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An assessment of potential of hybrid poplar for planting in the Virginia Piedmont

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Abstract Poplar species grow well across the temperate zone, but hybrid varieties have not previously been evaluated for planting in the Virginia Piedmont region. The top 12 clones in height growth and rust resistance from a screening trial involving 98 hybrid poplar varieties of three taxa (*Populus deltoides* × *P. maximowiczii*, DxM; *P. deltoides* × *P. nigra*, DxN; *P. deltoides* × *P. trichocarpa,* DxT) were selected for planting in replicated yield trials at two locations in the Virginia Piedmont. Results through the first four growing seasons showed that the DxM taxon had the most rapid height development. It was, however, the taxon most affected by a late spring frost at the Appomattox-Buckingham State Forest site and by *Septoria* stem canker at the Reynolds Homestead site. Analysis of variance of clonal and location effects showed highly significant differences among replicates within location and among clones within taxon. Among seven clones within the DxM taxon, pairwise comparison tests of height growth identified two groups: a group of four better clones that were significantly different ($p = 0.05$) from a second group of three. These early results suggest that multi-selection criteria, including growth, disease and frost resistance, are important when developing hybrid poplar clones for planting in the Piedmont region.

Keywords *Populus* · Growth · Yield · Genetic effects · Frost tolerance · Disease resistance

Introduction

Hybrid poplars are among the fastest growing trees within the temperate zone. Plantation silviculture is highly refined and commercial stands have been successfully managed through multiple rotations by the pulp and paper, timber, and the environmental-

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remediation industries in various regions (Czapowskyj and Safford 1993; Stanton et al. 2002; Goerndt and Mize 2008; Johnstone 2008; Traux et al. 2012). However, poplar varieties have not been evaluated for use in the Virginia Piedmont physiographic province. There is robust demand for hardwood fiber in the region, driven largely by pulp mills and—more recently—by pellet mills. The vast majority (approximately 90%) of the land base is privately owned, and these landowners need information on potential of fast-growing hardwood species for plantation culture.

Although hybrid poplar has not been developed specifically for Virginia, indications are that it should grow well in the Commonwealth. The native range of *Populus* is widespread throughout the Northern Hemisphere's temperate zone, and the tremendous genetic diversity of *Populus* can be repackaged through breeding to yield productive varieties for most temperate regions. Poplar plantations grown on rotations of 6–8 years in the Pacific Northwest region of the US have exhibited growth rates of 25–42 m^3/ha/year (Stanton et al. 2002). The yield trials in Virginia, reported on here, reflect yield potential with intensive silvicultural treatments.

The best-performing hybrid poplar varieties from a 2-year genetics screening trial of 98 clones (Brunner et al. 2009) were propagated and planted in replicated yield trials at the Reynolds Homestead in Patrick County and on the Virginia Department of Forestry State Forest in Buckingham County in spring 2012. The trial sites, which have been measured over a 4-year period, provide initial values of productive potential and pathogen susceptibility for hybrid poplar grown in the Virginia Piedmont.

Materials and methods

Screening trial

Nighty eight clones from three taxa (*P. deltoides* × *P.maximowiczii*, DxM; *P. deltoides* × *P. nigra*, DxN; and *P. deltoides* × *P. trichocarpa,* DxT) were included in the genetics screening trial established in May 2009 in Wise County, Virginia (Brunner et al. 2009). Trees were periodically monitored for signs of disease and insect damage. Where damage was present, trees were evaluated using separate rating systems for each causative agent (Table 1). Leaf rust (caused by *Melampsora* spp.) severity was scored during the first 2 years of the screening trial, where 90% of the clones scored none or light rust severity across all taxa in the first year. An outbreak of *Marssonina* leaf spot occurred in the spring of 2011 and in July 2011 at the Wise County site, but the selected clones continued to show resistance to rust. Selection of 12 clones for yield trials was based on growth, survival, and severity of leaf spot disease and weevil damage with different criteria values used for each taxon to ensure that all taxa were represented in the field trial (Table 1).

Cuttings from selected clones were collected from the screening trial and stored at 4 °C until rooting was initiated on January 27, 2012. Non-terminal stem sections of equal quality (0.6 cm diameter, 13 cm length and containing two lateral buds) were inserted into D16 cells; each cell contained 0.7 ml Osmocote Pro 8–9 month 20-4-8, 0.35 ml bonemeal, gypsum, and dolomite and 0.18 epsom salt. Rooted cuttings were placed under 16-h day lengths and shoots were topped to 30 cm before yield trials were planted at the Appomattox-Buckingham State Forest (AB) in Buckingham County (latitude 37.418 N, longitude 78.669 W, elevation 213 m) on May 16, 2012 and the Reynolds Homestead Forest

Table 1 Scoring codes for screening trial and clone selection criteria for yield trials

Scoring code for leaf rust					
0 = No rust					
1 = Traces of spores on a few leaves					
2 = Moderate infection, pustules on many leaves					
3 = Severe infection, dense clusters of orange pustules					
Scoring code for Marssonina leaf spot					
0 = No leaf spot or stem lesions observed on the tree					
1 = Light infection, leaf spots on less than 25% of the leaves, usually confined to lower, shaded leaves					
2 = Moderate infection, leaf spots seen on up to 50% of the leaves of the tree, some stem lesions seen					
3 = Heavy infection, leaf spots on more than 50% of the leaves, stem lesions frequent and readily observed					
Scoring code for wood boring weevil					
0 = Undamaged, no insect swelling apparent					
1 = Basal or lower stem swelling apparent on the tree, no lesions seen, tree not leaning					
2 = Basal or lower stem swelling apparent on the tree, lesions can be seen on the swollen area, tree not leaning					
3 = Basal or lower stem swelling or associated damage apparent on the tree; tree leaning or fallen but not dead (green shoots and leaves on stem)					
4 = Basal or lower stem swelling or associated damage apparent on the tree, tree fallen, main stem dead or dying, sprouting at ground level is apparent.					
5 = Basal or lower stem swelling or associated damage apparent on the tree, tree fallen, main stem dead or dying, no live sprouting at ground level is apparent.					
Selection criteria					
	DBH (mm)	Height (m)	Survival	Disease	Damage
DXM:	>11.9	>1.7	=100%	<2.6	<2.1
DXN:	>6.0	>1.5	>70%	<2.0	<1.0
DXT:	>8.9	>1.8	=100%	<3.1	<2.4

Resources Research Center (RH) in Patrick County (latitude 36.643 N, longitude 80.146 W, elevation 340 m) on April 27, 2012 (Fig. 1).

Yield trials

The yield trials located in Buckingham and Patrick counties were replicated four times with nine-ramet square plots of the 12 selected clones included in each replicate (Fig. 2). Soils at both sites are variable and somewhat acidic (pH = 6.2 at AB and 5.6 at RH). Herbicide (glyphosate) was applied to control grass competition at both sites. No additional herbicide treatments have been imposed at AB, but the grass between rows has been mowed each spring. In addition to the initial glyphosate treatment at RH, triclopyr was applied for control of invasive hardwoods after the second, third and fourth growing seasons and mowing occurred between rows each year. No fertilizers have been applied at either location. Spacing between trees is 2.4 × 2.4 m. Both sites were fenced to prevent deer browsing. Height measurements to the nearest cm were taken following growing seasons one through four using height poles. Diameter at breast height (1.37 m) was measured to the nearest mm for ages two through four with diameter tapes at the AB site and calipers at the RH location. Insect and disease damage was monitored during the growing season and scored at each measurement. Early in the third growing season (mid-

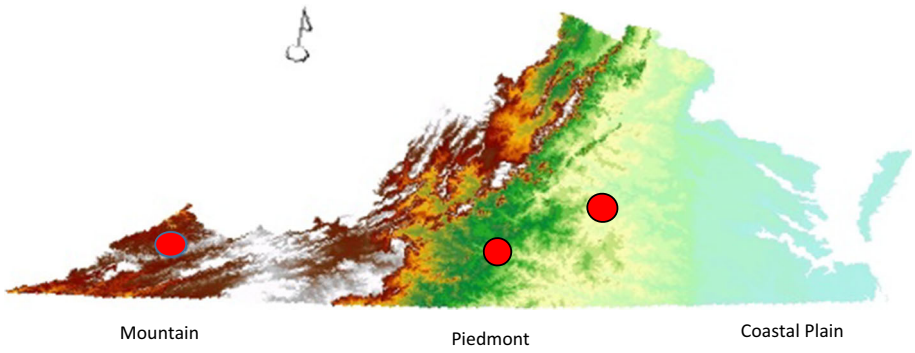

Fig. 1 Physiographic map of Virginia showing location of hybrid poplar screening trial in Wise County (*left*) and yield trials in Patrick County (*center*) and Buckingham County (*right*) in the Virginia Piedmont

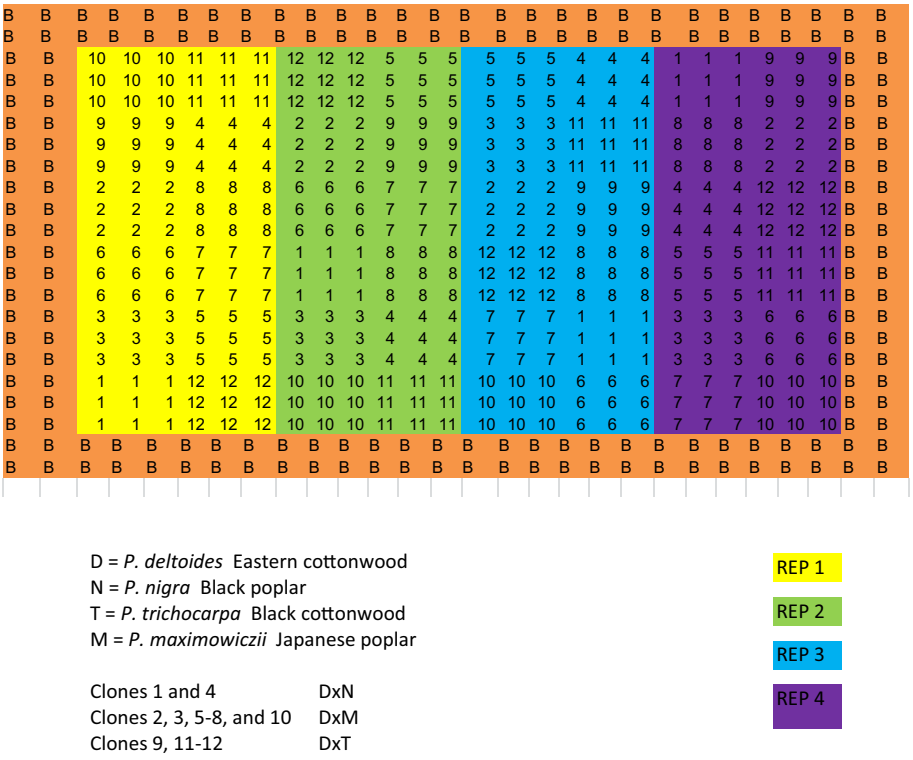

Fig. 2 Hybrid poplar yield trial layout at Appomattox-Buckingham State Forest consisting of 4 replicates (R-1 to R-4) of 12 clones with 9 ramets per clone for a total of 432 measured trees (*B* designates the two rows of border trees). The same design with new randomization for each replicate was installed at the Reynolds Homestead

April 2014), the extent of bud flushing was recorded for each taxon. Due to an unanticipated frost in late April of that year, bud flushing could be related to the extent of frost damage, as well as to height growth prior to the frost event. The primary goal of the yield

trials was to evaluate clones for good growth characteristics, thus providing insight into potential selection gains at the clone level. An analysis of variance with main effects clones within taxa and replicates within locations, as well as an interaction term, was specified for this part of the data analysis.

The yield trials build on promising results from varietal screening trials established with plant material developed by GreenWood Resources, Inc. (GWR), a leading developer of hybrid poplar varieties in North America (http://www.greenwoodresources.com).

Results and discussion

As shown in Fig. 3, the DxM taxon was clearly superior in height growth to the other two taxa in the original screening trial at Powell River. Further, within the DxM taxon, the best clones achieved heights after 2 years that were roughly double that of the poorest performing clones.

First year measurements from these two sites showed average height growth of 1.4 m at the Reynolds Homestead and 1.2 m at the Appomattox-Buckingham site, with some individual trees exceeding 3 m in height growth in the first growing season. Diameter at breast height values, as well as height measurements, were acquired starting in year two.

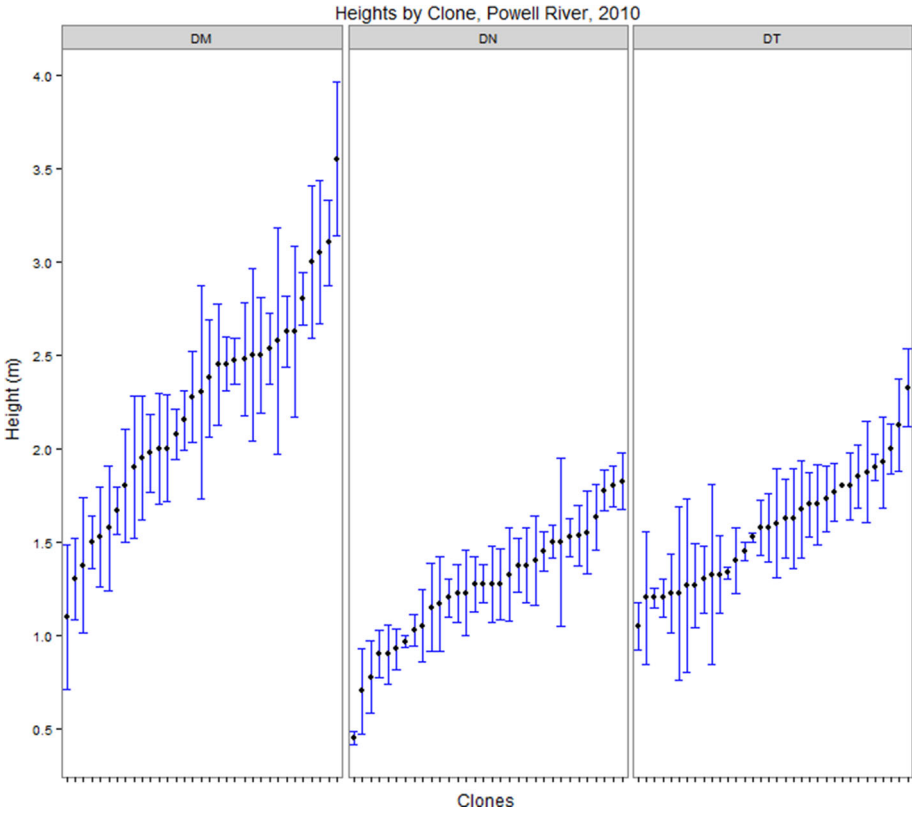

Fig. 3 Hybrid poplar heights (m) by clone within taxa, 2 years after planting at the Powell River site, Wise County, Virginia. Means by clone and the standard error of the mean are averaged from lowest to highest mean values within each taxon

Table 2 Mean values and standard deviations (sd) by hybrid poplar taxa of heights (m), diameter at breast height (DBH, cm), and volume per tree (m^3) for the Appomattox-Buckingham State Forest (AB) and Reynolds Homestead (RH) for ages 1 through 4

Location	Taxon	Measurement	HT mean (m)	HT sd (m)	DBH mean (cm)	DBH sd (cm)	Vol. per tree mean (m^3)	Vol. per tree sd (m^3)
AB	DxM	1	1.35	0.673	NA	NA	NA	NA
AB	DxM	2	2.83	0.854	1.542	0.875	0.000481	0.000603
AB	DxM	3	3.13	1.200	2.112	1.207	0.001079	0.001454
AB	DxM	4	4.32	1.568	3.014	1.586	0.002779	0.003482
AB	DxN	1	1.09	0.492	NA	NA	NA	NA
AB	DxN	2	2.48	0.754	1.231	0.655	0.000258	0.000304
AB	DxN	3	3.40	1.073	1.969	1.025	0.000876	0.000941
AB	DxN	4	4.42	1.556	2.893	1.444	0.002436	0.002347
AB	DxT	1	1.22	0.353	NA	NA	NA	NA
AB	DxT	2	2.28	0.453	1.181	0.541	0.000186	0.000197
AB	DxT	3	2.95	0.698	1.872	0.848	0.000615	0.000652
AB	DxT	4	3.75	0.902	2.821	1.221	0.001733	0.001791
RH	DxM	1	1.55	0.450	NA	NA	NA	NA
RH	DxM	2	4.72	0.882	3.291	1.051	0.002571	0.001833
RH	DxM	3	6.24	1.202	5.129	2.441	0.009299	0.027198
RH	DxM	4	8.26	1.617	6.376	1.517	0.015987	0.009011
RH	DxN	1	1.37	0.400	NA	NA	NA	NA
RH	DxN	2	3.90	0.716	2.262	0.843	0.001052	0.000858
RH	DxN	3	5.02	1.023	3.341	1.161	0.002904	0.002101
RH	DxN	4	6.70	1.690	4.336	1.450	0.006631	0.004965
RH	DxT	1	1.35	0.251	NA	NA	NA	NA
RH	DxT	2	3.82	0.652	2.968	1.058	0.001728	0.001367
RH	DxT	3	4.97	0.874	4.317	1.436	0.004698	0.003578
RH	DxT	4	6.78	1.241	5.743	1.480	0.010814	0.007140

Table 2 and Fig. 4 provide a summary of height (ages 1–4) and diameter (ages 2–4) measurements by taxon for the two planting sites. Average tree volume[1] is also shown for ages 2–4 in Table 2.

A summary of means and standard deviations of heights by clones is provided in Table 3. Although the number of clones in the DxN and DxT taxa is too few to draw general conclusions, the variability in height by clone is considerable and the tallest four clones (2, 5, 6, and 7) are the same at both locations, indicating a reasonably strong clone effect at this early age.

Early height growth of the selected hybrid poplar clones was better than what has been observed for loblolly pine, the primary species for planting on the Virginia Piedmont. A

[1] Volume per tree (V, m^3) was computed by assuming a form factor of 0.42 (average of a cone and paraboloid, MacDonald and Forslund 1986): $V = 0.000042D^2H$, where D is dbh in cm and H is total tree height in m.

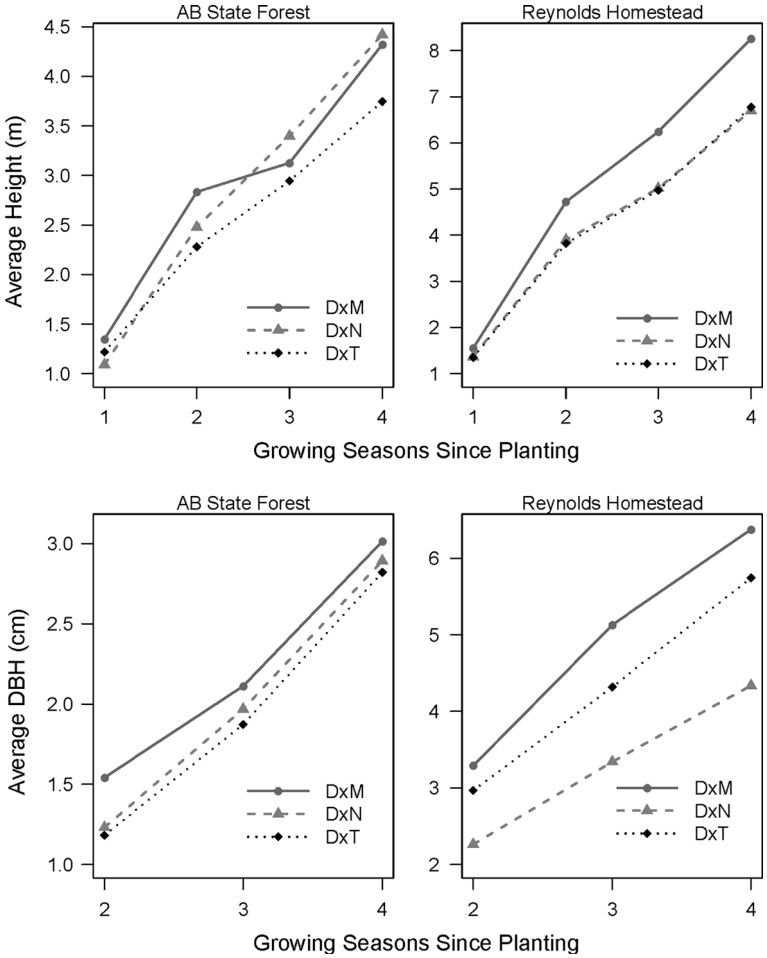

Fig. 4 Average heights (m) from ages 1–4 and average diameters at breast height (DBH, cm) for ages 2–4 for three taxa at Appomattox-Buckingham State Forest and at Reynolds Homestead

spacing trial planted with open-pollinated seed orchard stock that is well adapted for Piedmont sites was established at the AB State Forest in 1983 and measured annually through age 25 years (Amateis and Burkhart 2012). The Buckingham County location consisted of three blocks planted at a range of initial spacing. For the 2.4 × 2.4 m spacing at age four, the mean total height was 3.39 m with a standard deviation of 0.499 m. By contrast the mean height for the hybrid poplar DxM taxon was 4.32 m, DxN was 4.42 m, and DxT was 3.75 m at age four (Table 2). These mean heights are low compared to the RH site (DxM = 8.26 m, DxN = 6.7 m, and DxT = 6.78 m), but no replicates of the loblolly pine spacing trial were established at RH so a direct comparison cannot be made. However, if disease resistance and cold tolerance issues can be successfully addressed, these early results indicate that planting hybrid poplar might be an attractive option for plantation culture in the Piedmont region.

Table 3 Mean values and standard deviations (sd) of heights (m) at age four by hybrid poplar clones for the Appomattox-Buckingham State Forest (AB) and Reynolds Homestead (RH) sites

Clone[a]	HT mean (sd) (m)			
	AB	AB	RH	RH
Taxon DxM				
2	4.66	(1.286)	9.15	(0.971)
3	4.14	(1.612)	7.93	(1.531)
5	5.06	(1.227)	9.15	(1.157)
6	4.39	(1.586)	9.01	(0.915)
7	5.20	(1.666)	8.95	(1.313)
8	3.59	(1.040)	6.08	(1.083)
10	2.72	(0.986)	7.50	(1.464)
Taxon DxN				
1	4.42	(1.660)	7.09	(1.963)
4	4.04	(1.439)	6.31	(1.275)
Taxon DxT				
9	4.16	(0.793)	6.52	(1.291)
11	3.47	(1.018)	7.22	(1.450)
12	3.49	(0.789)	6.26	(1.141)

[a] Clone identity codes: 1 = 4031-8, 2 = 919-02-32560, 3 = 924-02-32676, 4 = 4021-85, 5 = 918-02-32523, 6 = 867-01-30909, 7 = 867-01-30943, 8 = 915-03-32392, 9 = 86-90-289, 10 = 605-97-19140, 11 = 97-91-1315, 12 = 69-90-81

April flushing and subsequent frost damage

In mid-April 2014, 2 years after planting, the trials were assessed for flushing/budding activity. Extent of early flushing is significantly correlated with accumulated height at age 2 for both sites (simple linear correlation r = 0.62 for RH, and 0.74 for AB; Fig. 5). In late April, unusually low temperatures—especially at the Appomattox site—were reached on two successive nights. The correlation between bud flushing in mid-April 2014 and frost damage later in the month is not significant for the RH site (r = −0.19), but it is highly significant at the AB site (r = 0.77; Fig. 5). Frost damage overall was very low at the RH site, resulting in the lack of correlation between flushing extent and amount of frost damage.

As shown in Table 4 and in Fig. 5, the DxM taxon flushes early and generally has superior accumulated height growth in the first 2 years, but it suffered the most frost damage among the three taxa (DxM, DxN, DxT) included in these trials. Late frost of the severity observed at the AB site is relatively rare, but this chance event in 2014 suggests that cold hardiness is another factor, in addition to growth and disease resistance, that could prove valuable when selecting hybrid poplars for planting in the Virginia Piedmont. Data in Table 2 and the upper left graph in Fig. 4 show the impact of the late spring freeze on height of the DxM taxon at the end of the third growing season and a significant recovery at the conclusion of the fourth season. Continued measurements at the AB site will provide a more thorough assessment of the extent to which frost-damaged trees might be expected to recover.

Septoria stem canker

The occurrence of Septoria stem canker caused by *Sphaerulina musiva* (syn = *Septoria musiva*) was recorded after four growing seasons. The disease was essentially absent at the AB site but was highly prevalent at the Patrick County (RH) location. Table 5 shows the

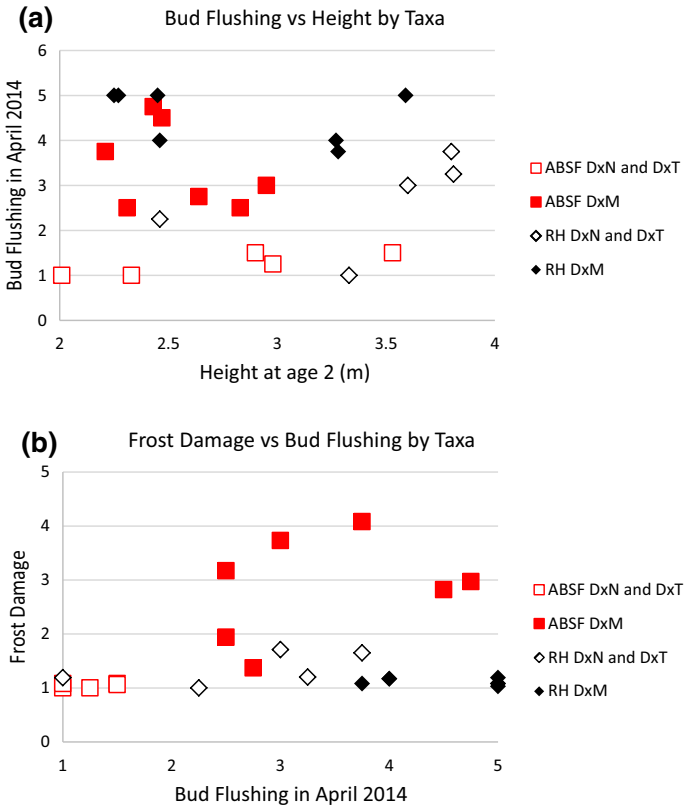

Fig. 5 **a** Bud flushing in mid-April versus height after two growing seasons (age 2); and **b** frost damage (late April) versus bud flushing for hybrid poplar taxa planted at two locations (ABSF Appomattox-Buckingham State Forest, and RH Reynolds Homestead) in the Virginia Piedmont. Scoring for bud flushing and frost damage is given in Table 4

average percent of main stems with infection by *Septoria* cankers at the Reynolds Homestead as 84.53% for DxM, 63.89% for DxT, and 19.94% for the DxN taxon. At this early stage, indications are that DxN may show greater resistance to Septoria canker than the other two taxa, but these trends may not hold over an extended time period. Within taxa there is a fairly wide range of percent incidence of main stem cankers by clone (55.56–100% for DxM, 8.33–30.56% for DxN, and 44.44–97.22% for DxT), but again, these are early indicators that may not hold over time.

ANOVA of clone and replicate effects

An analysis of variance (ANOVA) was carried out using the general linear model:

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k + e$$

The overall model, with Y as height at age 4, grand mean b_0, and main effects clones within taxon (X_1), and replicates within location (X_2), and the product of main effects (X_1

Table 4 Mean values by clone for frost damage, extent of bud flushing (evaluated in mid-April 2014) and total height at the end of the second growing season (measured in Fall 2013) for two locations in the Virginia Piedmont

Appomattox-Buckingham State Forest				Reynolds Homestead			
Clone[a]	Bud Flushing[b]	Frost Damage[c]	Height (m)	Clone[a]	Bud Flushing[b]	Frost Damage[c]	Height (m)
Taxon DxM				**Taxon DxM**			
2	3.75	4.08	2.208	2	5.00	1.19	2.348
3	2.50	1.94	2.307	3	3.75	1.08	3.275
5	4.75	2.97	2.430	5	5.00	1.08	2.271
6	4.50	2.82	2.472	6	5.00	1.08	2.253
7	2.75	1.37	2.641	7	4.00	1.17	2.464
8	2.50	3.17	2.834	8	4.00	1.17	3.273
10	3.00	3.73	2.946	10	5.00	1.03	3.588
Taxon DxN				**Taxon DxN**			
1	1.00	1.00	2.008	1	2.25	1.00	2.462
4	1.00	1.08	2.329	4	1.00	1.19	3.326
Taxon DxT				**Taxon DxT**			
9	1.50	1.08	2.898	9	3.00	1.71	3.600
11	1.25	1.00	2.975	11	3.75	1.65	3.806
12	1.50	1.06	3.536	12	3.25	1.20	3.814

[a] See Table 3 for clone identification numbers

[b] Bud flushing was scored as 1, no apparent activity; 2, bud swell; 3, bud break; 4, leaf expansion beginning; 5, visible leaves (1/4 leaf or so)

[c] Frost damage was evaluated as 1, no damage or only minor damage to new leaves; 2, damage to new leaves and some damage to new shoots; 3, significant damage to and die back of terminal leader and shoots; 4, frost crack near base of main stem and some damage to shoots; 5, frost crack near base of main stem and significant damage to terminal leader and shoots; 6, dead to ground

X_2) representing genetic by environment interaction (GxE) was highly significant ($F = 68.52$, $p < 0.0001$, where p is the probability of a F value of 68.52 or larger due to random chance). Testing with Type I (sequential) sum of squares for clones within taxon and replicates within location, and GxE interaction gave F ratios of 48.29, 403.72, and 4.16, respectively, with all being highly significant ($p < 0.0001$).

The overall model accounted for 81.27% of the total corrected sum of squares, with clones within taxon accounting for 12.35% and replicates within location accounting for 65.73%. The interaction term, although statistically significant, accounted for only 3.19% of the total corrected sum of squares.

Dividing the data into three groups consisting of the tallest, middle, and shortest four clones in each replicate showed a reasonably consistent pattern of rank stability. For example, Clone 7 was in the tallest group in three of four replicates at the AB location and in all four replicates at the RH site. Clone 12 was in the shortest group at three of the replicates at both sites. These results are consistent with a review of performance of improved genotypes of loblolly pine planted across different soils and climates in the southeastern US (McKeand et al. 2006). With only a few exceptions, open-, control-pollinated, and clones of loblolly pine were generally stable in performance across all sites within climatic zones. The authors conjectured that as tree improvement progresses

Table 5 Proportion of main stems of hybrid poplar clones with *Septoria* canker after four growing seasons for the Appomattox-Buckingham State Forest (AB) and Reynolds Homestead (RH) sites

Clone[a]	Proportion infected	
	AB	RH
Taxon DxM		
2	0	0.5556
3	0	0.6667
5	0	0.9167
6	0	1.000
7	0	1.000
8	0	0.8611
10	0	0.9167
Mean	0	0.8453
Taxon DxN		
1	0	0.0833
4	0	0.3056
Mean	0	0.1944
Taxon DxT		
9	0.1667	0.4444
11	0	0.5000
12	0.1111	0.9722
Mean	0.0926	0. 6 389

[a] See Table 3 for clone identification numbers

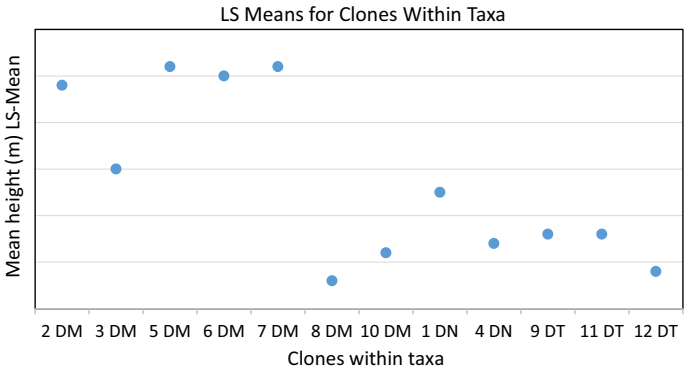

Fig. 6 Plot of least squares mean heights of seven clones in taxon DxM, two clones in DxN, and three clones in DxT

towards development of more intensively selected genotypes, the GxE effects on growth may become more pronounced.

Figure 6 shows the least squares mean heights by clones within taxa. Only the DxM taxon with seven clones had sufficient numbers for making meaningful pairwise comparisons. The pairwise comparison of least squares means of clones within the DxM taxon revealed two groups. Clones 2, 5, 6 and 7 were not significantly different within the group of better performing clones when applying the Tukey–Kramer test with an alpha level

(probability of a Type I error) of 0.05 but were significantly different from clones 3, 8, and 10 that constitute the second group.

Conclusion

In conclusion, early data indicate that selected hybrid poplar clones grow well in the Piedmont region. Height growth through age four exceeded that of the primary conifer (loblolly pine) that is widely planted and managed on Piedmont sites. However, when selecting clones for deployment in parts of the Piedmont that regularly experience late spring frost events, frost tolerance, in addition to height growth, and resistance to *Melampsora* rust and *Septoria* canker, should be considered. A highly significant positive correlation between bud flush stage and frost damage was observed at the AB site. In the RH site where the *S. musiva* fungus is prevalent, high rates of stem cankers were observed, especially for the DxM taxon.

Although DxM exhibited superior early height and diameter growth as compared to DxN and DxT in these trials, it is also the taxon that showed the greatest susceptibility to frost damage and *Septoria* canker. Thus, a multi-criteria clone development and deployment strategy is indicated.

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