study does not answer the question of the effects of *Sphaerulina* as sites are located east of the Mississippi.

Newcombe and Ostry (2001) who studied *Sphaerulina* resistance in *Populus*, noted stem cankers present on all the F_1 TD hybrids following the third growing season, but found no cankers on CTW varietals. The results of the study appear very similar to observations from the 2010 and 2011 Upland sites. The 2010 and 2011 Upland sites were located in a pine region of northeast Mississippi about 61 miles east of the Mississippi River, thus it is uncertain if *Sphaerulina* would play a significant role in affecting survival and growth. *Sphaerulina* cankers were first noticed in these trials during the third-year measurements, but their appearance seemed inconsequential. However, this was not the case with the more susceptible HYB genotypes exhibiting increased mortality. There were some HYB genotypes that were capable of walling off the disease to a certain extent, but this led to slower growth. Similar results were shown by Niemczyk and Thomas (2020) where growth rates and mortality resulted from genotype selection that included *Sphaerulina musiva* resistance. *Sphaerulina* cankers were also observed in a *Populus* planting of the Integrated Biomass Supply System (IBSS) study located just south of Columbus, MS In this location, the disease affected growth of the HYB varietal 7388 (DM) prior to coppice regeneration harvest at age 2, while varietal 6329 (DM) only revealed stem cankers following the coppice regeneration harvest. Additionally, varietals 5077 (TD) and 8019 (DM) at the Columbus, MS IBSS site exhibited some ability to wall off cankers. The IBSS sites near Columbus, MS and Raleigh, NC were compared for incidence of stem cankers and found that the HYBs were more susceptible at Columbus, MS. However, at Raleigh, NC there was no difference between the CTW and HYBs, even though the canker scores for the HYBs were the same. Kaczmarek and others (2013) examined 23 CTW varietals and eight HYB varietals grown on sandy soils near Aiken, SC. The authors did not observe limb or stem cankers; thus, it appears that this particular environment was not conducive to the fungus *Sphaerulina*.

Rooting in *Populus* is a strongly inherited genetic trait, so careful selection for this trait should provide gains needed to increase rooting at establishment for improved age 1 survival. Zalesny and Zalesny (2009) showed that adventitious roots, termed basal roots, typically form near the callus tissue that develops on the cut surfaces created when whips are cut into segments for planting stock. However, more importantly are the adventitious roots, termed lateral roots which are from either preformed or induced primordia above the callus tissue. Survival and growth are greatly improved when numerous lateral roots develop along the length of the cutting. Additionally, Zalensy and others (2005) showed that position of the cutting along the parent whip influenced rooting. They showed that rooting was best when the cutting originated from the lower portion of the whip and its diameters was greater than 0.6 inches. The CTW material produced by MSU as well as the HYB cuttings produced by MSU for the 2013 LMAV site followed the protocol shown by Zalesny and others (2005). The HYB cuttings for the 2010 and 2011 trials were grown at the various locations of the owners and then shipped to MSU. Prior to 2012, all the cuttings received by MSU were stored in a cooler at 36 °F to 38 °F. This changed in the 2013 Trial with all of the CTW and HYB varietals cuttings being grown, processed, and graded at MSU. Storage of the processed dormant unrooted cuttings for the 2013 Trial was in a walk-in freezer at 28 °F prior to planting. This change in handling and storage may account for the perfect survival of the eight HYB varietals established in the 2013 LMAV Trial. In this study we used age 1 survival as a surrogate for rooting ability. Cottonwood varietals such as AG414 (DD) and S7C1 (DD) showed excellent survival over both site types whereas varietals AG437 (DD) and 12804 (DT) varied greatly among the four sites questioning their rooting ability and thus the inclusion into further testing.

The combined analysis of all four locations revealed consistency with earlier studies that found age 1 height to be more dependent upon on planting stock quality and weed control rather than species or hybrid background. This remained true even though nearly one-fourth of the tested genotypes originated from colder climates than that of the sites used in this study. Interestingly, as age increased so did difference between CTW and HYB groups. This appears to result from an inability by the HYB group to tolerate LMAV site conditions, which included periodic flooding. The ability of the CTW group to exhibit growth like the HYB group when planted on upland sites was unexpected, with the assumption being that the HYB group would be far superior to CTW. This expectation was based on the superior rooting of the *Populus* hybrids shown by the literature (Kaczmarek and others 2013, Rousseau and others 2013).[1] Given that there are CTW varietals that root well, there is an opportunity to advance this trait in the future. In essence, the 21 common varietals represent a microcosm of the overall larger test population. The lack of significant differences for all age 3 growth traits clearly indicates that selected CTW varietals are capable of good growth on Upland sites. This is shown by the age 3 volume performance of the CTW varietal AG414 which exhibited similar or better than the top performing varietal 6329 (DM) on the 2010 and 2011 Upland sites.

SUMMARY

Common CTW and HYB varietals were examined in four trials of the SunGrant Consolidated Populus Feedstock program established by MSU on two test sites in the LMAV of southeast Missouri and two test sites on upland soils of northeast Mississippi. Survival and growth traits were analyzed for differences among sites, types, and varietals. Genotype by environmental interactions were only significant when sites of different geographic areas were combined, as in the case of LMAV versus Upland sites. The common varietals represented a microcosm of the entire test population, showing that except for age 1, CTW survival was generally higher than HYB survival except on Upland sites at age 5. Additionally, age 3 volumes began trending larger for CTW such that volume of the CTW group was greater than that of the HYB group on all sites by age 5. An important finding is that no HYB varietals will survive in the LMAV, but some CTW varietals performed well on the uplands, especially when held longer than 5 years. Survival of the HYB varietals diminished through time due to *Sphaerulina* susceptibility. As the trees aged, stem cankers increased resulting in lower survival or greater mortality.

These SunGrant trials illustrate the great need to test other *Populus* taxa to determine their viability for growth in southern environments. At MSU we began this process with test numerous *P. nigra* varietals at multiple locations. Recent selections were made to be mated with highly selected CTW varietals for the purpose of generating a F_1 population appropriate for the Southern United States. This procedure is only a first step, but the example could be replicated for a variety of other *Populus* species such as *P. simonii* and *P. yunnanensis*.

Although, the use of hybrid poplars outside of a 100-mile radius of the Mississippi River seems very likely, it is still appropriate to test for *Populus* diseases, especially *Sphaerulina*, prior to any commercial deployment in the South. In addition, the development of a rapid screening technique to use on specific genotypes for resistance/susceptibility to *Sphaerulina musiva* would greatly aide in the selection process for breeding and deployment. Also, there is no doubt that *Sphaerulina* should be further examined to determine the extent and virulence of the disease throughout the South.

[1] Personal communication. 2016. Brian Stanton, GreenWood Resources, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831.

REFERENCES

Berguson, B.; Eaton, J.; Stanton, B.J. 2010. Development of hybrid poplar for commercial production in the United States: The Pacific Northwest and Minnesota Experience. Proceedings of the sustainable feedstocks for advanced biofuels workshop. Sustainable alternative fuel feedstock opportunities, challenges, and roadmap for six U.S. regions. Soil and Water Conservation Society: 282–299. Chapter 17.

Isik, F.; McKeand, S.E. 2019. S.E. Fourth cycle breeding and testing strategy for *Pinus taeda* in the N.C. State university cooperative tree improvement program. Tree Genetics and Genomes. 15(70): 1–12. https://doi.org/10.1007/s11295-019-1377-y.

Kaczmarek, D.J.; Coyle, D.R.; Coleman, M.D. 2013. Survival and growth of a range of *Populus* clones in central South Carolina USA through age ten: do early assessments reflect longer-term survival and growth trends. Biomass and Bioenergy. 49: 260–272. https://doi.org/10.1016/j.biombioe.2012.12.005.

Langholtz, M.H.; Stokes, B.J.; Eaton, L.M. 2016. 2016 Billion Ton report: Advancing domestic resources for a thriving bioeconomy, Volume 1: Economic availability of feedstock. ORNL/TM-2016/160. Oak Ridge, TN: U.S. Department of Energy. Oak Ridge National Laboratory. 411 p.

Maisenhelder, L.C. 1970. Eastern cottonwood selections outgrow hybrids on southern sites. Journal of Forestry. 68: 300–301.

Mohn, C.S.; Krinard, R.M. 1971. Volume tables for small cottonwoods in plantations. Res. Note. SO-RN-113. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 4 p.

Newcombe, G.; Ostry, M.E. 2001. Recessive resistance to Septoria stem canker of hybrid poplar. Phytopathology. 91: 1081–1084.

Niemczyk, M.; Thomas, B.R. 2020. Growth parameters and resistance to *Sphaerulina musiva*-induced canker are more important than wood density for increasing genetic gain from selection of *Populus* spp. hybrids for northern climates. Annals of Forest Science. 77: 26. https://doi.org/10.1007/s13595-020-0931-y.

Ostry M.E.; McNabb, H.S. 1985. Susceptibility of *Populus* species and hybrids to disease in the North Central United States. Plant Disease. 69: 755–757.

Prakash, C.S.; Heather, W.A. 1986. Inheritance of resistance to races of Melampsora medusae in *Populus deltoides*. Silvae Genetica. 35(2,3): 74–77.

Prakash, C.S.; Thielges, B.A. 1987. Pathogenic variation in *Melampsora medusae* leaf rust of poplars. Euphytica. 36: 563–570. https://doi.org/10.1007/BF00041503.

Rousseau, R.J.; Adams, J.P.; Wilkerson, D.W. 2013. Nine-year performance of a variety of *Populus* taxa on an upland site in western Kentucky. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 299–305.

SAS Institute. 2016. SAS Proprietary Software 9.4 (TS1M6). https://documentation.sas.com/doc/en/pgmsascdc/9.4_3.4/statug/statug_mixed_syntax.htm. [Date accessed: March 14, 2022].

Westvaco Central Forest Research Center, Central Region. 1991. Unpublished research report. On file with: Westvaco Central Region Research, Hwy. 121, Wickliffe, KY 42087.

Zalesny, R.S.; Hall, R.B.; Bauer, E.O.; Riemenschnieder, D.E. 2005. Soil temperature and precipitation affect the rooting ability of dormant hardwood cuttings of *Populus*. Silvae Genetica. 54(2): 47–58.

Zalesny, R.S., Jr.; Zalesny, J.A. 2009. Selecting *Populus* with different adventitious, root types for environmental benefits, fiber, and energy. In: Niemi, K.; Scagel, C., eds. Adventitious root formation of forest trees horticulture plants—from genes to applications. Research Signpost: 359–384. Chapter 18.