A COMPARISON OF FIRST AND SECOND ROTATION DOMINANT AND CODOMINANT HEIGHTS FOR FLATWOODS SLASH PINE PLANTATIONS

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SUMMARY

The PMRC initiated a non-old field slash pine (*Pinus elliottii* Engelm.) plantation productivity study in 1978-79 for the North Florida and South Georgia flatwoods. Five installations were established in four soil types for a total of 20 installations. At each installation 13 treatment plots were established with one treatment plot selected to be the plantation productivity plot. Currently only 16 of the 20 installations remain. The plantation productivity plots duplicated the first rotation seed source, site preparation, planting method and density. The assumption is that the only difference between the two rotations is the intrinsic productivity of the site. The comparison between the two rotations is based upon the average dominant/codominant height differential between rotation 1 and 2 across a range of soil types and ages.

The first rotation was harvested in 1978 and site preparations were applied in 1978-79. The productivity plots were established using 1-0 slash pine seedlings during the 1979-80 planting season. Prior to harvesting rotation 1, six dominant/codominant trees were randomly selected for stem analysis. For rotation 2, one-half of the trees within each plot were randomly selected for height measurement with the heights of these trees recorded at each measurement period. The rotation 2 measurements have been taken on a 3-year cycle beginning at age 2 and currently are recorded to age 17.

A mixed model was used to obtain point estimates at age 8, 11, 14 and 17 by rotation and plot. Age was considered the fixed effect and trees within a plot the random effect. A split plot unbalanced mixed model was used to compare rotation differences by age using the point estimates. The soil type was treated as the whole plot and rotation as the split plot. The soil types and rotations were considered fixed effects and the plots within a soil type were considered the random effect.

The profile plots revealed little interaction across the sites with the height differential between rotation 1 and 2 remaining consistent over the data range. There is a significant difference between rotation 1 and 2 across the sites. Rotation 1 is 4.37 feet higher at age 17, which represents approximately a 10% reduction in mean dominant/codominant height. A significant difference exists at age 8 and 11 for the spodosol soil type with marginal significance at age 14 and 17. The non-spodosol soil type and soil type III contrasts reveals a significant difference only for age 8. Soil type I exhibits no significant difference. For both soil type II and IV there is a significant difference at age 8, but by age 17 the significance is marginal.

Two concerns for the spectrum of sites is a height reduction for rotation 2 and a increasing height differential between rotation 1 and 2 from age 14 to 17. The main factor(s) for the height reduction have not currently been identified but the reduction may be the result of severe weather during rotation 2 seedling growth period or a nutrient deficiency. A study limitation is that currently the trees for rotation 2 cannot be traced back to age 2 but should be rectified by either re-tagging the trees within plots or conducting a stem analysis in accordance with rotation 1 standards. The study results validates earlier studies on successive rotations that suggest maintaining or increasing plantation productivity requires intensive management.

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INTRODUCTION

Plantation forestry has an enormous economic impact on the Southeastern United States and as forest products demands continue to increase there is increased interest in accessing successive plantation productivity. Maintaining or increasing site productivity is an important economic consideration in the Southeastern United States. During the past several decades there have been conflicting reports with respect to successive rotations productivity. The PMRC addressed this issue by implementing a second rotation site preparation study for slash pine plantations in the coastal plains as a component of a larger study that addresses effects of site preparation and cultural treatments on plantation productivity. A treatment plot at each installation was selected to duplicate the first rotation seed source, site preparation, planting method and density. The assumption is that the only difference between the two rotations is the intrinsic productivity of the site.

Keeves (1966) presented evidence that successive plantations of Monterey pine (*Pinus radiata* D. Don) in South Australia had declined from one to three site quality classes across a spectrum of sites. There was a significant drop in basal area per acre for the second rotation versus the first rotation but no correlation between loss of productivity and site quality was found. Thomas (1961) reported a decline for a second rotation of Monterey pine in South Australia but Boardman's (1978) analysis showed no long-term loss in site productivity for the same sites under three successive rotations. Boardman inferred that the decline in the second rotation site productivity reported by Thomas (1961) was likely caused by severe weather during the first three years of the second rotation. The evidence in South Australia points to a net effect from several mitigating factors (i.e. nutrient deficiency, precipitation, temperatures) rather than a single dominant cause that results in a decline for successive pine plantation productivity (DeVries, Raupach and Boardman 1972, Boardman 1978).

There is some controversy over reported decreasing forest growth in the Southeast United States. The Forest Inventory and Analysis unit (FIA) of the Southeastern Forest Experiment Station has reported decreasing average radial growth in the Southeast for naturally regenerated southern pines (Sheffield et al. 1985). Two studies using FIA data to analyze naturally regenerated forest stands by Bechtold et al. (1991) and Ruark et al. (1991) have reported declining growth in Georgia and Alabama, respectively. Zeide (1992) analyzed the FIA data used by Sheffield et al. (1985), Bechtold et al. (1991), and Ruark et al. (1991). He inferred that by changing the FIA data collection protocol for the third inventory in 1961 when the Forest Service switched from fixed area plots to point sampling that “no reliable evidence of reduction in basal area growth of southern pines after 1972 can be derived from the FIA data.” Zahner (1989) reported a pattern of declining growth for Southeastern forests using tree data from Georgia, North Carolina and South Carolina. This study reported a decline of 36% in radial growth between 1949 and 1984 after factoring for stand structure, tree age, and drought. Cleveland et al. (1992) analyzed plots maintained by International Paper Company and reported that some dbh classes increased basal area growth while other dbh classes had no growth rate change from 1972-82.

There is some evidence of declining second rotation growth rates for loblolly (*Pinus taeda* L.) and slash pines when grown on the same sites (Haywood 1994). This study minimized woody competition and maintained grasses as the principle competitor as for the first rotation. By age seven, loblolly dramatically and slash pine moderately decreased in growth rates for the second rotation. A study limitation is that it was undertaken at only one site for both loblolly and slash pine but did report that the rainfall pattern during the first seven years was not significantly different for the two rotations. Loblolly pine is known to be more sensitive than slash pine to phosphorus deficiencies on aquult and udult soils in the lower gulf coast (Tiarks and Shoulders 1982). The greater decline in loblolly height growth in comparison to slash may indicate that nutrient deficiency may be a major contributing factor in average height reduction growth in the second rotation.

Site productivity is the sum of environmental factors that includes soils, topography, temperature, and precipitation. A major contributor for decreasing forest growth is likely nutrient deficiency, which accelerates as a tree ages (Proe and Dutch, 1994). A disadvantage of whole tree harvesting versus conventional harvesting is the additional loss of nutrients (Kimmins 1987). Additionally, silvicultural treatments and variations in allogenic factors can have an impact on successive rotation productivity (Squire et al. 1985, Boardman 1978). Second rotation productivity for slash pine may be maintained if harvesting disturbance is minimized and nutrient levels are maintained (Tiarks and Haywood 1996).

The study objective is to compare the productivity of the first and second rotation slash pine for North Florida and South Georgia flatwoods plantations. The definitive comparison will be based upon the average dominant/codominant height differential between rotation 1 and 2 across a range of sites and ages. The first and second rotations are contrasted by soil types and across the spectrum at age 8, 11, 14 and 17.

DATA

During the spring of 1978, 20 installations were established on non-old-field plantation slash pine sites in the flatwoods of South Georgia and North Florida. Plantations that were drained or fertilized were excluded from this experiment. Installations selected were at least 20 years old and based upon uniformity of site index and soil classes. 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.

Each installation consists of 13 0.5-acre treatment plots with one plot considered the plantation productivity (previous treatment) plot. A soil profile description was made from an auger core on the “previous treatment" plot. The site index (base age 25) is based upon measurements taken on trees for the first rotation. The site index was calculated for all plots within an installation and the range of site indexes had to be less than five feet for the installation to be included in the experiment. Thus, the measured responses can be considered a result of a given treatment rather than site quality. The site indexes range from 55 to almost 80 for the 20 installations. After the 13 plots within each installation were located, treatments were randomly assigned to plots. 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 planting density replicated those of the first rotation plantation for 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. Two seedlings were planted at each planting spot with one seedling removed after the first growing season to ensure a high survival rate. If two seedlings survived at one location the taller seedling was retained. Further details of the study protocols are provided in PMRC technical report 1991-5.

First Rotation Data Collection

The following information was collected from plots considered the previous treatment plots 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 six inches above the ground, five feet above ground, and thereafter at five-foot intervals. Ring counts and radius from the pith to the first ring was determined for each disk, and the top disk was also measured for diameter inside bark. The outside bark diameter were measured for each disk.

Second Rotation Data Collection

A 0.2-acre measurement plot was approximately centered in the previous treatment plots. The plot corners were established halfway between rows and trees within rows when possible to remove bias of plot characteristics on a per acre basis. All trees within the 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 two and currently measurements for the second rotation previous treatment plots are recorded to age 17.

METHODS

Point estimates for the first and second rotation mean dominant/codominant heights at age 8, 11, 14 and 17 were first obtained for each rotation and plot. The point estimates were used to perform an ANOVA for rotation 1 and 2 by ages for soil types and across the sites. The soil types, ages, and rotations were considered fixed effects. The plots and trees nested within soil type were considered random effects.

The stem analysis data for rotation 1 of the six trees sampled within each plot were pooled to model mean dominant/codominant height for each plot. For rotation 2, a random sample of six dominant/co-dominant trees was selected from each plot and the heights were obtain for ages 8, 11, 14 and 17. A study limitation is that currently the trees cannot be traced back to age 2 for rotation 2 because no tag numbers for ages 2 and 5 exist.

A mixed model was used to obtain point estimates of mean dominant/codominant height by rotation and plot to account for within and between tree correlation. Rotations 1 and 2 were fitted to the following model separately by plot to obtain point estimates for the mean dominant/codominant height at age 8, 11, 14 and 17.

$$Y_{ij} = \beta_0 + \beta_1 A + \beta_2 A^2 + \varepsilon_{ij} \tag{1}$$

Where:

Y_{ij} is the height of the j^{th} tree on the i^{th} installation,
A is the tree age,
ε_{ij} is the random error associated with the j^{th} tree on the i^{th} installation and
β's are plot and rotation specific.

Model 1 was chosen based upon preliminary results of fitting the model by rotation and plot using ordinary least squares (OLS). The OLS results revealed a good fit ($r^2 > 0.90$ " plots) and no serious departures from the homogeneous variance assumption. Model 1 was fitted using PROC MIXED in SAS with the RANDOM statement modeling the variation between trees on the same plot and the REPEATED statement modeling the variation within trees over time (Little et al. 1998). Thus trees within a plot were treated as random.

The covariance structure specification is an important part of the model identification process to insure the reliability of predictions (Gregoire et al. 1995). An unstructured covariance specification was fitted first to determine the correlation trend. The unstructured covariance specification revealed a decreasing correlation as lag increased. Hence, traditional time series covariance structures such as AR(p) and ARMA(p,q) were fitted. Spatial covariance structures were investigated because longitudinal data is a one-dimensional spatial process. The criteria used to determine which function modeled the covariance and provided the best fit were Akaike's Information Criterion (AIC) and Schwarz's Bayesian Criterion (BIC). The AIC and BIC criteria are analogous to the adjusted r^2 in multiple regression in that they impose a penalty for additional parameters. A log-likelihood ratio test for Model 1 was performed to determine if the between trees correlation modeled using the RANDOM statement in SAS PROC MIXED for trees within a plot was significant.

A split plot model was used to test for rotation differences using the point estimates for each rotation by plot and age obtained from Model 1. The current data results 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:

$$Y_{ijk} = \mu + \tau_i + \varepsilon_{ij} + \beta_k + (\tau\beta)_{ik} + e_{ijk} \tag{2}$$

Where:

Y_{ijk} is the mean dominant/codominant height for the j^{th} plot and i^{th} soil type of rotation k,

μ is the overall mean,

τ_i is the i^{th} soil type effect (whole plot),

ε_{ij} is the whole plot error term (random error on plot j in soil type i),

β_k is the rotation effect,

$(\tau\beta)_{ik}$ 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).

The sources of variation and associated degrees of freedom for Model 2 are presented in Table 1. Plots within a soil type are considered the random effect and are listed in the RANDOM statement of SAS PROC MIXED (Littell et al. 1996).

Table 1. The analysis of variance table for Model 2 (16 plots).

Source of Variation		Degrees of Freedom
Soil		3
Plot (soil)	Error (soil)	12
Rotation		1
Soil*Rotation		3
Rotation*Plot (soil)	Error (split plots)	12
Total		31

RESULTS

The Gaussian spatial covariance model structure for Model 1 provided the best fit based upon the AIC and SBC criteria. The Gaussian models the covariance as $\text{cov}(e_i, e_j) = \sigma^2 [\exp(-\delta^2_{ij} / \rho^2)]$, where σ^2 is the estimated variance, ρ is the parameter to be estimated and δ_{ij} is the lag between time periods i and j. The Model 1 log-likelihood ratio test statistic for plot 1 of rotation 1 is 18.645 and the corresponding $\chi^2_{(1)}$ p-value is less than 0.005. This indicates a significant amount of between-trees correlation for plot 1 of rotation 1 with the other plots for both rotations exhibiting similar results.

The point estimates obtained from Model 1 by plot and rotation for the mean dominant/codominant heights are summarized in Table 2. The summary statistics indicate the mean dominant/codomiant heights are consistently lower for rotation 2 and the standard error is usually larger.

Table 2. Summary statistics for the slash pine average dominant/codominant height (ft) by pooled soil types, soil types, spodosols and non-spodosols soils by rotation obtained using Model 1.

Age		8		11		14		17	
	N	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Pooled Soil Types									
R1	16	23.27	0.987	32.25	1.19	40.74	1.31	48.74	1.39
R2	16	18.74	0.978	27.95	1.25	36.40	1.51	44.07	1.72
Rotation/Soil Type									
R1/A	3	22.94	1.38	32.10	1.73	40.89	1.89	49.29	1.86
R2/A	3	21.33	1.42	31.61	1.98	40.50	3.14	47.99	4.55
R1/B	4	27.05	2.46	36.58	3.06	45.18	3.45	52.85	3.66
R2/B	4	21.06	2.19	30.20	3.29	38.48	4.16	45.91	4.66
R1/C	4	22.61	1.75	31.43	1.82	39.76	1.63	47.62	1.24
R2/C	4	18.02	1.67	27.18	1.70	35.99	1.59	44.44	1.48
R1/D	5	20.97	1.17	29.53	1.61	37.87	2.14	46.03	2.78
R2/D	5	15.90	1.46	24.59	1.86	32.61	2.32	39.96	2.80
Spodosols (Soil Types III & IV)									
R1	9	21.70	0.99	30.37	1.18	38.71	1.35	46.74	1.58
R2	9	16.84	1.09	25.74	1.29	34.11	1.51	41.95	1.78
Nonspodosols (Soil Types I & II)									
R1	7	25.29	1.64	34.66	1.98	43.34	2.16	51.32	2.20
R2	7	21.18	1.29	30.80	1.93	39.34	2.55	46.80	3.05

The point estimates by rotation and plot were used to make inferences for the four age classes across the sites and by soil type. The profile plot by rotation for the spectrum of soil types (Figure 1) illustrates little interaction occurring and the height differential between rotation 1 and 2 remains consistent throughout the data range.

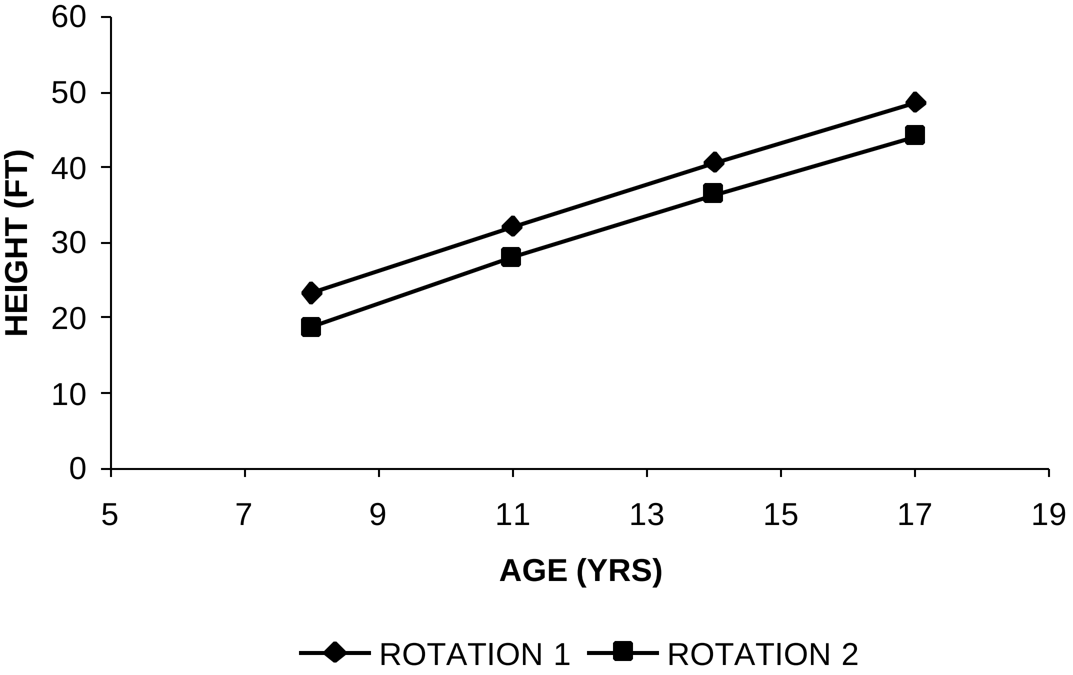

Figure 1. Average dominant/codominant height by rotation for pooled soil types.

Figure 2 illustrates the profile plots for non-spodosol soil types I and II. The profile of soil type I indicates some interaction occurring with marginal differences between the two rotations. For soil type II, the lines appear parallel across the range of the data.

Figure 3 illustrates the profile plots for spodosol soil types III and IV. Soil type III exhibit marginal interaction. The height differences between rotation 1 and 2 remain consistent across the data range.

The profile plots for spodosol and non-spodosol soil types (Figure 4) illustrate no interaction between the two rotations. The height differential between rotation I and II remains consistent across the age range.

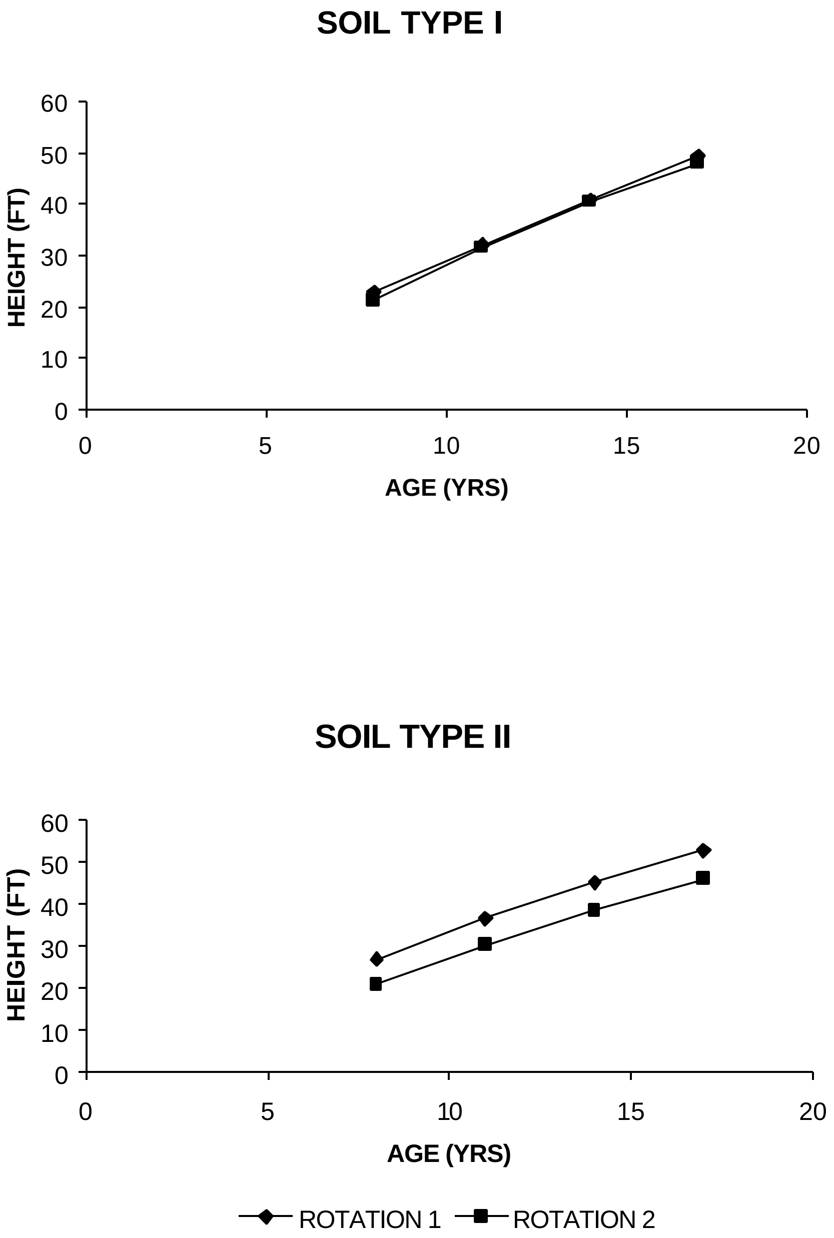

Figure 2. Average dominant/codominant height by rotation for soil types I and II.

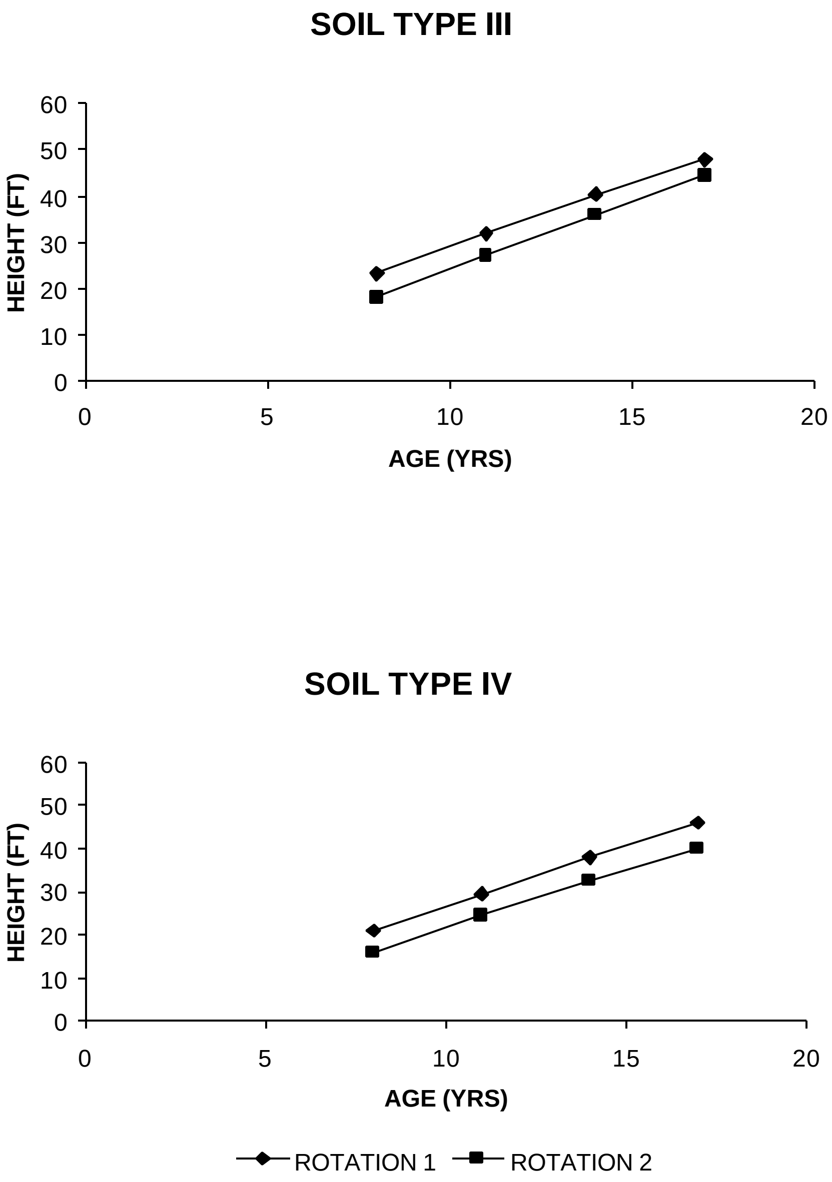

Figure 3. Average dominant/codominant height by rotation for soil types III and IV.

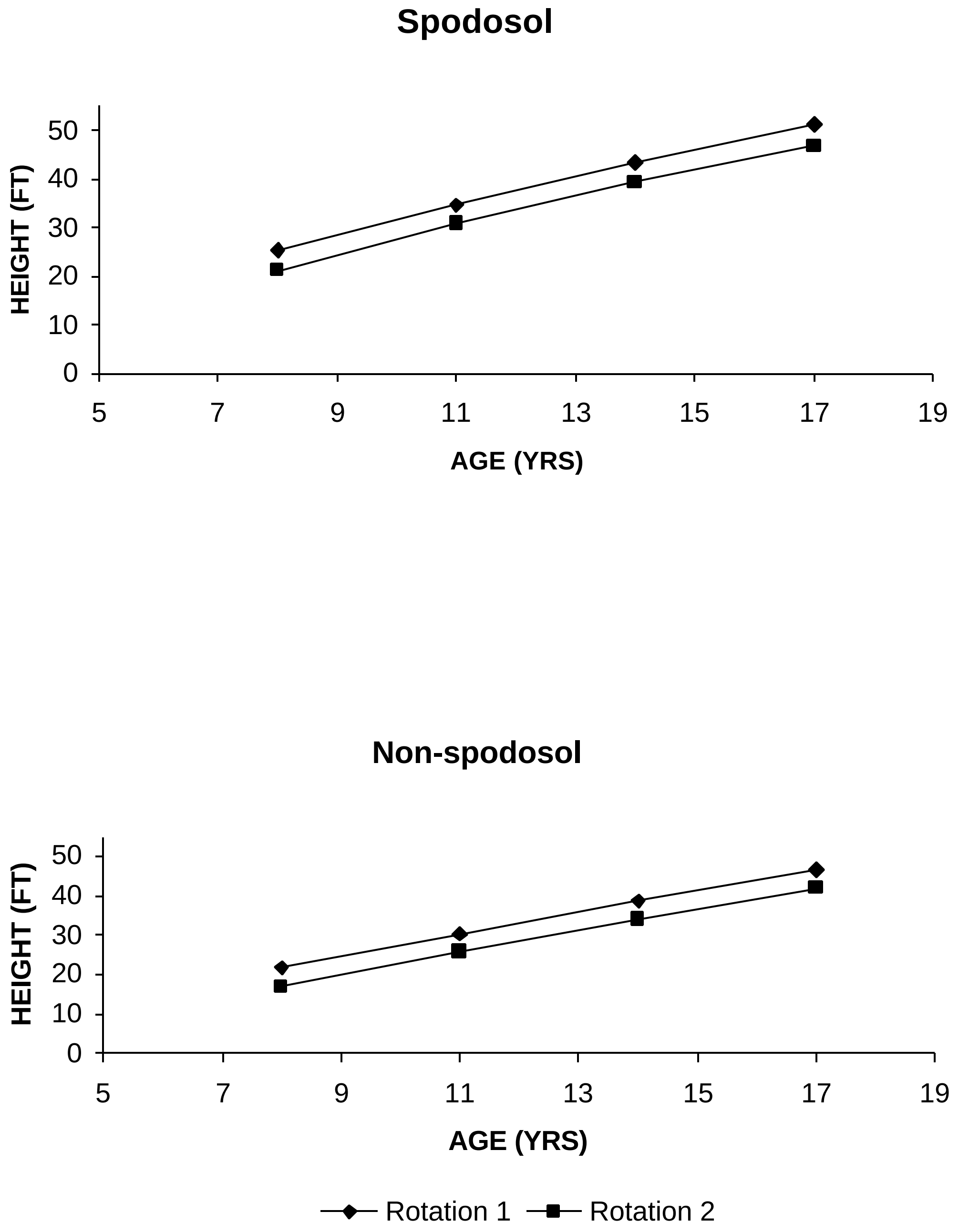

Figure 4. Average dominant/codominant height by rotation for spodosol and non-spodosol soil types.

Model 2 was used to perform an ANOVA and contrast the rotations height means at the different time points using the point estimates obtained in Model 1. The REML covariance parameter estimates for the whole plot error and split plot error show an increasing covariance as age increases (Table 3).

Table 3. The REML covariance parameter estimates for Model 2.

	Covariance Parameter	
Age	Plot (soil)	Residual
8	4.796	7.453
11	5.435	14.549
14	7.601	21.242
17	11.543	26.848

The interaction and main effects test results for Model 2 (Table 4) indicate no significant interaction between soil and rotation. The soil factor significance is inversely related to age with marginal significance at age 8 and 11. There is a significant difference between rotations for all ages but the significance decreases as age increases.

Table 4. Tests for fixed effects by age for Model 2.

Source of Variation	NDF	DDF	Type III F	Pr > F
Age 8				
Soil	3	12	2.97	0.0746
Rotation	1	12	19.35	0.0009
Soil*Rotation	3	12	0.80	0.5175
Age 11				
Soil	3	12	2.66	0.0959
Rotation	1	12	8.58	0.0126
Soil*Rotation	3	12	0.72	0.5598
Age 14				
Soil	3	12	2.07	0.1574
Rotation	1	12	5.93	0.0315
Soil*Rotation	3	12	0.58	0.6371
Age 17				
Soil	3	12	1.46	0.2758
Rotation	1	12	5.51	0.0369
Soil*Rotation	3	12	0.45	0.7187

Contrasts for Model 2 were constructed using the ESTIMATE statement in SAS PROC MIXED to test for significant rotation differences by soil types and estimate the least squares height differences (Tables 5 and 6). For all contrasts except for those by soil type, the least square means do not equal the marginal means because of the unbalance split-plot design (unequal replication sizes within soil types). The least square means are the correct means to use for inferences across the sites even though they may be lower than the height differential for rotation 1 and 2 using the marginal means of the summary data (Table 2).

Table 5. Contrast results for rotation 1 versus rotation 2 by spodosol, non-spodosol and pooled soil types.

Age	Estimate	Std Error	DF	t	Pr > |t|
	Spodosol				
8	4.832	1.295	12	3.73	0.0029
11	4.592	1.809	12	2.54	0.0260
14	4.520	2.186	12	2.07	0.0610
17	4.623	2.458	12	1.88	0.0845
	Non-spodosol				
8	3.799	1.474	12	2.58	0.0242
11	3.438	2.060	12	1.67	0.1210
14	3.546	2.489	12	1.42	0.1798
17	4.118	2.798	12	1.47	0.1669
	Pooled for all Soil Types				
8	4.316	0.981	12	4.40	0.0009
11	4.015	1.371	12	2.93	0.0126
14	4.033	1.656	12	2.43	0.0315
17	4.370	1.862	12	2.35	0.0369

The height differential for rotation 1 versus 2 is significant at all ages (alpha = 0.05) with an average height differential of over four feet. The contrasts for the spodosol soil types (III & IV) illustrate that there is a significant different at age 8 and 11 with only marginal significance at ages 14 and 17. For the non-spodosol soil types (I & II) there is a significant different only at age 8. The spodosol soil types have a greater height differential at all ages than the non-spodosol soil types.

Table 6. Contrast results for rotation 1 versus rotation 2 by soil type and age.

Age	Estimate	Std Error	DF	t	Pr > |t|
Soil Type I					
8	1.603	2.229	12	0.72	0.4857
11	0.497	2.697	12	0.16	0.8759
14	0.397	3.763	12	0.11	0.9178
17	1.300	4.231	12	0.31	0.7639
Soil Type II					
8	5.995	1.930	12	3.11	0.0091
11	6.380	2.697	12	2.37	0.0357
14	6.695	3.259	12	2.05	0.0624
17	6.935	3.664	12	1.89	0.0827
Soil Type III					
8	4.593	1.930	12	2.38	0.0348
11	4.248	2.697	12	1.57	0.1413
14	3.775	3.259	12	1.16	0.2693
17	3.178	3.664	12	0.87	0.4028
Soil Type IV					
8	5.072	1.727	12	2.94	0.0124
11	4.936	2.412	12	2.05	0.0633
14	5.264	2.915	12	1.81	0.0961
17	6.068	3.277	12	1.85	0.0888

The soil type I contrast shows no significance difference between the two rotations for all ages. Soil type II does have a significant difference between the rotations for ages 8 and 11, but the significance decreases gradually so that by age 14 there is no significant difference. Soil type III only has a significant difference at age 8. For soil type IV, there is a significant difference at age 8 but by age the 11 the difference is marginally significant. Soil types I, II and IV have a decrease in height differential between ages 8 and 11 and then an increase in height differential at age 17. Soil type III has a decreasing height differential from age 8 to 17.

DISCUSSION

The results show a significant difference between the two rotations across the sites. Rotation 1 is on average 4.31, 4.02, 4.03 and 4.37 feet higher for mean dominant/codominant height than rotation 2 at age 8, 11, 14 and 17, respectively. This represents an approximate 20% and 10% decline in site productivity at age 8 and 17, respectively. The significance of the decline decreases as age increases but an average loss of 4.37 feet at age 17 for mean dominant/codomiant height is considerable.

The height differential for both rotations for the spodosol soil type is higher than for the non-spodosol soil type, 4.623 and 4.118 feet respectively. Soil type I has the smallest height differential for rotation 1 versus 2 but does have the largest percentage increase in the height difference between age 14 and 17. Soil types II and IV have the most significant difference overall and by age 17 rotation 1 mean dominant/codomiant height is 6.935 and 6.068 feet higher, respectively. The trend for soil types I, II and IV is a height differential decrease from age 8 to 14 and then increasing for age 17. The height differential for soil type III decreases across the age range.

Two concerns with respect to rotation 2 are the decrease in average dominant/codominant height and the increasing height differential from age 14 to 17. There are several main factors that may contribute to the decline in productivity for rotation 2. During the early stages of the second rotation development this region experienced some of the driest and warmest weather on record this century. A nutrient deficiency may have existed and/or competition may have increased for rotation 2. In addition, this region has experienced a policy of diminishing open land grazing by cattle with the associated change in vegetation. Fencing was required to restrain cattle from some installations.

The site productivity class achieved by canopy closure tends to be maintained (Boardman 1978) and it is accepted that extreme weather temperatures, marginal precipitation, competition and nutrient deficiency can adversely affect seedling growth. The second rotation is exhibiting a productivity reduction over the data range 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. Further investigation is necessary to determine the possible effects of temperature and rainfall including the spatial distribution of these factors for both rotations. It will be difficult to quantify competing vegetation or nutrient availability for either rotation because of the lack of data for these factors. A study by Tiarks and Haywood (1996) showed that short rotation slash pine productivity could be maintained by minimizing disturbance and maintaining nutrient levels. If it is reasonable to assume that the main mitigating factor is not from the weather but from a combination of competition and nutrient deficiency, then fertilization and site preparation should correct the disparity for successive rotations of slash pine for this region.

The profile plot across the soil types illustrates a consistent height differential between the two rotations for the data range and this trend is similar to an earlier study by Haywood and Tiarks (1995). A study limitation noted earlier is the current inability to trace trees within a plot back to the earliest stages of development for the second rotation. This should be rectified in the near future either by re-mapping the trees within plots or conducting a stem analysis of the second rotation in accordance with the first rotation standards. This study validates the aforementioned studies on successive rotations that suggest maintaining or increasing plantation productivity requires intensive management.

LITERATURE CITED

Bechtold, W.A., G.A. Ruark, and F.T. Lloyd. 1991. Changing stand structure and regional growth reductions in Georgia's natural pine stands. For. Sci. 37:703-717.

Boardman, R. 1978. Productivity under successive rotations of radiata pine. Aust. Fors. 41:177-179.

Cleveland, G., W. Haines, S. Jahromi, and R. Bryant. 1992. Height and diameter growth trends over time. In R. Flagler, editor. The response of southern commercial forests to air pollution. In press.

DeVries, M.P.C., M. Raupach, and R. Boardman. 1972. Some glasshouse experiments to investigate the second rotation effect on three forest soils from South Australia. Proc. Australian Forest-Tree Nutrition Conference, Canberra, September 1971.

Gregoire, T.G., O. Schabenberger, and J.P. Barrett. 1995. Linear modelling of irregularly spaced, unbalanced, longitudinal data from permanent-plot measurements. Can. J. For. Res. 25:137-156.

Haywood, J.D. 1994. Early growth reductions in short rotation loblolly and slash pine in Central Louisiana. South. J. Appl. For. 18:35-39.

Haywood, J.D., and A.E. Tiarks. 1995. Growth reductions in short-rotation loblolly and slash pines in central Louisiana—10th year results. In: Proceedings of the eight biennial southern silvicultural research conference. P 268-274.

Keeves, A. 1966. Some evidence of loss of productivity with successive rotations of *Pinus radiata* in the southeast of South Australia. Aust. For. 30:51-63.

Kimmins, J.P. 1987. Forest Ecology. McMillan Publishing Company, New York.

Littell, R.C., P.R. Henry, and C.B. Ammerman. 1998. Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci. 76:1216-1231.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS System for Mixed Models. SAS Institute, Inc. Cary, NC. 633 p.

Proe, M.F., and J. Dutch. 1994. Impact of whole-tree harvesting on second-rotation growth of Sitka spruce: the first 10 years. For. Ecol. Manage. 66:39-54.

Ruark, G.A., C.E. Thomas, W.A. Bechtold, and D. M. May. 1991. Growth reductions in naturally regenerated southern pine stands in Alabama and Georgia. South. J. Appl. For. 15:73-79.

Sheffield, R.M., N.D. Cost, W.A. Bechtold, and J.P. McClure. 1985. Pine growth reductions in the Southeast. USDA For. Serv. Res. Bull. SE-83.

Squire, R.O., P.W. Farrell, D.W. Flinn, and B.C. Aeberli. 1985. Productivityof first and second rotation stands of radiata pine on sandy soils. II. height and volume growth at five years. Aust. For. 48:127-137.

Thomas, J. 1961. Two rotations of *Pinus radiata.* Institute of Foresters of Australia, Newsletter Vol. 2 13:4-5.

Tiarks, A.E., and J.D. Haywood. 1996. Site preparation and fertilization effects on growth of slash pine for two rotations. Soil Sci. Soc. Am. J. 60:1654-1663.

Tiarks, A.E., and E. Shoulders. 1982. Effects of shallow waters tables on height growth and phosphorus uptake by loblolly and slash pines. USDA For. Serv. Res. Note SO-285. 5 p.

Zahner, R., J.R. Saucier, and R.K. Meyers. 1989. Tree-ring model interprets growth decline in natural stands of loblolly pine in the southeastern United States. Can. Jour. For. Res. 19:612-621.

Zeide, B. 1992. Has pine growth declined in the Southeastern United States? Conserv. Biol. 6:185-195.