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NRRI TECHNICAL REPORT

INTER-TREE COMPETITION EFFECTS IN HYBRID POPLAR GENOTYPE TESTING

Submitted by
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ABSTRACT

The effects of inter-tree competition on growth in family field trials (FFT), clone trials (CT) and yield blocks (YB) were studied in NRRI experimental field plots in Minnesota, USA. FFT and CT competition is inter-clonal , YB competition is intra-clonal. Two approaches were explored: (1) regression analysis of growth of individual trees versus growth of immediate neighboring trees in FFT and CT; (2) bole volume growth as measured by DBH^2 in CT versus YB for the same clones on each site to determine whether inter- clonal competition in CT overestimates tree growth in YB. In CT on five sites planted the same year with the same population of clones ("simultaneous CT"), significant negative slopes, indicating the onset of inter-tree competition, occurred in the fifth and sixth years for the two fastest-growing CT. The top 50^{th} growth percentile clone group in the fastest-growing of the simultaneous CT had a significant negative regression line slope; the lower 50^{th} group did not. The three slower growing CT did not exhibit competition (significant negative slopes) from three through six years. A separate clone trial measured through 9 years showed little evidence of inter-tree competition. The regression slopes in FFT were almost all positive, indicating no inter-tree competition effects from three through ten years of stand age. All significant regression R^2 values were low–a maximum of 24 % for CT, 22 % for FFT. Clonal genetic potential for growth likely predominates prior to significant inter-clonal competition, suggesting that randomization of single-tree replications of each clone within each block is effective in evaluating clone genetic growth potential within the initial six years selection window that we have used in our program. There was no significant difference between CT and YB for tree bole volume growth (yield) in a population of clones. There was wide variation in the YB/CT yield ratios between individual clones on a site. Some individual clones exhibited wide variation in YB/CT ratios between different sites, indicating a clone x site interaction for this trait. The commercial clone NM6, used as a check clone in most of our studies, had the widest variation of any clone in YB/CT ratios between sites, ranging from 53 % to 104 %. Of the 22 YB/CT yield ratios for specific clones on 14 sites, only four were above 100 %, indicating a clear trend for CT overestimating yields in YB. The average of the 22 YB/CT ratios was 86 %, again indicating overestimation of YB yield in the CT. The YB/CT ratio for NM6 averaged 79 %, while five elite (fast growing, disease resistant) clones averaged a YB/CT yield ratio of 89 % over the 14 sites. CT/YB yield ratios are too variable to use CT growth as an estimate of growth for specific clones under near commercial conditions (YB).

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INTRODUCTION

Inter-tree competition is an important research subject in forestry and has been studied for decades. Spacing and stand stocking underly these studies, which have evolved into increasingly sophisticated modeling efforts, eg., Bella (1971), Radtke et al. (2003), and Boone and Bullock (2008).

Several studies on inter-tree competition, spacing, and inter-clonal versus intra-clonal competition in *Populus* have been reported. Hall (1994) investigated the use of the crown competition factor concept to select clones and spacings. DeBell and Harrington (1997) reported a highly significant clone x spacing interaction for diameter (DBH) and height at three years for four poplar clones grown at three spacings (0.5, 1.0, 1.5 m) in the Pacific Northwest, USA. (PNW). DeBell et al. (1997) found that four clones at 1.0 m spacing in monoclonal plots in the PNW appeared to differ in tolerance to crowding or competition at age 8, as reflected in diameter growth. DeBell et al. (1997) also reported that differences among clones in tree growth and stand productivity were much less in large monoclonal plots (intra-clonal competition; similar to yield blocks in the NRRI system) than for smaller plots (inter-clonal competition; represented by family field trials and clone trials in the NRRI system). Nelson et al. (2021a) in field experiments in Minnesota, USA, found that clone rank in clone trials at full rotation (9/10 years) was more highly correlated with rank at full rotation in yield blocks than was clone rank at half rotation in clone trials, which could be explained by a clone x neighbor tree competition interaction that was manifested after crown closure in the clone trials and/or disease manifestation after half-rotation age in the CT.

The multi-step NRRI hybrid poplar improvement system is a sequential field testing and selection process utilizing, in chronological order, family field trials (FFT), clone trials (CT), and yield blocks (YB) (Nelson et al. 2021a). The FFT and CT designs are randomized complete blocks with randomized single tree plots of each clone within each block. In our existing databases FFT have either 3 or 5 blocks (3-5 replications per clone), the CT 6 blocks (6 replications per clone). Most FFT and CT have 3.05 x 3.05 m spacing. FFT and CT individual clones are surrounded by up to four neighboring clones, depending on survival. These neighboring clones are of different genotypes, ie., any competition with each clone will be inter-clonal competition. This is in contrast to YB, where each single genotype (clone) is surrounded by the same genotype, ie., intra-clonal competition (Nelson et al. 2021a). The inter-clonal competition in FFT and CT potentially provides more variable inter-tree competition than in YB, which could affect the growth rate and clone rank.

Clone performance differences under inter-clonal and intra-clonal competition was recognized as an important area of research in *Populus* clonal improvement by Riemenschneider et al. (1996). Stanton (2001) states that clonal field trials exaggerate clonal growth differences. This suggests that CT overestimates “true yield” as measured in YB. We sought to minimize or eliminate the clone x neighbor competition interaction by randomizing the position of each clone within each block in FFT and CT.

Here we use regression analysis to determine whether growth of each tree in FFT and CT is related to growth of immediate neighboring trees. To our knowledge, the earliest use of this approach was in Steneker and Jarvis (1963), Stern (1966), and Sakai et al. (1968). Our hypothesis, in line with these earlier studies, is that the regression slope will be negative after competition is significant in the trials, ie., faster growth by neighbors will reduce growth of each tree. We will test the slope and R^2 for direction and significance of the relationship. Non-significance or small R^2 s would imply that genetic potential is being reflected accurately in FFT and CT and that differential competition is not a significant factor in determining clone growth potential.

We also compare tree bole volume estimates from CT and YB for specific clones as another method to determine whether inter-clonal competition in CT overestimates tree growth in YB, which tests intra-clonal competition.

MATERIALS AND METHODS

Field tests

The experimental sites are all in Minnesota, and all but the Waseca trial are in central or northern Minnesota (Table 1 here and Table 3 in Nelson et al. 2021a). Study designs for most of the trials are in Nelson et al. (2018, 2021a). The trials not described in those tables have similar designs (all randomized complete blocks, most with one single-tree replication of each clone in each block of a trial at a site. Species composition of the CT and YB plots is in Table 2. Species composition of the FFT is in Table 1 in Nelson et al. (2021a). Spacing varied from 1.5 x 1.5 m to 3.0 x 3.0 m, and each CT versus YB comparison was at a single uniform spacing (Table 6). Plantation establishment and maintenance for most of the plots are described in Nelson et al. (2018, 2021a) and are similar for those not described there. Five CT (Crabtree, Koljonen, Riewer, Wanderscheid, Wheeler) were all planted the same year with identical clones (Nelson et al. 2018) and are referred to in this report as "simultaneous clone trials (CT)."

Statistical analysis

Diameter breast height squared (DBH^2) is the unit of measurement for all growth comparisons.

For CT and FFT, linear regressions were done for each experimental site, where y = tree growth, x = neighboring tree(s) growth at each age (3 – 9 years for CT, 3 – 10 years for FFT). We did five regressions for each tree, one for each of four neighbors in the north, south, and east and west cardinal directions, and one for tree growth vs the average of the 4 neighbors' growth. Dead neighboring trees were given a value of zero for growth rate. Regressions were done for both raw measurements and clone means. Analysis variables were R^2 and b (slope of the regression line). Significant negative slopes indicate inter-tree competition (Sakai et al. 1968). Significant positive slopes and insignificant regressions suggest little effect of competition, reflecting the heterogeneous distribution of micro-environmental effects within a site and the similar environmental effects upon adjoining trees (Sakai et al. 1968), ie., soil quality and other micro-environmental properties result in all neighbor trees growing at a relatively similar rate at any point location within the stand.

We then ranked clones in each simultaneous CT at age 6 and each FFT at age 5 and separated clones into the top and bottom 50th percentiles. The regression analyses were then repeated for each of the two ranking groups within each CT and FFT site at each age.

We also compared bole volume yield, using DBH^2 as a yield indicator, for the same specific clones in CT and YB on each site to test the effect of inter-clonal (CT) versus intra-clonal competition (YB). Comparisons included the Hansen site, which had 22 clones in common between CT and YB (Table 15) and individual clone comparisons (Table 16) which were for commercial check clone NM6 (a *Populus nigra* x *Populus maximowiczii* cross or taxon type), elite *Populus deltoides x Populus nigra* (DN) clones 99059016, 9732-11, 9732-24, and the *P. deltoides* female parent (D124) of elite DD clone 9605-35 (Nelson et. 2021b). For the CT versus YB individual clone comparisons, only individual clones that had 67 % or greater survival in the CT were used in the comparisons.

Box plots were used to evaluate the significance of the CT versus YB yield estimates at the Hansen site. In the box plots used here, the top of the rectangle indicates the extent of the third quartile (75 % of data fall below this value), the horizontal line near the middle of the rectangle indicates the median, and the bottom of the rectangle indicates the upper extent of the first quartile (25 % of the data fall below this value). The vertical line (upper whisker) extending from the top of the rectangle is the range of non-extreme values above the third quartile; the vertical line (lower whisker) from the bottom of the rectangle is the range of non-extreme values below the second quartile. Extreme data points are excluded from the whiskers by setting whisker length equal to 1.5 times the box length. The relative vertical spacing between the labels is proportionate to the actual values of the variable.

RESULTS

Survival at each site is in Tables 3 – 6. CT had higher survival than FFT, likely due to the greater genetic diversity in the FFT , which include the maladapted D x M cross. All survivals are adequate for including the data in analyses.

Regression results are in Tables 7 – 14. Regressions based on raw measurements had more significant relationships than those based on clone means, probably due to the larger n in the former. The significant R^2 values in all CT and FFT regression analyses explained a small proportion of the variation–a maximum of 24 % for CT, 22 % for FFT. FFT had more significant regression line slopes (almost all with a positive slope) and R^2 than CT, probably due to the larger sample sizes in the FFT. In both CT and FFT, more E and W neighbor and neighbor-average regressions were significant than were N and S neighbor regressions. In the simultaneous CT, significant negative slopes (reflecting competition) occurred predominantly in the E and W and neighbor-average regressions.

In the simultaneous CT, significant negative slopes occurred in the fifth and sixth years for the two fastest-growing CT, Wheeler (fastest) and Crabtree (second fastest), indicating the onset of inter-tree competition. The top 50^{th} growth percentile clone group in the Wheeler CT had a significant negative regression line slope; the lower 50^{th} group did not. The three slower growing CT (Koljonen, Riewer, and Wanderscheid) did not exhibit competition (ie., no significant negative slopes) through six years.

Only one regression with a negative slope was significant in the Hansen CT through age 9, indicating little inter-tree competition.

Only three regressions with a negative slope were significant in the FFT, indicating no significant competition effects for 3 through 10 years.

CT versus YB DBH^2 comparisons are in Tables 15 and 16 and Figure 1.

In the Hansen comparisons) for 22 clones common to both CT and YB on that site (Table 15), the theoretically more uniform competition in the YB resulted in a 3 – 8 % nominal reduction in the yield estimate versus the CT for ages 4 through 9 years, with a greater reduction at age 9 (near full rotation) than at younger ages. The coefficient of variation (CV) for the Hansen site was inversely related to stand age from ages 4 through 9 in both CT and YB, although only the change from age 3 to 4 was large. The age trends are clear, but the box plot (Figure 1) indicates that the differences in yield estimates between YB and CT at any given age at the Hansen site are not significant.

There was wide variation in the YB/CT yield ratios between clones on a site (Table 16). Some clones at similar ages exhibited wide variation between different sites, eg., the clone 99059016 (‘NextGen’ variety, InnovaTree™) YB/CT ratio ranged from 75 % to 118 % over four sites. The commercial clone NM6, used as a check clone in most of our studies, had the widest variation of any clone in YB/CT ratios between sites, ranging from 53 % to 104 %. Three of the elite clones had higher yields in the YB than in the CT on certain sites, specifically 9732-11 and D124 at Foote and 99059016 at MP. Of the 22 YB/CT ratios for specific clones on 13 sites, only four were above 100 %, indicating a clear trend for CT overestimating yields in YB (Table 16). The average of the 22 YB/CT ratios in Table 16 is 86 %, again indicating overestimation of YB yield in the CT. The YB/CT ratio for NM6 averaged 79 %, while the elite clones averaged 89 % over the 12 sites.

DISCUSSION

The predominance of positive values and low R^2 across the regression analyses suggest that little inter-tree competition is occurring over the first six years of stand age in the five simultaneous CT and over the first ten years of the FFT. Clonal genetic potential for growth likely predominates prior to significant inter-clonal competition, suggesting that randomization of single-tree replications of each clone within each block is effective in evaluating clone genetic growth potential within the first six years selection window that we have used in our program. Competition effects start to appear by age 6 in the two fastest growing CT sites (Wheeler and Crabtree) and in the fastest growing clones at the Wheeler site, suggesting that competition as measured by the regression technique here may occur over the other simultaneous CT sites between 6 and 9 years stand age. However, there was little evidence of inter-tree competition in the Hansen CT through 9 years. The assumption is that competition becomes significant when crown expansion reaches a critical point. However, confounding factors in CT such as disease incidence potentially become more prevalent as the stands age, making correlations of the growth of neighboring trees more difficult to interpret in older CT. Aside for these possible confounding factors, the regression technique used here may be a method of judging when crown closure occurs in a plantation, ie., when regressions between the growth of immediately neighboring trees become significant with a negative slope, as in Sakai et al. (1968).

In the simultaneous CT, E and W neighbor comparisons have significant regressions and negative slopes, N and S hardly ever. This likely reflects the sun’s trajectory from E to W. There are also more significant regressions with a positive slope for the E and W versus the N and S in the simultaneous CT, which may be an interaction between sun position and micro-environmental effects. It could also be statistical noise, considering the low R^2 values.

The almost universally positive regression line slopes in the FFT, indicating little inter-tree competition, are probably related to the much greater genetic diversity for growth and lower survival (longer time to crown closure) in the FFT than in the CT.

The coefficients of variation (CV) for DBH^2 at Hansen for CT and YB (Table 15) and the box plot for the Hansen site (Figure 1) indicate that growth differences between clones in CT and YB are not significantly different for this population of 22 clones, varying from the conclusion of DeBell et al. (1997). This result indicates that CT and YB may give similar tree bole volume growth estimates for a collection of clones. This may be expected from the paucity of significant inter-tree competition effects in the regression analyses reported here. However, individual clones exhibit wide variation in YB/CT yield ratios, as explained below.

The wide variability of YB/CT growth ratios for specific clones on different sites (Table 16) suggests a clone x site interaction in inter-tree competition effects. Commercial check clone NM6 had wider variability in YB/CT growth ratios than the elite clones and a lower YB/CT ratio than the average of the elite clones (Table 16). This may be partially due to the canker susceptibility of NM6 on some sites (Nelson et al. 2018). The elite clones in Table 16 have shown canker resistance in all tests to date (Nelson et al. 2021b). The apparent large clone x site interaction in YB/CT ratios precludes using CT for accurate yield predictions for specific clones.

The DBH² YB/CT ratios for specific clones on 13 sites (Table 16) confirm overestimation of volume growth in CT for most individual clones, which agrees with Stanton (2001), but YB/CT yield percentages are too variable to substitute CT for YB for yield estimates for single clones. Nelson et al. (2021a) found that clone rank at age 9/10 (full rotation age) in CT provided a good estimate of clone rank at age 9/10 in YB and that YB is not needed for clone selection, but as shown here YB is still needed for accurate yield estimates for specific clones under near commercial conditions.

While the results clearly show an over-estimation of growth in CT versus YB for most individual clones, the regression technique used here had low R^2 values and did not clearly show inter-tree competition effects in the FFT and CT. However, as explained above, these effects may have appeared at later stand ages on some sites. Another possibility is that there is some intrinsic property of intra-clonal competition that is fundamentally different from inter-clonal competition and is not measured by the regression technique.

While these results apply strictly only to the clones and sites in Minnesota in this study, the principles provide a framework for the relationships studied here with other clones in other locations.

CONCLUSIONS

- Regressions of growth of trees versus their four immediate neighbor trees in family field trials (3 – 10 years) and clone trials (3 – 9 years) did not indicate inter-tree competition, except in the fastest-growing clone trials. Significant regressions had low R^2.
- Clone trials (inter-clonal competition) overestimated growth rate in comparison with yield blocks (intra-clonal competition) for single clones but not for a population of clones.
- Yield Block/Clone Trial (YB/CT) growth rate ratios for specific clones were highly variable on different sites, indicating a clone x site interaction for this trait.
- YB/CT ratio was higher and less variable for tested elite fast-growing clones in our Program than for the commercial check clone NM6.
- Variability of growth between clones decreased with stand age in both CT and YB.
- CT growth did not provide an accurate measure of yield under near commercial conditions (YB) for single clones, even though clone rank in CT was shown in an earlier study to accurately gauge clone rank in yield blocks.
- Yield blocks are required to predict actual yield at full rotation for specific clones.

REFERENCES

Bella I.E. 1971. A new competition model for individual trees. Forest Sci. 17 (3): 364-372.

Boone, E.L., and B.P. Bullock. 2008. Spatial correlation matrix selection using Bayesian model averaging to characterize inter-tree competition in loblolly pine trees. J. Applied Statistics 35 (9): 967-977.

DeBell, D.S., and C.A. Harrington. 1997. Productivity of *Populus* in monoclonal and polyclonal blocks at three spacings. Can. J. For. Res. 27: 978-985.

DeBell, D.S., C.A. Harrington, G.W. Clendenen, and J.C. Zasada. 1997. Tree growth and stand development of four *Populus* clones in large monoclonal plots. New Forests 14: 1-18.

Hall, R.B. 1994. Use of the crown competition factor concept to select clones and spacings for short-rotation woody crops. Tree Physiol. 14: 899-909.

Nelson, N.D., W.E. Berguson, B.G. McMahon, M. Cai, and D.J. Buchman. 2018. Growth performance and stability of hybrid poplar clones in simultaneous tests on six sites. Biomass & Bioenergy 118, 115–125. https://doi.org/10.1016/j.biombioe.2018.08.007

Nelson, N.D., W.E. Berguson, B.G. McMahon, M. Cai, and D.J. Buchman. 2021a. Vectors of efficiency in hybrid poplar genotype testing. Silvae Genetica 70: 39-56.

Nelson, N.D., W.E. Berguson, B.G. McMahon, J. Jackson, D.J. Buchman, J. DuPlissis, and T.W. White. 2021b. Intellectual Property in the NRRI Hybrid Poplar Program – Inventory, Commercialization Plan, and Progress Report, Technical Report NRRI/TR-2021/07 Natural Resources Research Institute, University of Minnesota Duluth, 13 p. https://conservancy.umn.edu/handle/11299/218837

Radtke, P.J., J.A. Westfall, and H.E. Burkhart. 2003. Conditioning a distance-dependent competition index to indicate the onset of inter-tree competition. Forest Ecol. and Management 175: 17-30.

Riemenschneider, D.E., H.E. Stelzer, and G.S. Foster. 1996. Quantitative genetics of poplar and poplar hybrids. *In* Biology of *Populus* and its implication for management and conservation. *Edited by* R.F. Stettler, H.D. Bradshaw, P.E. Heilman, and T.M. Hinckley. NRC Research Press, Ottawa, Ont. pp. 159-182.

Sakai, K-I, H. Mukaide, and K. Tomito. 1968. Interspecific competition in forest trees. Silvae Genetica 17 (1): 1-5.

Stanton, B.J. 2001. Clonal variation in basal area growth patterns during stand development in hybrid poplar. Can. J. For. Res. 31: 2059-2066.

Steneker, G.A,. and J.M. Jarvis. 1963. A preliminary study to assess competition in a white spruce – trembling aspen stand. For. Chron. 39: 334-336.

Stern, K. 1966. Volistandige Varianzen und Kovarianzen in Planzenbestanden. II. Phanotypische Korrelationen zwischen Baumen in gleichaltrigen Kiefern- und Fichtenbestanden und den sie umgebenden Gruppen von Konkurrenten. Silvae Genetica 15: 6-11.

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TABLES AND FIGURES

Table 1. Study site descriptions.

Site	Captain	Olander	MP	LEA Grand Rapids	Hansen
County (MN)	Todd	Todd	Itasca	Itasca	Todd
Nearest town (MN)	Eagle Bend	Staples	Cohasset	Grand Rapids	Eagle Bend
Latitude	46.2096	46.2399	47.2484	47.2435	46.1297
Longitude	-95.1225	-94.8763	-93.7009	-93.4919	-95.058
Slope%	2-6	2-6	0-10	0-6	2-6
Soil texture	sandy loam	sandy loam	loamy very fine	fine sandy loam	sandy loam
Soil pH	6.2	5.8	6.1	5.3	6
Soil particulate organic matter (%)	1.88	3	0.52	10.42	2.43
Soil bulk density (g/cm3)	1.49	1.65	1.59	1.36	1.61
Average high/low temperature (C)	26.9/-19.8	25.8/-19.1	26.8/19.3	26.8/19.3	24.2/-17.1
Minnesota Crop Productivity Index (range 0 to 100)	88	83	45	90	85
Average precipitation – rainfall (mm)	723	702	735	735	638
Site	Hansmeyer	Rudd	Crabtree	Foote	Waseca
County (MN)	Todd	Douglas	Clearwater	Todd	Waseca
Nearest town (MN)	Browerville	Rose City	Bagley	Clarissa	Waseca
Latitude	46.0420	46.0907	47.4206	46.1476	44.0619
Longitude	-95.0336	-95.1620	-95.4851	-94.8959	-93.5429
Slope%	2-6	1-8	2-8	2-6	0-2
Soil texture	sandy loam	loam	loamy fine sand	sandy loam	clay loam
Soil pH	6	6.5	6.5	5.8	6.5
Soil particulate organic matter (%)	2.43	4	1.25	3	7
Soil bulk density (g/cm3)	1.61	1.5	1.5	1.65	1.05
Average high/low temperature (C)	24.2/-17.1	24.2/-17.1	25.2/-20.3	26.8/-17.9	28.0/-15.6
Minnesota Crop Productivity Index (range 0 to 100)	85	83	93	85	93
Average precipitation – rainfall (mm)	638	638	677	769	908

Site	Koljonen	MP Joppru	Wanderscheid	Boise
County (MN)	Otter Tail	Goodridge	Todd	Koochiching
Nearest town (MN)	New York Mills	Pennington	Clarissa	Birchdale
Latitude	46.4654	48.1511	46.1129	48.6280
Longitude	-95.3765	-95.7606	-95.0118	-94.1775
Slope%	2-6	0-1	2-6	0-2
Soil texture	sandy loam	loamy fine sand	sandy loam	silt loam
Soil pH	6.5	6.5	6.5	6.0
Soil particulate organic matter (%)	3	5	3	4.6
Soil bulk density (g/cm3)	1.48	1.35	1.48	1.26
Average high/low temperature (C)	27.1/-19.3	27.2/-20.9	26.8/-17.9	26.4/-21.8
Minnesota Crop Productivity Index (range 0 to 100)	88	80	85	82
Average precipitation – rainfall (mm)	669	501	769	568

Soil data from https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Climate data from https://www.usclimatedata.com/ U.S. Climate Data, three-decade (1981–2010) averages (National Centers for Environmental Information, NOAA).

Crop Productivity Index from https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Table 2. Species composition of clone trials (CT) and yield blocks (YB); number of clones in each species group.

Site	Year planted	*P. deltoides* & DxD	DxM	DxN	*P. nigra*	NxM	Total clones
Boise (YB)	1998			3		1	4
Boise (CT)	1998	45	32	17		1	95
Captain (YB)	2009			8	1	1	10
Captain (CT)	2009	1	4	36	1		42
Crabtree (YB)	2008		2	4		1	7
Crabtree (CT)	2008		4	57		1	62
Foote (YB)	2006	5	4	7		2	18
Foote (CT)	2006	44	9	14		1	67
Hansen (YB)	2006	5	4	7		2	18
Hansen (CT)	2006	44	8	14		1	67
Hansmeyer (YB)	2009			8	1	1	10
Hansmeyer (CT)	2009	1	4	37	1		43
Koljonen (YB)	2008		2	4		1	7
Koljonen (CT)	2008		4	57		1	62
LEA GrRpds (YB)	2007		2	2		1	5
LEA GrRpds (CT)	2007	8		22		1	31
MP (YB)	2015			8		1	9
MP (CT)	2015			52		1	
MPJoppru (YB)	1998			4		1	5
MPJoppru (CT)	1998	45	32	7		1	85
Olander (YB)	2008		3	4		1	8
Olander (CT)	2008		4	57		1	62
Rudd (YB)	1998			3		1	4
Rudd (CT)	1998	45	32	7		1	85
Wanderscheid (YB)	2008		3	4		1	8
Wanderscheid (CT)	2008		4	57		1	62
Waseca (YB)	2007	1	2	3		1	7
Waseca (CT)	2007	49	4	10			63

D is *Populus deltoides*, M is *Populus maximowiczii*, N is *Populus nigra*.

Table 3. Survival rates for the simultaneous clone trials (CT).

	Survival %				
	Test Site	North	South	East	West
	Crabtree				
3 Year Diameter^2(cm)	97.9%	97.9%	97.9%	98.1%	97.9%
4 Year Diameter^2(cm)	97.6%	97.6%	97.6%	98.1%	97.6%
5 Year Diameter^2(cm)	96.2%	96.2%	96.2%	96.7%	96.2%
6 Year Diameter^2(cm)	95.0%	95.0%	95.0%	95.5%	95.2%
	Koljonen				
3 Year Diameter^2(cm)	93.1%	93.1%	93.3%	93.1%	93.6%
4 Year Diameter^2(cm)	88.6%	88.6%	88.8%	89.3%	89.0%
5 Year Diameter^2(cm)	82.6%	82.9%	82.9%	83.8%	83.8%
6 Year Diameter^2(cm)	75.0%	75.5%	75.5%	76.2%	76.7%
	Riewer				
3 Year Diameter^2(cm)	95.7%	95.7%	96.0%	95.7%	95.7%
4 Year Diameter^2(cm)	95.0%	95.0%	95.2%	95.2%	95.0%
5 Year Diameter^2(cm)	91.9%	91.9%	92.1%	92.6%	92.1%
6 Year Diameter^2(cm)	91.2%	91.2%	91.7%	91.9%	91.4%
	Wanderscheid				
3 Year Diameter^2(cm)	99.5%	99.5%	99.5%	99.5%	99.5%
4 Year Diameter^2(cm)	94.8%	95.0%	95.5%	95.2%	94.8%
5 Year Diameter^2(cm)	90.5%	91.0%	91.4%	91.2%	91.0%
6 Year Diameter^2(cm)	85.0%	85.5%	86.0%	86.7%	85.7%
	Wheeler				
3 Year Diameter^2(cm)	92.6%	93.3%	92.9%	92.6%	92.9%
4 Year Diameter^2(cm)	85.2%	86.2%	86.0%	85.2%	85.7%
5 Year Diameter^2(cm)	78.6%	79.8%	79.8%	80.0%	79.0%
6 Year Diameter^2(cm)	74.0%	75.2%	75.2%	75.5%	74.5%

Test site is average for all trees. N, S, E and W are survival at those neighbor tree cardinal directions.

Table 4. Survival rates for the Hansen clone trial (CT) based on 22 clones common to the Hansen CT and YB.

	Survival %				
	Test Site	North	South	East	West
2 Year Diameter^2(cm)	97.73%	81.82%	88.64%	93.94%	95.45%
3 Year Diameter^2(cm)	98.48%	83.33%	87.88%	94.70%	96.21%
4 Year Diameter^2(cm)	98.48%	83.33%	87.88%	94.70%	96.21%
5 Year Diameter^2(cm)	98.48%	83.33%	87.12%	95.45%	95.45%
7 Year Diameter^2(cm)	96.97%	80.30%	85.61%	91.67%	93.18%
8 Year Diameter^2(cm)	96.97%	79.55%	85.61%	91.67%	93.18%
9 Year Diameter^2(cm)	93.18%	77.27%	84.09%	88.64%	90.15%

Test site is average for all trees. N, S, E and W are survival at those neighbor tree cardinal directions.

Table 5. Survival rates for the family field trials (FFT).

	Survival %				
	Test Site	North	South	East	West
	Sturges1				
3 Year Diameter^2(cm)	64.8%	65.2%	65.6%	66.1%	65.7%
4 Year Diameter^2(cm)	61.6%	62.0%	62.4%	62.9%	62.5%
5 Year Diameter^2(cm)	57.1%	57.6%	58.1%	58.5%	58.2%
10 Year Diameter^2(cm)	45.4%	46.0%	46.4%	46.8%	46.5%
	Woelfel				
3 Year Diameter^2(cm)	89.1%	89.2%	89.1%	89.1%	89.2%
4 Year Diameter^2(cm)	85.8%	86.1%	85.8%	85.9%	85.9%
5 Year Diameter^2(cm)	83.0%	83.6%	83.1%	83.2%	83.2%
10 Year Diameter^2(cm)	72.4%	73.1%	72.4%	72.7%	72.6%

Test site is average for all trees. N, S, E and W are survival at those neighbor tree cardinal directions.

Table 6. Survival and number of trees measured for each clone in the CT vs YB comparisons.

			Clone Trial			Yield Block		
site	spacing (m)	clone	replications	total trees measured	percent survival	replications	total trees measured	percent survival
Boise	2.4x2.4	NM6	3	6	100%	3	36	88%
Captain	2.4x2.4	99059016	6	5	83%	3	48	92%
Crabtree	3.0x3.0	NM6	6	6	100%	3	48	100%
Crabtree	3.0x3.0	9732-24	6	6	100%	3	48	98%
Foote	3.0x3.0	9732-11	6	6	100%	3	27	100%
Foote	3.0x3.0	9732-24	6	6	100%	3	27	100%
Foote	3.0x3.0	D124	6	6	100%	3	27	96%
Hansen	3.0x3.0	9732-11	6	6	100%	3	27	100%
Hansen	3.0x3.0	9732-24	6	6	100%	3	27	100%
Hansen	3.0x3.0	D124	6	6	100%	3	27	100%
Hansmeyer	3.0x3.0	99059016	6	5	83%	3	48	100%
Koljonen	3.0x3.0	NM6	6	6	100%	3	48	93%
LEA Grand Rapids	2.4x2.4	9732-11	6	6	100%	3	27	100%
MP Cohasset	1.5x1.5	NM6	8	8	100%	3	64	100%
MP Cohasset	1.5x1.5	99038022	8	8	100%	3	64	100%
MP Cohasset	1.5x1.5	99059016	8	8	100%	3	64	100%
MP Cohasset	1.5x1.5	9732-11	8	8	100%	3	64	100%
MPJoppru	2.4x2.4	NM6	3	6	100%	3	54	94%
Olander	3.0x3.0	NM6	6	4	67%	3	48	98%
Rudd	3.0x2.1	NM6	2	4	100%	3	108	95%
Wanderscheid	3.0x3.0	NM6	6	6	100%	3	48	85%
Waseca	1.5x1.5	9732-11	6	5	83%	3	27	100%

Replications are the number of single-tree replications for each clone in the study design.

Table 7. Simultaneous clone trials (CT) - The linear regression slope coefficient and R^2 of the raw measurement (420 samples for each site) for DBH^2.

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
	Crabtree									
3 Year	0.10	*0.10*	*0.23*	*0.23*	*0.51*	0.01	*0.01*	*0.05*	*0.05*	*0.08*
4 Year	0.04	0.05	0.13	*0.13*	*0.29*	0.00	0.00	0.02	*0.02*	*0.02*
5 Year	-0.06	-0.05	0.03	0.03	-0.07	0.00	0.00	0.00	0.00	0.00
6 Year	*-0.10*	-0.10	-0.03	-0.03	*-0.29*	*0.01*	0.01	0.00	0.00	*0.02*
	Koljonen									
3 Year	*0.11*	0.09	*0.12*	*0.16*	*0.43*	*0.01*	0.01	*0.02*	*0.02*	*0.05*
4 Year	*0.10*	0.08	*0.10*	*0.14*	*0.38*	*0.01*	0.01	*0.01*	*0.02*	*0.04*
5 Year	0.02	0.00	0.07	0.09	0.18	0.00	0.00	0.00	0.01	0.01
6 Year	-0.04	-0.05	0.02	0.03	-0.05	0.00	0.00	0.00	0.00	0.00
	Riewer									
3 Year	0.01	0.01	0.04	0.04	0.09	0.00	0.00	0.00	0.00	0.00
4 Year	0.03	0.03	*0.10*	0.08	*0.20*	0.00	0.00	*0.01*	0.01	*0.01*
5 Year	-0.04	-0.05	0.08	0.07	0.05	0.00	0.00	0.01	0.00	0.00
6 Year	-0.06	-0.06	0.04	0.04	-0.03	0.00	0.00	0.00	0.00	0.00
	Wanderscheid									
3 Year	0.07	0.08	0.01	0.00	0.15	0.00	0.01	0.00	0.00	0.01
4 Year	0.05	0.05	-0.02	-0.02	0.07	0.00	0.00	0.00	0.00	0.00
5 Year	0.02	0.01	-0.06	-0.06	-0.10	0.00	0.00	0.00	0.00	0.00
6 Year	0.04	0.04	-0.10	-0.08	-0.13	0.00	0.00	0.01	0.01	0.00
	Wheeler									
3 Year	0.05	0.07	-0.04	-0.03	0.04	0.00	0.00	0.00	0.00	0.00
4 Year	0.00	0.00	-0.09	-0.09	-0.18	0.00	0.00	0.01	0.01	0.01
5 Year	-0.04	-0.04	*-0.11*	*-0.11*	*-0.31*	0.00	0.00	*0.01*	*0.01*	*0.02*
6 Year	-0.06	-0.06	*-0.12*	*-0.11*	*-0.36*	0.00	0.00	*0.01*	*0.01*	*0.03*

The coefficients with significant linear regression (p value <0.05) are shown in italic font and in gray shading.

Table 8. Simultaneous clone trials (CT) - The linear regression slope coefficient and R^2 of the clone mean-based measurement (70 clones on each site) for DBH^2.

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
	Crabtree									
3 Year	0.01	0.06	*0.49*	0.12	0.54	0.00	0.00	*0.13*	0.00	0.05
4 Year	0.14	0.20	0.16	0.09	0.56	0.01	0.02	0.02	0.00	0.04
5 Year	0.00	0.00	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.00
6 Year	-0.07	-0.02	-0.08	-0.03	-0.19	0.00	0.00	0.00	0.00	0.00
	Koljonen									
3 Year	0.09	0.11	-0.17	0.21	0.19	0.00	0.01	0.02	0.02	0.00
4 Year	0.20	0.13	-0.03	0.41	0.63	0.02	0.01	0.00	0.05	0.04
5 Year	0.17	-0.01	0.05	0.32	0.41	0.01	0.00	0.00	0.03	0.02
6 Year	-0.04	-0.07	0.04	0.13	0.04	0.00	0.00	0.00	0.00	0.00
	Riewer									
3 Year	-0.15	-0.08	0.12	0.13	0.02	0.01	0.00	0.01	0.01	0.00
4 Year	-0.27	-0.13	0.10	0.14	-0.16	0.04	0.01	0.00	0.01	0.00
5 Year	-0.27	-0.33	0.17	0.13	-0.26	0.03	0.05	0.01	0.01	0.01
6 Year	-0.26	-0.27	0.16	0.08	-0.26	0.03	0.03	0.01	0.00	0.01
	Wanderscheid									
3 Year	-0.21	0.22	-0.01	0.06	0.13	0.02	0.03	0.00	0.00	0.00
4 Year	0.07	0.09	-0.12	0.11	0.14	0.00	0.00	0.01	0.00	0.00
5 Year	0.00	0.02	-0.26	0.01	-0.19	0.00	0.00	0.02	0.00	0.00
6 Year	0.02	0.10	-0.33	-0.20	-0.40	0.00	0.00	0.02	0.01	0.01
	Wheeler									
3 Year	-0.22	0.08	-0.21	*-0.45*	-0.55	0.02	0.00	0.02	*0.09*	0.05
4 Year	-0.13	0.09	-0.29	-0.38	-0.52	0.00	0.00	0.03	0.05	0.03
5 Year	-0.27	-0.05	-0.31	*-0.57*	*-0.92*	0.02	0.00	0.02	*0.09*	*0.07*
6 Year	-0.16	-0.15	-0.46	*-0.65*	*-1.14*	0.01	0.01	0.05	*0.10*	*0.10*

The coefficients with significant linear regression (p value <0.05) are shown in italic font and in gray shading.

Table 9. Simultaneous clone trials (CT) - The linear regression slope coefficient and R^2 of the clone mean-based DBH^2 at age 6 years for the top and bottom groups (top 50th and bottom 50th percentiles for growth rate).

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
	Crabtree									
top group	*0.27*	0.06	-0.17	-0.08	0.10	*0.14*	0.01	0.06	0.01	0.00
bottom group	-0.06	0.08	-0.20	0.05	-0.13	0.00	0.01	0.03	0.00	0.00
	Koljonen									
top group	0.12	0.12	-0.12	0.13	0.17	0.03	0.04	0.05	0.04	0.02
bottom group	-0.20	0.03	-0.02	0.06	-0.16	0.03	0.00	0.00	0.00	0.00
	Riewer									
top group	0.07	-0.21	0.23	-0.10	0.01	0.01	0.03	0.05	0.01	0.00
bottom group	0.07	0.04	0.26	0.20	0.46	0.00	0.00	0.06	0.03	0.06
	Wanderscheid									
top group	0.23	-0.05	0.05	-0.15	-0.03	0.05	0.00	0.00	0.04	0.00
bottom group	0.26	0.06	-0.53	0.02	-0.04	0.03	0.00	0.11	0.00	0.00
	Wheeler									
top group	-0.23	-0.15	*-0.39*	-0.30	*-0.75*	0.05	0.03	*0.19*	0.11	*0.24*
bottom group	-0.02	-0.01	-0.15	-0.24	-0.38	0.00	0.00	0.01	0.02	0.02

The clones are ranked by DBH^2 within each site from large to small (fastest and slowest growing), top 50th and bottom 50th percentiles. The coefficients with significant linear regression (p value <0.05) are shown in italic font and in gray shading.

Table 10. Hansen clone trial (CT) - The linear regression slope coefficient and R^2 of the raw measurement (132 samples) for DBH^2.

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
2 Year	0.19	0.20	0.02	0.00	0.40	0.05	0.05	0	0	0.05
3 Year	0.14	0.07	0.00	-0.03	0.18	0.03	0	0	0	0.01
4 Year	0.05	0.01	-0.01	-0.08	-0.03	0	0	0	0.01	0
5 Year	0.05	0.06	-0.03	0.00	0.01	0	0	0	0	0
7 Year	-0.03	-0.02	-0.12	-0.02	-0.14	0	0	0.02	0	0.01
8 Year	-0.02	-0.03	-0.13	0.00	-0.14	0	0	0.02	0	0.01
9 Year	-0.04	-0.07	-0.13	0.00	-0.19	0.00	0.01	0.02	0.00	0.01

None of the linear regressions are significant ($p<0.05$).

Table 11. Hansen clone trial (CT) - The linear regression slope coefficient and R^2 of the clone mean-based measurement (22 samples) for DBH^2.

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
2 Year	-0.12	0.23	-0.35	0.00	-0.34	0.01	0.03	0.09	0.00	0.02
3 Year	0.04	-0.11	-0.27	0.14	-0.19	0.00	0.01	0.05	0.01	0.01
4 Year	0.00	-0.05	-0.16	0.00	-0.16	0.00	0.00	0.02	0.00	0.01
5 Year	-0.04	-0.10	-0.05	0.03	-0.14	0.00	0.01	0.00	0.00	0.01
7 Year	-0.29	-0.19	-0.27	0.10	-0.52	0.07	0.04	0.05	0.01	0.07
8 Year	-0.38	-0.22	-0.27	0.08	-0.63	0.09	0.05	0.04	0.01	0.09
9 Year	*-0.69**	-0.21	-0.65	0.12	-0.89	0.23	0.03	0.13	0.01	0.13

The only significant linear regression is marked *.

Table 12. Family field trials (FFT) - The linear regression slope coefficient and R^2 of the raw measurement for DBH^2

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
	Sturges1 (n=3240)									
3 Year	*0.068*	*0.084*	*0.194*	*0.187*	*0.447*	*0.005*	*0.007*	*0.038*	*0.035*	*0.059*
4 Year	*0.072*	*0.083*	*0.168*	*0.163*	*0.402*	*0.005*	*0.007*	*0.028*	*0.026*	*0.048*
5 Year	*0.048*	*0.065*	*0.132*	*0.128*	*0.326*	*0.002*	*0.004*	*0.017*	*0.016*	*0.030*
10 Year	-0.032	-0.006	*0.096*	*0.090*	*0.152*	0.001	0.000	*0.009*	*0.008*	*0.006*
	Woelfel (n=3420)									
3 Year	*0.110*	*0.113*	*0.175*	*0.176*	*0.461*	*0.012*	*0.013*	*0.030*	*0.031*	*0.065*
4 Year	*0.055*	*0.058*	*0.155*	*0.154*	*0.368*	*0.003*	*0.003*	*0.024*	*0.023*	*0.039*
5 Year	0.005	0.005	*0.199*	*0.197*	*0.366*	0.000	0.000	*0.039*	*0.038*	*0.037*
10 Year	*-0.110*	*-0.124*	*0.264*	*0.260*	*0.313*	*0.012*	*0.015*	*0.069*	*0.068*	*0.023*

The coefficients with significant linear regression (p value <0.05) are shown in italic font and in gray shading.

Table 13. Family field trials (FFT) - The linear regression slope coefficient and R^2 of the clone mean-based measurement for DBH^2.

	Slope					R^2				
	North	South	East	West	Average	North	South	East	West	Average
	Sturges1 (n=914)									
3 Year	-0.019	0.050	*0.287*	*0.271*	*0.556*	0.000	0.002	*0.064*	*0.056*	*0.062*
4 Year	-0.006	0.067	*0.273*	*0.282*	*0.548*	0.000	0.003	*0.056*	*0.057*	*0.061*
5 Year	-0.005	0.065	*0.242*	*0.259*	*0.504*	0.000	0.002	*0.043*	*0.046*	*0.049*
10 Year	-0.063	0.042	*0.244*	*0.292*	*0.495*	0.002	0.001	*0.043*	*0.055*	*0.043*
	Woelfel (n=983)									
3 Year	0.057	*0.099*	*0.229*	*0.225*	*0.488*	0.002	*0.006*	*0.039*	*0.036*	*0.053*
4 Year	0.017	0.055	*0.271*	*0.264*	*0.521*	0.000	0.002	*0.052*	*0.046*	*0.053*
5 Year	-0.045	-0.003	*0.413*	*0.406*	*0.707*	0.001	0.000	*0.123*	*0.112*	*0.096*
10 Year	*-0.256*	*-0.239*	*0.545*	*0.546*	*0.862*	*0.035*	*0.028*	*0.220*	*0.215*	*0.118*

The coefficients with significant linear regression (p value <0.05) are shown in italic font and in gray shading.

Table 14. Family field trials (FFT) - The linear regression slope coefficient and R-squared of the clone mean-based DBH^2 at age 5 years for the top group and the bottom group (top 50th and bottom 50th percentiles for growth rate).

	N	Slope					R-sq				
		North	South	East	West	Average	North	South	East	West	Average
		Sturges1									
top group	457	-0.031	0.066	*0.213*	*0.214*	*0.450*	0.001	0.003	*0.048*	*0.042*	*0.051*
bottom group	457	0.014	*-0.036*	0.000	0.009	-0.009	0.001	*0.009*	0.000	0.001	0.000
		Woelfel									
top group	491	0.018	-0.012	*0.112*	*0.074*	*0.179*	0.001	0.000	*0.022*	*0.008*	*0.014*
bottom group	492	-0.035	0.022	*0.153*	*0.120*	*0.226*	0.002	0.001	*0.055*	*0.032*	*0.034*

The clones are ranked by DBH^2 within each site from large to small (fastest and slowest growing), top 50th and bottom 50th percentiles. The coefficients with significant linear regression (p value <0.05) are shown in italic font and in gray shading.

Table 15. Hansen clone trial (CT) and yield block (YB) growth data for the same 22 clones in each trial.

	CloneTrial_Dbh^2 (cm^2)				YieldBlock_Dbh^2 (cm^2)			
	3Yrs	4Yrs	5Yrs	9Yrs	3Yrs	4Yrs	5Yrs	9Yrs
Mean	24.7	72.0	121.4	280.4	25.2	69.5	117.8	258.6
Standard deviation	7.2	14.2	18.6	52.0	7.8	14.7	18.1	40.0
Coefficient of variation	29.36%	19.71%	15.29%	18.53%	30.97%	21.20%	15.33%	15.49%

YB/CT growth ratio: 3 years = 102 %, 4 years = 97 %, 5 years = 97%, 9 years = 92%.

Table 16. CT to YB comparisons for specific clones.

					Clone Trials	Yield Blocks	YB/CT
Site	Clone	Clone Origin	Plantation Age	Spacing (m)	Dbh² (cm²)	Dbh² (cm²)	%
Captain	*99059016	NRRI	7	3.0x3.0	278.1	208.6	75%
Crabtree	9732-24	NRRI	5	3.0x3.0	129.5	106.3	82%
Crabtree	NM6	Commercial	5	3.0x3.0	84.3	44.5	53%
Foote	9732-11	NRRI	7	3.0x3.0	128.1	144.8	113%
Foote	9732-24	NRRI	7	3.0x3.0	195.1	152.6	78%
Foote	D124	**UM-Mohn	7	3.0x3.0	146.0	146.8	101%
LEA Grand Rapids	9732-11	NRRI	7	2.4x2.4	259.2	192.3	74%
Hansen	9732-11	NRRI	9	3.0x3.0	262.1	242.1	92%
Hansen	9732-24	NRRI	9	3.0x3.0	267.9	228.0	85%
Hansen	D124	**UM-Mohn	9	3.0x3.0	287.9	278.6	97%
Hansmeyer	99059016	NRRI	7	3.0x3.0	214.9	193.2	90%
MP	99038022	NRRI	5	1.5x1.5	26.1	25.4	97%
MP	99059016	NRRI	5	1.5x1.5	23.4	27.5	118%
MP	9732-11	NRRI	5	1.5x1.5	33.5	27.7	83%
MP	NM6	Commercial	5	1.5 x 1.5	31.9	19.1	60%
Waseca	9732-11	NRRI	5	1.5x1.5	81.1	53.9	66%
Boise	NM6	Commercial	8	2.4 x 2.4	121.4	101.2	83%
Koljonen	NM6	Commercial	4	3.0 x 3.0	34.6	27.4	79%
MPJoppru	NM6	Commercial	8	2.4 x 2.4	132.3	137.1	104%
Olander	NM6	Commercial	4	3.0 x 3.0	31.9	28.5	89%
Rudd	NM6	Commercial	7	3.0 x 2.1	156.8	112.3	72%
Wanderscheid	NM6	Commercial	4	3.0 x 3.0	33.6	31.5	94%

*Experimental Code 99059016, Cultivar Name *Populus deltoides x Populus nigra* 'NextGen', Trade Name InnovaTree™.

**Open-pollinated P. deltoides from Carl Mohn University of Minnesota program, tested in NRRI Hybrid Poplar Program, female parent of NRRI elite clone 9605-35.

Figure 1. Box plot of the Hansen CT and YB data.