ASSESSMENT OF DOMINANT/CODOMINANT HEIGHT GROWTH FOR SECOND ROTATION SLASH PINE PLANTATIONS IN SOUTH GEORGIA AND NORTH FLORIDA

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Abstract—A slash pine (*Pinus elliottii* Engelm.) successive rotation plantation study was established in 1978-79 for the north Florida and south Georgia flatwoods. The second rotation duplicated the first rotation seed source, site preparation, planting method, and density. The comparison between the two rotations is based on the mean height differential for the spectrum and by soil type for each age class. There is a significant rotation 1 minus rotation 2 height difference for all age classes. Rotation 1 is 1.9 and 5.4 ft higher for mean height at ages 2 and 20. Rotation 1 generally experienced more favorable precipitation, for both the amount and timing of the precipitation within a year, than rotation 2. Rotation 2 experienced drought events and high temperatures during the first two growing seasons, while rotation 1 was near normal for this period. The evidence suggests that the main contributor to the decrease in height across the spectrum of plots and age classes is the less favorable overall growing season climatic conditions experienced by rotation 2 relative to rotation 1.

INTRODUCTION

Plantation forestry has an enormous economic impact on the southeastern United States. Maintaining or increasing site productivity is an important economic consideration in the Southeastern United States. There have been conflicting reports with respect to successive rotation productivity during the past several decades (e.g. Thomas 1961, Keeves 1966, Boardman 1978, Haywood 1994, Haywood and Tiarks 1995). Zeide (1992) suggested that there is no reliable evidence that pine growth has declined in the southeast. This issue was addressed by implementing a successive rotation productivity study for slash pine (*Pinus elliottii* Engelm.) plantations in the north Florida and south Georgia flatwoods.

The objectives of this study are to compare the productivity and associated climatic data (precipitation and temperature) for the first and second rotations of these north Florida and south Georgia flatwoods slash pine plantations. The productivity comparison is based on the rotation 1 minus rotation 2 (R1-R2) mean height differential for a range of sites and ages. The height differentials are contrasted by soil types and for the spectrum of soil types for ages 2, 5, 8, 11, 14, 17, and 20. The precipitation comparison is based upon the yearly and monthly total precipitation received by each rotation. The climatic data will also be used to assess any drought events and/or extreme temperature fluctuations by rotation.

DATA

Twenty installations were established on non-old-field plantation slash pine sites in the flatwoods of south Georgia and north Florida during the spring of 1978. Each installation consists of 13 0.5-arce-treatment plots with one plot considered the plantation productivity (previous treatment) plot. The other 12 plots at each installation encompass a slash pine site preparation, fertilization, and vegetation control study, and results from these plots have been reported in several publications, e.g., Shiver et al. (1990), Pienaar and Rheney (1993), Pienaar et al. (1996). Five installations were established in each of the following four soil classes:

- I) poorly drained non-spodosol,
- II) somewhat poorly to moderately drained non-spodosol,
- III) poorly to moderately drained spodosol with an underlying argillic horizon; and
- IV) poorly to moderately drained spodosol with no underlying argillic horizon.

The site indices (base age 25) ranged from 55 to approximately 80. The previous treatment plot at each installation was designed to replicate, as accurately as possible, the characteristics and preparations of the first rotation for a given installation. The previous treatment plot's seed source, site preparation method, planting method and density replicated those of the first rotation at each installation. Currently only 16 of the original 20 installations remain.

The first rotation was harvested in 1978, and site preparation treatments were applied in 1978-79. The previous treatment plots were hand planted using the first rotation spacing design, which varied by location, during the 1979-80 planting season with 1-0 slash pine seedlings.

First Rotation Data Collection

The following information was collected from the plot randomly chosen to be the "previous treatment" plot at each

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Table 1—The Standardized Precipitation Index (SPI) values and their interpretation (McKee et al. 1993)

SPI value	Interpretation
2.0 and greater	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

location prior to harvesting the first rotation plots in 1978. All trees within the plot were measured for dbh, total height, crown class, and presence or absence of cronartium (*Cronartium fusiforme*, Hedgc. and Hunt). Additionally, six dominant/co-dominant trees were randomly selected from the previous treatment plot for stem analysis, with disks cut at 6 inches above the ground, 5 feet above ground, and thereafter, at 5 foot intervals.

Second Rotation Data Collection

All trees within the 0.2 acre measurement plots were measured for dbh with the crown class and presence or absence of cronartium recorded. Additionally, one-half of the trees were randomly selected for height measurement with the height being measured on these trees at each measurement period. The second rotation previous treatment plots have been measured on a three-year cycle beginning at age 2 and currently measurements are recorded to age 20.

Climate Data

The climate surface data for a given installation were obtained from the National Climatic Data Center (NCDC 2000). The climate data were obtained from the nearest viable weather station for a given plot. A viable weather station was defined as a station containing the monthly precipitation and temperature information for both rotations. Twelve different weather stations were obtained using this selection method. Most of the viable weather stations were within 5-10 miles of the plots, but some weather stations were approximately 25 miles from the plots. The climatic surface data from these weather stations contain the monthly mean temperature and total monthly precipitation.

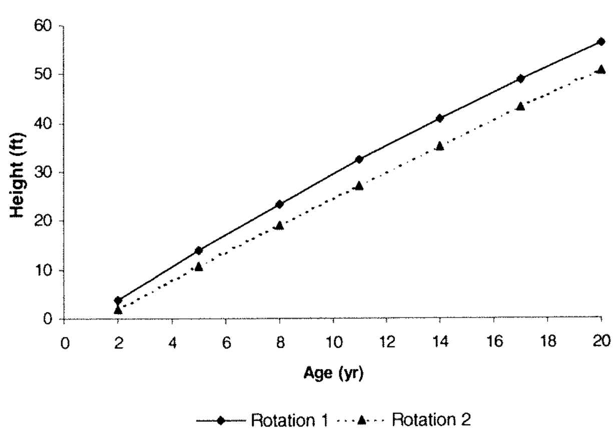

Figure 1—The north Florida and south Georgia slash pine mean

Mean Dominant/Codominant Height Methods

A two-step process was used to assess the height differential between rotations 1 and 2. The first step was to obtain estimates of the mean dominant/codominant heights by rotation and plot for each age class. A mixed model was used to obtain height estimates by rotation and age class for each plot. Secondly, the height point estimates were used to perform an ANOVA by age class. A split-plot model was used to test for rotation height differences. The current data result in an unbalanced split plot model because the replications per soil type are not equal due to the loss of some plots. Soil type was treated as the whole plot and rotation as the split plot. The plots within a soil type were treated as random effects to make inferences across the region. The statistical model used is:

$$H_{ijk} = m + t_i + e_{ij} + b_k + (tb)_{ik} + e_{ijk}.$$

Where H_{ijk} is the mean dominant/codominant height for the j^{th} plot and i^{th} soil type of rotation k, m is the overall mean height, t_i is the i^{th} soil type effect (whole plot), e_{ij} is the whole plot error term (random error on plot j in soil type i), b_k is the rotation effect, $(tb)_{ik}$ is the soil type and rotation interaction effect, and e_{ijk} is the split plot error term (random error for plot j in soil type i and rotation k).

Climatic Data Assessment Methods

An unbalanced split-plot mixed model was used to test for precipitation differences between the rotations. The rotations are treated as the whole plot effect and time is the split-plot effect. The plots within a rotation are treated as random to make region wide inferences. The Standardized Precipitation Index (SPI) and its classification system (table 1) were used to quantify yearly and monthly drought events. McKee et al. (1993) defined a drought event as when the SPI is continuously negative and falls to -1.0 or less. The drought event ends when the SPI becomes positive; therefore the drought event length is defined. The drought magnitude is the sum of the absolute values for all the months or years within a drought period. The average annual and summer temperatures were computed by installation and across the region to assess when or if a rotation experienced extreme temperature fluctuations. The annual and summer temperatures were calculated both as an average for the 16 installations and for each installation individually by rotation.

Dominant/Codominant Height Growth Results

The height estimates for the 16 plots revealed that by age 2, the rotation 1 mean height is substantially higher than rotation 2. The profile plots for both rotations for the spectrum of soil types illustrate that the mean height for rotation 1 is consistently higher than rotation 2 (figure 1). The profile plot exhibits little interaction, which implies that height is an additive effect of rotation and age. The R1-R2 height differential gradually increases across the data range. Profile plots by soil types and soil groups (non-spodosol and spodosol) revealed similar trends.

Table 2—The north Florida and south Georgia first and second rotations slash pine mean dominant/codominant height ANOVA results by age

Source of Variation	NDF*	DDF**	Type III F	Pr > F
Age 2				
Soil	3	12	1.34	0.3083
Rotation	1	12	31.99	0.0001
Soil*Rotation	3	12	1.92	0.1810
Age 5				
Soil	3	12	3.02	0.0719
Rotation	1	12	19.88	0.0008
Soil*Rotation	3	12	0.62	0.6137
Age 8				
Soil	3	12	2.95	0.0757
Rotation	1	12	15.45	0.0020
Soil*Rotation	3	12	0.41	0.7481
Age 11				
Soil	3	12	2.63	0.0982
Rotation	1	12	13.44	0.0032
Soil*Rotation	3	12	0.34	0.7999
Age 14				
Soil	3	12	2.11	0.1517
Rotation	1	12	11.78	0.0050
Soil*Rotation	3	12	0.29	0.8323
Age 17				
Soil	3	12	1.47	0.2724
Rotation	1	12	9.74	0.0089
Soil*Rotation	3	12	0.25	0.8600
Age 20				
Soil	3	12	0.84	0.4983
Rotation	1	12	7.14	0.0204
Soil*Rotation	3	12	0.21	0.8882

* NDF = numerator degrees of freedom.
**DDF = denominator degrees of freedom.

The ANOVA for height by age class revealed that the interaction and main effects tests indicate no significant interaction between soil and rotation (table 2). The soil factor is not significant for all ages (a = 0.05). There is a significant height difference between rotations for all ages, but the significance decreases as age increases. Contrasts for the rotation 1 minus rotation 2 (R1-R2) height differential were constructed and the following is the result synopsis. The contrasts for the R1-R2 pooled height differential are significant for all age classes (a = 0.05). The R1-R2 height differential increases from age 2 to 20, with an average height differential of 5.4 ft by age 20 for the spectrum of plots. The contrasts for the spodosol soil group (soil types III and IV) revealed a significant R1-R2 height differential from ages 2-17, with borderline significance at age 20 (p-value = 0.0518). The spodosols soil group R1-R2 height differential increases to 5.8 ft by age 20. The non-spodosol soil group (soil types I and II) has a significant R1-R2 height differential for ages 2, 5, 8, and 11, and a marginal significant differential for ages 14 and 17 (p-values 0.0532 and 0.0768, respectively). The soil type I contrast revealed no significant R1-R2 height differential for all age classes. Soil type II does have a significant R1-R2 height differential for ages 2, 5, 8, 11, and 14; but the significance decreases so that by age 17, there is only borderline significance (p-value = 0.0693). Soil type III only has a significance R1-R2 height difference at age 2. For soil type IV, there is a significant R1-R2 height difference for the 2-17 age classes and a marginal significance difference at age 20 (p-value = 0.0612). There is an increase in the R1-R2 height differential as a function of age for all soil types except from age 17 to 20 of the soil types II and III.

Table 3—The north Florida and south Georgia first and second rotations slash pine annual precipitation ANOVA results

Source of Variation	NDF*	DDF**	Type III F	Pr > F
Annual Rainfall				
Rotation	1	9.84	2.76	0.1280
Year	19	247	7.61	0.0001
Rotation*Year	19	247	6.91	0.0001

* NDF = numerator degrees of freedom.
**DDF = denominator degrees of freedom.

Climatic Surface Data Results

The ANOVA results for annual precipitation revealed that the interaction between rotation and year is significant (p-value = 0.0001) (table 3). This implies that the amount of annual precipitation for each rotation or year depends upon the level of the other predictor variable. Hence, it is not appropriate to test for rotation main effects across the spectrum of years, but it is appropriate to test for rotation differences by year. The contrasts for testing R1-R2 average annual precipitation differences revealed that rotation 1 received on average, 5.6 and 14.0-inches more precipitation than rotation 2 for the first two years. Rotation 1 had 98 and 104 percent while rotation 2 had 88 and 78 percent of the average precipitation during their first two respective rotation years. Rotation 1 received significantly less rainfall than rotation 2 (8.8 and 9.8-inches) during years 3 and 4, but still had 88 and 97 percent of the average annual precipitation. The years 11 and 12 exhibited the greatest differences with respect to precipitation. Rotation 1 received 19.8 inches more and 11.6 inches less average annual precipitation for these respective years. Rotation 2 received 68 percent of the average annual precipitation for year 11. Although rotation 1 received substantially less precipitation than rotation 2 for year 12, it still received 109 percent of the average annual precipitation.

To compute the SPI index, a square-root transformation was necessary to normalize the precipitation data. The SPI profile plots of the average annual precipitation by rotation reveal that rotation 2 exhibits more variability relative to rotation 1 for the yearly SPI index (figure 2). Rotation 1 experienced one minor drought event (years 3-4) for annual precipitation during the 20 years. Rotation 2 has experienced two previous drought events (years 1-2, and 10-11), and is currently in the third year (1998-2000) of a drought event. Since the height growth decrease for rotation 2 loss relative to rotation 1 was expressed by age 2, the SPI precipitation by month was computed for the initial two years of each rotation (figure 2). The average monthly SPI revealed that rotation 1 did not experience a growing season drought event during the first two growing seasons. Rotation 2 experienced growing season drought events during both of the first two growing seasons.

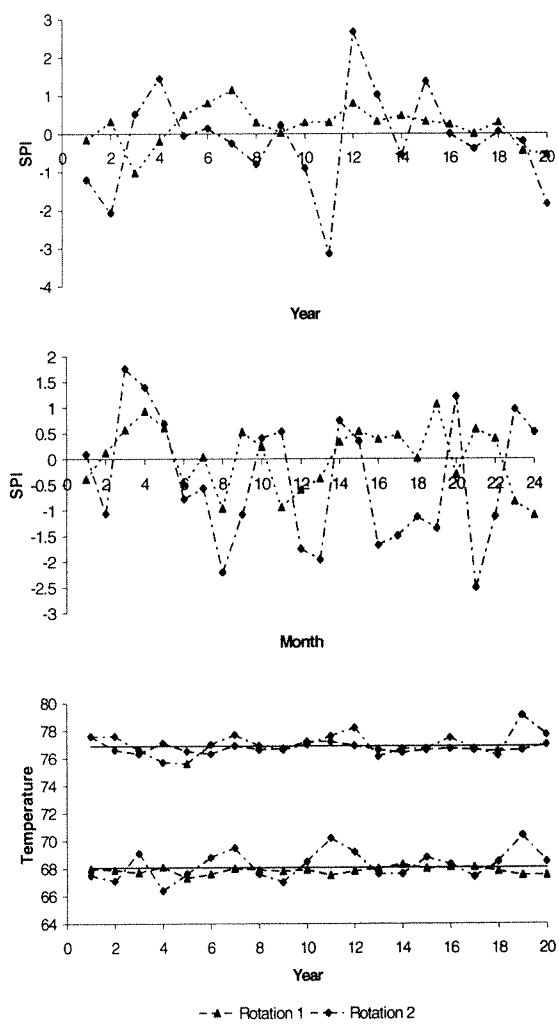

Figure 2—The north Florida and south Georgia slash pine standardized precipitation index (SPI) for mean annual precipitation by year and for the first 24 months (month 1 corresponds to January of the first year). The mean annual and growing season (higher) temperatures by rotation and year. The 69-year weighted average for the growing season and annual temperatures are represented by the solid lines.

The temperature data revealed that rotation 2 had below average annual temperatures during the first two years, but during the same period, it had substantially above normal temperatures for the growing season (figure 2). Rotation 2 average growing season temperature for the first 2 years was 77.6° F, which is substantially above the average growing season temperature of 76.9° F.

DISCUSSION

The results from the ANOVA for the spectrum of plots by age class revealed a significant height difference between the rotations. Rotation 1 is, on average, 1.9, 3.2, 4.2, 5.0, 5.4, 5.6, and 5.4 feet higher for height than rotation 2 at ages 2, 5, 8, 11, 14, 17, and 20, respectively. The height significance decreases as age increases; but an average R1-R2 height loss of 5.4 feet at age 20 is considerable. The contrasts by soil types don't insinuate any general trend between soil type and the R1-R2 height differential.

It is difficult to quantify competing vegetation or nutrient availability for either rotation because of the lack of data for these factors. The main competitors at most plots for both rotations are gallberry (*Ilex glabra*) and saw palmetto (*Serenoa repens*). There is no indication that the quantity of gallberry and/or saw palmetto has dramatically changed from rotation 1 to rotation 2. The climate data analyses suggest that drought events and warmer growing season temperatures generally correspond with smaller height growth, especially during the first two years. The data revealed that the decrease in height growth experienced by rotation 2 was expressed by age 2. This age 2 height differential corresponds with less favorable growing conditions, on average, experienced by rotation 2 during the first two growing seasons.

The plantation productivity plots used for this study are a separate entity of the study on slash pine site preparation, fertilization, and vegetation control. The goals of the larger study are to evaluate the growth, yield, and stand structure of slash pine plantations using different combinations of site preparation, fertilization, and vegetation control. The site preparation methods used for the productivity study plots were, on average, similar to a chop and burn site preparation. The heights for rotations 1 and 2 were compared with the chop and burn treatment heights. The genetic stock of the first and second rotation productivity plots are different, likely inferior, to the site preparation study plots. The chop and burn plots average heights are 2.7 and 48.8 feet at ages 2 and 20, respectively. The first and second rotation productivity plots mean heights for ages 2 and 20 are 3.4 and 57.1 feet, and 2.1 and 47.0 feet, respectively. This implies that the early rotation climatic conditions have a more profound effect on height growth than genetic stock, for these chop and burn plots.

It is generally accepted that extreme weather temperatures, marginal precipitation, competition, and nutrient deficiency can adversely affect seedling growth. The second rotation, on average, exhibits a height reduction, but the first rotation harvest disturbance is not likely a mitigating factor because management impact was minimized to insure the second rotation duplicated the first rotation as accurately as possible. The main competition for both rotations is gallberry and saw palmetto, but not necessarily at the same densities, therefore competition is not likely the main factor for the mean dominant/codominant height growth loss experienced by rotation 2. Since the genetic stock was the same for both rotations, genetics is not likely the major factor for the height differential between rotations 1 and 2. Because no information is available, a nutrient deficiency can't be eliminated, although it is unlikely, as a major contributor to the R1-R2 height differential. The evidence suggests that the more severe drought events and warmer temperatures experienced by rotation 2, especially during the first two growing seasons, is the main factor for the rotation 2 reduction in height for the spectrum of plots and age classes.

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