A COMPARISON OF TWO GROUPS OF YIELD PLOTS REPRESENTATIVE OF LOBLOLLY PINE PLANTATIONS IN THE SOUTHEASTERN UNITED STATES

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Abstract—Stand growth and productivity during the first decade for two groups of yield plots established in managed loblolly pine plantations growing in the Southeastern United States were compared. Both groups were established on site-prepared areas in operational stands growing under intensive management. Group 1 plots represented stands established during the 1990s with open pollinated single family or multi-family stock and received silvicultural treatments typical of the period. Group 2 plots were established approximately 10 years later in the same physiographic region with clones and subjected to site-suitable silvicultural treatments. After accounting for the difference in age, average height growth of dominant and codominant trees (site trees) was not significantly different between the groups. Individual tree diameter and height growth were different resulting in stem form characteristics that were significantly different for the two groups. Characteristics that negatively affect stem quality were generally reduced in the clonal plantings suggesting a greater proportion of large trees will be suitable for sawtimber. Simulations with a growth and yield model showed increased productivity and future potential value for plantations established with clones.

INTRODUCTION

Over the past 60 years loblolly pine plantations in the Southern United States have become some of the most productive forests in the world (Fox and others 2004, 2007). The reasons for this are many. Prudent harvesting practices and effective site preparation methods have reduced damage to the site and suppressed competing vegetation resulting in improved seedling survival and faster early growth. Where needed, nutrient amelioration and more effective early chemical release treatments have allowed young stands to develop quickly with reduced competition. With each new generation, genetically enhanced planting stock selected for faster growth, better stem form and resistance to disease has been a large contributor to this incremental improvement in productivity (Schmidtling and others 2004).

To test hypotheses about the individual effects of any subset of these factors on stand growth requires designed experiments where the treatment of interest is assessed using ANOVA methods while other factors are held constant. This is often not possible due to the large size of such experiments and the limited resources available. An alternative approach uses growth and yield data from permanent long-term remeasurement plots in existing plantations to compare stand conditions at desired stages of stand development. This approach acknowledges the obvious confounding of all factors contributing to growth and utilizes regression methods to test for differences in existing conditions (ANCOVA) and to make projections for future conditions. While lacking the inferential rigor of a designed study, it is well suited for applications where the objective is to assess the overall growth performance of a population of stands across a broad range of climatic, edaphic influences and management practices (Burkhart and Amateis 2012).

The purpose of this study was to assess the early growth of two groups of growth and yield plots in existing managed operational loblolly pine plantations, one established with open pollinated stock and the other with clones, and to make comparisons at similar ages. A further goal is to provide a glimpse into the future productivity of both groups to assist managers tasked with planning for the future.

METHODS

Data

Over the past 20 years, the Forest Modeling Research Cooperative (FMRC) has installed permanent growth and yield plots in two populations of intensively managed loblolly pine plantations on cutover sites established with improved genetic material. The newer group (G2) consists of 42 plots in stands established during the period 2005-2010 with varietal material and the latest

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silvicultural treatments. Although understory brush and herbaceous vegetation is prevalent, non-pine competition in the main canopy is negligible. These stands lie in the Coastal Plain areas of AL, GA, FL, SC, and NC between latitudes 30.5°N and 35.0°N and longitudes -78.0°W and -87°W (fig. 1). Ages at time of plot establishment were between 2 and 6 years with measurements at 2-year intervals. This schedule resulted in 125 plot measurements with 14,503 trees (tables 1 and 2).

The older group of plots (G1) is a subset of a study established across the natural loblolly pine growing region in stands established during the 1990s. Ages at time of plot establishment ranged from 3 to 8 years (Russell and others 2010). These stands received operational silvicultural treatments common for the era and suited for the site, climate, and management objectives of the owner. Some competition with hardwoods in the main canopy exists for some of the plots. All were established with open-pollinated single family or multi-family genetic material. Forty-six of these G1 plots lie in the same Coastal Plain corridor as the G2 plots and were used for this comparative study (fig. 1). Measurement data at ages 3 to 10 years were used from the G1 plots to correspond to the measurement ages of the G2 plots. Intervals between measurements were 2 years. The G1 data resulted in 133 plot measurements with 12,604 tree measurements (tables 1 and 2). Stem quality codes based on a tiered hierarchical classification system were collected at each measurement for both G1 and G2 datasets. First, the stem was classified as single-stemmed or forked, then having a normal top or broken top. Condition of the bole was assessed as straight, bole or butt sweep, or short crook. Finally, the health of the tree was categorized as having or not having insect or disease damage.

Height-Age Relationship

An analysis of covariance (ANCOVA) approach was used to examine the height-age relationship for the two populations. The response variable was 2-year dominant and codominant height growth and the covariate was stand age at the midpoint of the 2-year growth period:

$$HDg_{ij} = \mu + \tau_i + B(\tau_{ij} - \bar{\tau}_i) + \varepsilon_{ij} \qquad (1)$$

where

HDg_{ij} is the 2-year average height growth of dominant and codominant trees for the ith dataset (G2 or G1), μ is the grand mean, $\bar{\tau}_i$ is the effect of the ith dataset, τ_{ij} is the jth observation of the covariate in the ith dataset, $\bar{\tau}_i$ is the ith population mean and ϵ_{ij} is the error term. Equation (1) assumes equal slopes between the two populations. Table 3 summarizes the height-age data used for the evaluation. To test the validity of the assumption of equal slopes, the interaction term between the covariate and the two categorical independent variables (populations) was included in equation (1). The Chapman-Richards equation was fitted to the dominant height-age data for both datasets:

$$HD = \beta_1(1 - \exp(-\beta_2 A))^{\beta 3} \qquad (2)$$

where

HD is the average height of the dominant and codominant trees (feet), A is stand age and β_1 - β_3 are parameters. Equation (2) was fitted to each dataset using nonlinear least squares. Due to the limited range of the height-age data, the asymptote parameter (β_1) was set to 100 feet for both datasets and β_2 (the rate parameter) and β_3 (the shape parameter) were estimated for each dataset.

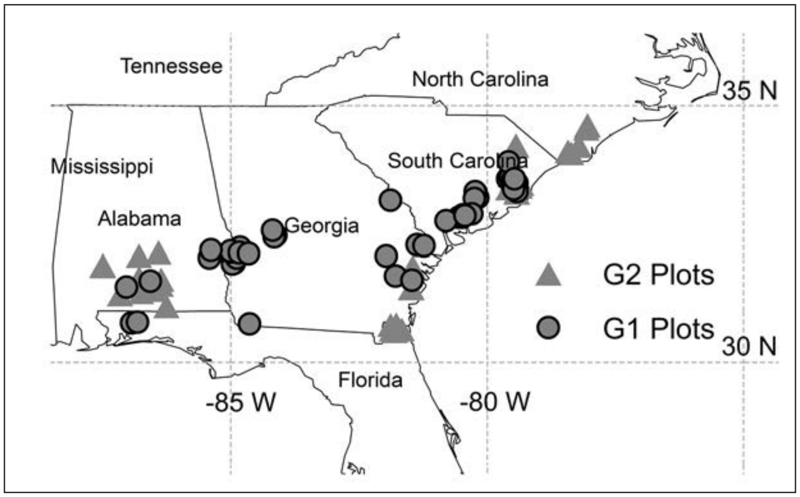

Figure 1—Location of 42 G2 and 46 G1 growth and yield plots in operational loblolly pine plantations in the Southeastern United States.

Table 1—Summary statistics for dbh, total height and 2-year growth increment of two populations of loblolly pine trees growing in the Coastal Plain areas of AL, GA, FL, SC, and NC

Variable	Mean	Std. Dev.	Coef. Var.	Minimum	Maximum
----------G2 (obs=14503)----------					
D.b.h. (inches)	3.1	1.76	56.7	0.1	8.3
DGro(2-yr.) (inches)	1.8	0.7	35.4	-0.1	5.7
H (feet)	17.3	9.2	53.0	0.6	45.7
HGro(2-yr.) (feet)	9.0	3.2	35.4	-10.3	27.5
H/d.b.h. (feet per inches)	6.9	3.2	46.3	1.5	50.0
----------G1 (obs=12604)----------					
D.b.h. (inches)	4.2	1.7	39.5	0.1	10.0
DGro(2-yr.) (inches)	1.0	0.52	52.2	-0.2	3.9
H (feet)	26.0	9.9	38.0	1.8	55.6
HGro(2-yr.) (feet)	7.8	2.5	33.8	-15.0	19.7
H/d.b.h. (feet per inches)	6.4	1.6	25.0	1.7	53.0

Std. dev. = standard deviation; Coef. Var. = coefficient of variation.

Table 2—Summary statistics for per unit area plot-level data representing two populations of loblolly pine stands growing in the Coastal Plain areas of AL, GA, FL, NC, and SC

Variable	Mean	Std. Dev.	Coef. Var.	Min.	Max.
----------G2 (obs=125)----------					
Age (years)	4.6	1.9	41.0	2	9
Hd	18.0	8.8	49.0	4.3	38.5
Trees (acre)	461	89.7	19.4	344	704
BA	30.5	26.9	88.3	0.17	110.8
Dq (inches)	3.0	1.7	55.8	0.28	6.4
PercNPComp[a]	0	0	0	0	0
----------G1 (obs=133)----------					
Age (years)	7.4	1.9	25.7	3	10
Hd	26.8	9.1	34.0	8.6	49.3
Trees (acre)	636	92.8	15.1	437	875
BA	71.8	36.4	50.8	2.9	147.7
Dq (inches)	4.4	1.4	31.8	0.82	7.4
PercNPComp[a]	3.5	3.0	86.2	0.4	14.2

Std. dev. = standard deviation; Coef. Var. = coefficient of variation; Hd= the average height of dominant and codominant trees (feet); BA = basal area (square feet per acre).

[a] Percent of total stand basal area in non-planted pine overstory competition.

Table 3—Two-year height growth for the dominant and codominant trees and the age at the midpoint of that growth period for the G2 and G1 plots

Variable	N	Mean	Std. Dev.	Coef. Var.	Min.	Max.
G2						
Age (year)	83	4.6	1.35	29.7	3	8
HD Growth	83	9.4	2.6	23.9	4.4	15.0
G1						
Age (year)	91	7.3	1.4	19.8	4	9
HD Growth	91	8.4	1.8	21.8	3.7	12.4

Std. dev. = standard deviation; Coef. Var. = coefficient of variation; HD = the average height of dominant and codominant trees (feet).

Growth and Allometry of D.b.h. and Height

ANCOVA methods were used to compare d.b.h. and height relationships between the G1 and G2 populations over the 4-year period. A comparison of the sample group means for height and d.b.h. growth was conducted using age as a covariate. The models were:

$$Hg_{ij} = \mu + \tau_i + B(\tau_{ij} - \bar{\tau}_i) + \varepsilon_{ij} \qquad (3)$$

$$Dg_{ij} = \mu + \tau_i + B(\tau_{ij} - \bar{\tau}_i) + \varepsilon_{ij} \qquad (4)$$

$$(H / D)_{ij} = \mu + \tau_i + B(\tau_{ij} - \bar{\tau}_i) + \varepsilon_{ij} \qquad (5)$$

where

HDg_{ij} and Dg_{ij} are the 2-year average height and d.b.h. growth, respectively, of trees for the ith population (G2 or G1) and $(H/D)_{ij}$ is the height over d.b.h. The overall mean is μ, τ_i is the effect of the ith population, τ_{ij} is the jth observation of the covariate, age, in the ith population, $\bar{\tau}_i$ is the ith population mean, and ϵ_{ij} is the error term.

Stem Quality Assessments

Three assessments of stem quality were evaluated at three measurements for the G2 and G1 populations: forking, disease or insect damage, and stem sweep. Trees with either bole or butt sweep were considered as having a defect of the main stem that would preclude them from being considered sawtimber quality. Frequencies by population for each of these defects were tested with Chi-square and Odds Ratio tests of significance. In this comparison, the closer an odds ratio is to 1 the more likely it is that the defect will occur in both groups. An odds ratio > 1 indicates the defect will be more likely to occur in the G1 plots. An odds ratio < 1 indicates the defect will be more likely to occur in the G2 plots.

Simulation with PTAEDA

For comparison purposes the PTAEDA growth and yield model was used to project current stand conditions to age 25 for the G2 and G1 plots. PTAEDA was chosen over other growth and yield models because it carries a long and well-vetted history (Amateis and Burkhart 2016), was not parameterized with data from either of these datasets, and allows an existing diameter distribution that accounts for stem size and stem quality to be inputted. Yield predictions for total tons and three product classes are outputs.

The number of trees by d.b.h. class and the percent of defective stems for each d.b.h. class along with stand age, site index and percent of total stand basal area in non-planted loblolly pine for each plot at the third measurement were inputted to PTAEDA and projected to age 25. Per acre output included total tons, large sawtimber (defined as 12 inches d.b.h. class and above to a top diameter limit of 8 inches), small sawtimber (defined as 8 inches d.b.h. class to the 12 inches d.b.h. class to a top diameter limit of 6 inches) and pulpwood (5 inches d.b.h. class and above to a top diameter limit of 4 inches including large trees not qualified to make sawtimber quality) tons. Topwood from each sawtimber tree to a 4 inch top limit was added to the pulpwood component. Topwood above 4 inches was considered unmerchantable. To be classified as sawtimber a tree had to meet both the size requirements and stem quality requirements of no forking, no excessive sweep, no broken top, and no disease or insect damage on the main stem at the third measurement.

RESULTS

Height-Age Relationship

The Type I SS for equation (1), which disregards the covariate, was significant (Pr>F = 0.0008). The Type III SS, which accounts for the age covariate, was not significant (Pr > F =0.4623). Thus the hypothesis that dominant height growth is not different between the two datasets could not be rejected at this early age of stand development. Table 4 presents the results of fitting equation (2) to the height-age data. The 95 percent confidence limits on and overlap for the two datasets. At these ages, the slope of the height growth trajectory is not significantly different between the two populations but the G2 plots are growing toward a higher level than the G1 plots (fig 2).

Growth and Allometry of D.b.h. and Height

Results of fitting equations (3), (4) and (5) by 2-year measurement periods are summarized in table 5. These results suggest that the G2 plots have generally been growing faster in height and dbh resulting in a stem form that is significantly different than the G1 population.

Stem Quality Assessment

Table 6 summarizes the frequency analyses for stem defects between the two populations. Generally the G1 plots exhibit greater frequencies of defects than the G2 plots. This is particularly evident for the disease and insect damage category. They also noted that faster height growth was weakly associated with more forking and straightness with less forking.

Results of the simulations with PTAEDA (table 7) suggest that productivity of the varietal stands of loblolly pine should be significantly greater than the open pollinated ones. Mean site index for the G2 plots was about 8 percent higher than the G1 plots. Total tons for the G2 plots were about 25 percent greater than the G1 plots. When total tons are merchandized into products, sawtimber tons were on the order of 2 times as much

Table 4—Parameter estimates and fit statistics for fitting equation (2) to the G2 and G1 datasets using nonlinear least squares

Parameter	Estimate	Std. error	Approximate 95 percent confidence limits	
-------------------------------------G2 (N=98; MSE=12.9)--------------------				
β_2	0.0746	0.00832	0.0581	0.0911
β_3	1.3835	0.1161	1.1531	1.6139
---------------------------------------G1 (N=117; MSE=32.8)------------------------				
β_2	0.0740	0.0110	0.0522	0.0957
β_3	1.4841	0.1899	1.1080	1.8601

MSE=mean squared error.

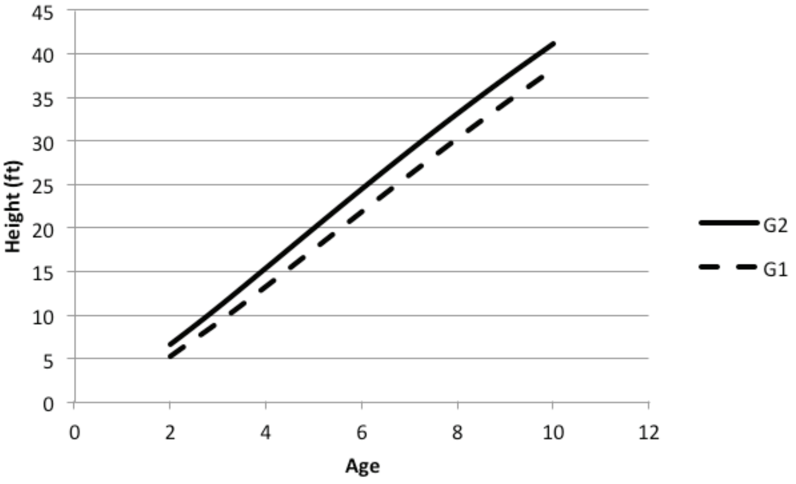

Figure 2—Plot of the Chapman-Richards equation fitted to the G2 and G1 datasets (common asymptote of 100 feet assumed).

Table 5— Analysis of covariance (ANCOVA) results of fitting equations (3) and (4) to 2-year height and d.b.h. growth increment data and equation (5) to three measures of height over d.b.h. for the G1 and G2 groups

Measurement	Mean		Coef. Var.		Type III SS
	G2	G1	G2	G1	Pr>F
-------------------------------2-year height growth (feet)------------------------------					
1 - 2	9.0	8.3	30.7	31.8	<.0001
2 - 3	9.0	7.9	39.7	29.0	0.6550
-----------------------------2-year diameter growth (inches)----------------------------					
1 - 2	2.0	1.3	34.4	44.1	<.0001
2 - 3	1.7	0.9	33.3	46.2	<.0001
-------------------------------Height over d.b.h. ratio-------------------------------					
1	9.3	6.5	47.1	33.1	0.0738
2	6.0	6.3	31.3	19.7	0.0020
3	5.7	6.5	24.5	17.4	<.0001

Coef. Var. = coefficient of variation.

Table 6—Frequencies (number of trees) for three types of stem defects (forking, disease and insect damage, and bole or butt sweep) by population and measurement period with Chi-square test of significance and the odds ratio[a]

	Measurement 1		Measurement 2		Measurement 3	
	No	Yes	No	Yes	No	Yes
--Forking--						
G2	4894	55	4696	155	4266	438
G1	4174	231	4022	330	3527	341
Chi-square	134.3 (Pr<.0001)		88.46 (Pr<.0001)		0.6303 (Pr=0.4273)	
Odds ratio	4.925 (3.659, 6.627)		2.486 (2.045, 3.022)		0.942 (0.812, 1.092)	
--Disease and insect damage------------------------------------						
G2	4888	61	4775	76	4313	391
G1	4021	384	3718	636	3156	713
Chi-square	288.2 (Pr<.0001)		546.8 (Pr<.0001)		193.6 (Pr<.0001)	
Odds ratio	7.652 (5.582, 10.06)		10.75 (8.44, 13.69)		2.492 (2.185,2.843)	
--Bole or butt sweep--						
G2	4826	120	4185	617	3550	699
G1	4069	278	3843	411	3091	709
Chi-square	88.9 (Pr<.0001)		22.77 (Pr<.0001)		6.770 (Pr=.0093)	
Odds ratio	2.748 (2.209, 3.417)		0.725 (0.636, 0.828)		1.165 (1.038, 1.3070)	

[a] Ninety-five percent lower and upper confidence limits in parentheses.

Table 7—Predicted site index and tons per acre at age 25 for unthinned Coastal Plain G2 and G1 growth and yield plot projections using the PTAEDA model

Variable	Mean	Std. Dev.	Min.	Max.
----------G2----------				
Site index (feet)[a]	79.4	10.4	50.9	100.2
Total tons per acre	213	49	96	343
Pulpwood tons per acre	90	57	14	224
Chip and saw tons per acre	57	32	3	141
Sawtimber tons per acre	43	36	1	154
----------G1----------				
Site index (feet)*a*	73.5	11.5	47.2	99.6
Total tons per acre	168	47	66	276
Pulpwood tons per acre	76	30	30	151
Chip and saw tons per acre	56	33	3	117
Sawtimber tons per acre	12	14	0	48

Std. dev.=standard deviation.

[a] Site index estimated using the model of Diéguez-Aranda and others (2006).

(table 7). A t-test of the mean predicted tons at age 25 indicates there is a significant difference in total weight and sawtimber weight between the two populations but no significant difference for pulpwood and chip and saw (all comparisons done at the alpha=0.05 level).

DISCUSSION

Comparing the early growth from the G1 and G2 growth and yield plots showed the varietal plantations growing faster than the open pollinated generation planted in the same general area. It should be noted that the G1 plantations were established with open-pollinated stock available in the late 1980s to early 1990s, while the G2 varietal plantings used were clones available over a roughly 5-year period spanning 2003-2008. The varietal stands have almost no hardwood competition in the main canopy and generally exhibit better form and less disease incidence. At the first and second measurements forking was more likely to occur in the G1 plots than the G2 plots. Xiong and others (2010) found the forking defect to be partially related to family but at the individual level to be mostly determined by environment.

The simulations with PTAEDA are not meant to quantify, in an absolute sense, productivity differences between the two populations. Rather, the intent is to preview, in a relative sense, the difference in productivity that might be expected from predictions made using inventory plot data where climatic, edaphic, planting stock, and management treatment factors are confounded. While no mid-rotation treatments have been applied in the G2 stands to this point, it's likely that treatments such as thinning and fertilization will be just as effective or even more effective than similar treatments applied to previous generations of plantations. Environmental factors that affect productivity over time may come into play including elevated levels of CO_2, changing amounts and patterns of rainfall and number and intensity of storms.

The implications from this study for managers are considerable. Due to a higher proportion of sawtimber quality trees reaching merchantable size sooner means earlier thinnings and generally shorter rotations will be possible. Nutrient amelioration, where needed, will likely occur sooner. Although the genetic component of variation has been eliminated with varietal planting stock there is still considerable variation in height and diameter growth due to environmental variation.

It is not possible to determine the extent that any particular factor has had on the results found in this study. The effects of site conditions, management treatments, and the planting stock selected for each site are confounded. What can be said from this observational study is that newer plantations established with more advanced silvicultural treatments and planted with clones will likely be more productive than previous populations.

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