The effect of spacing rectangularity on stem quality in loblolly pine plantations

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Abstract: The effect of spacing rectangularity on tree stem quality was evaluated using data collected from a loblolly pine (Pinus taeda L.) spacing trial measured at age 19. In this trial, bole condition, branch size, and stem asymmetry were examined on plots with an initial planting density of 2240 trees/ha planted at slight (3:4) and greater (1:3) rectangular spacings to determine suitability for sawtimber production. Results indicated that rectangularity had no significant effect on survival or the number of potential sawtimber trees by age 19. While the 1:3 spacing treatment had a significantly larger maximum branch size than the 3:4 spacing treatment, it could not be attributed to the within-row or between-row direction. Additional measurements on stem diameter at breast height within and between rows failed to show stem asymmetry in the 1:3 spacing treatment. Consequently, rectangular spacings up to 1:3 should not have much impact on overall stem quality.

Résumé : L’effet d’un espacement rectangulaire sur la qualité des tiges a été évalué à l’aide de données récoltées dans un test d’espacement de pin à encens (Pinus taeda L.) mesuré à l’âge de 19 ans. Dans cet essai, l’état du tronc, la dimension des branches et l’asymétrie de la tige ont été examinés dans des parcelles avec une densité initiale de 2240 arbres/ha plantés avec un espacement légèrement (3:4) ou plus fortement (1:3) rectangulaire pour déterminer lequel était approprié pour la production de bois de sciage. Les résultats indiquent qu’un espacement rectangulaire n’a pas d’effet significatif sur la survie ou le nombre d’arbres potentiellement aptes au sciage à l’âge de 19 ans. Même si la dimension maximale des branches était significativement plus grande avec un espacement 1:3 qu’avec un espacement 3:4, cela ne pouvait être attribué à la direction dans ou entre les rangées. Des mesures supplémentaires du diamètre à hauteur de potrine des tiges dans et entre les rangées n’ont pas permis de déceler une asymétrie des tiges avec un espacement 1:3. Par conséquent, des espacements rectangulaires jusqu’à un rapport 1:3 ne devraient pas avoir d’impact significatif sur la qualité des tiges.

Introduction

Loblolly pine (Pinus taeda L.) is among the most important timber-producing species in the southern United States. Much of the loblolly pine production comes from plantations managed intensively on short rotations for pulp and fiber production and longer rotations for solid wood products. Among the most important decisions at plantation establishment are the initial density and spacing. Initial density strongly affects the rate at which per unit area yield accrues and the mean tree size at rotation (Zhang et al. 1996; Harms et al. 2000; Sharma et al. 2002a).

Compared with density, spacing has relatively little effect on per unit area yield and tree size. Even at within- to between-row spacing ratios of 1:3, Sharma et al. (2002b) found that yields and average tree size were not significantly different from nearly square spacings of the same density. Nevertheless, the choice of spacing is an important consideration at plantation establishment because it affects site preparation, thinning, and harvesting operations. Greater between-row spacing, for example, reduces the number of bedded rows on sites where bedding is needed and provides access corridors for future thinning operations.

While spacing may not have much impact on yield, it is not clear what effect, if any, it may have on stem quality. Salminen and Varmola (1993) examined branch size and stem cross-sectional eccentricity in a Scots pine (Pinus sylvestris L.) spacing study in Finland where the rectangularity ratio (within row distance to between row distance) varied from 1:1 to 1:6.3. They found no differences between mean branch diameters within and between rows for rectangular spacing patterns at densities above 1600 stems/ha. They also detected only small differences in stem diameter measured within and between rows. Gerrand and Neilsen (2000) found that rectangularity ranging from 1:1 to 1:3 did
not affect the growth and branching habit of *Eucalyptus nitens* Dean & Maid. trees. Their conclusion was based on tree measurements at age 5. A study by Niemisto (1995a, 1995b), however, with silver birch (*Betula pendula* Roth) showed that for rectangularities varying from 1:1 to 1:6.25, aspects of branching habit were affected at more extreme rectangularities.

For loblolly pine, Sharma et al. (2002b) determined that crown width ratios (crown width within rows/crown width between rows) are significantly smaller in higher rectangular spacings. That is, the 1:3 spacings have produced asymmetric crowns where branches growing between rows are longer, larger, and more persistent than branches growing within rows. If branch diameters in the lower portion of the main stem become too large, they may negatively impact lumber grade (Clark and McAlister 1998). The purpose of this study was to examine the effect of spacing rectangularity on loblolly pine stem quality and its suitability for sawtimmer production.

**Materials and methods**

**Data**

In 1983, a set of loblolly pine spacing trials was established at four site-prepared areas in Virginia and North Carolina. Two were situated in the Coastal Plain and two in the Piedmont region. The experimental design for the study was the nonsystematic design presented by Lin and Morse (1975). In this design, spacings were randomly assigned in two dimensions to row and column positions, which resulted in a factorial arrangement with equal numbers of trees per plot and different plot sizes and shapes. Row and column spacing factors occur perpendicular to each other in a grid. The intersection of the row and column spacing factors defines a specific density and spacing. Details of the experimental design as applied to this study can be found in Amateis et al. (1988); growth and yield relationships in this study can be found in Sharma et al. (2002a, 2002b) and Zhang et al. (1996).

Treatment spacings of 1.83 m × 2.44 m, 2.44 m × 1.83 m, 1.22 m × 3.66 m, and 3.66 m × 1.22 m were used in this investigation, since these constitute nearly square (3:4 or 4:3) and more rectangular (1:3 or 3:1) spacings with the same density (2242 trees/ha) at time of establishment. In the summer of 2002, in each of the replications at the two Coastal Plain sites and one Piedmont site, either the 1.83 m × 2.44 m or the 2.44 m × 1.83 m and either the 1.22 m × 3.66 m or the 3.66 m × 1.22 m were randomly selected for branch diameter measurement. Thus, nine plots of the 3:4 (or 4:3) spacing treatment and nine plots of the 1:3 (or 3:1) spacing treatment were selected for inclusion in the study.

An assumption was made that rectangularity effects in the treatment plots were not affected by plot aspect and orientation. Therefore, data from the 2.44 m × 1.83 m and 1.83 m × 2.44 m treatments have been considered equivalent for this study and will be referred to as 1.83 m × 2.44 m (or 3:4) spacing treatment. Similarly, data from the 3.66 m × 1.22 m and 1.22 m × 3.66 m treatments have been considered equivalent and will be referred to as 1.22 m × 3.66 m (or 1:3) spacing treatment. Unless otherwise specified, within-row distance refers to the smaller distance for each spacing treatment (1.22 m is the within-row distance for the 1.22 m × 3.66 m spacing and 1.83 m is the within-row distance for the 1.83 m × 2.44 m spacing) and between-row distance refers to the larger distance for each spacing treatment (3.66 m is the between-row distance for the 1.22 m × 3.66 m spacing and 2.44 m is the between-row distance for the 1.83 m × 2.44 m spacing) in this paper.

On the selected treatment plots, only potential sawtimber crop trees were selected to receive branch diameter measurements. To be considered sawtimber, a candidate tree occupied a dominant or codominant position in the canopy, was single stemmed, and was without a major rust gall in the stem or mechanical damage within 5.5 m of the ground and without significant bole sweep. A tree was considered to have significant bole sweep if a straight line connecting the center of the stem at the stump and 5.5 m lay outside the tree bole. A tree with a major rust gall on the stem near the ground might still be a candidate crop tree if it was mechanically sound and a 5.2-m butt log could be cut above the gall.

A height pole was extended to 5.5 m and placed alongside each potential sawtimber crop tree. The largest branch within the first 5.5 m of the bole in each of four quadrants, or faces, was identified. Quadrants 1 and 3, on opposite sides of the bole, contained branches extending in the within-row direction. Quadrants 2 and 4, on opposite sides of the bole, contained branches extending in the between-row direction. The largest branch in each face may or may not have occurred in the same whorl. Sample branches were severed from the tree at the point of entry into the bole and the branch diameter measured to the nearest 0.25 cm. The base of the live crown had receded above 5.5 m on all measurement trees; thus, all sample branches were dead at the time of measurement.

At the Piedmont site, diameter at breast height (DBH) of all trees in the 1.83 m × 2.44 m and the 2.44 m × 1.83 m spacings and all trees in the 1.22 m × 3.66 m and the 3.66 m × 1.22 m spacings was measured in two directions, between and within rows, with a caliper to examine the effect of spacing on stem asymmetry. Table 1 summarizes the data acquired for this study.

**Methods**

A set of hypotheses was defined to examine the effect of rectangularity on stem quality up to age 19 when the data were collected: (1) $H_0$: mortality does not differ between the 1:3 rectangularity and the 3:4 rectangularity, (2) $H_0$: the number of potential sawtimber trees is independent of rectangularity for the 1:3 and 3:4 spacings, (3) $H_0$: maximum branch diameter was not affected by spacing, and (4) $H_0$: stem asymmetry, as measured by DBH, was not affected by spacing.

Hypothesis 1 was evaluated by applying a $\chi^2$ test to the number of living and dead trees by spacing. In a similar way, hypothesis 2 was evaluated by applying a $\chi^2$ test to the proportion of living trees in the two spacing treatments that were assessed as being potential sawtimber trees.

Hypothesis 3 was evaluated by applying analysis of variance (ANOVA) procedures to the branch diameter data with main effects being spacing treatment (3:4 or 1:3 rectangularity) and branch quadrant (within or between rows). Spe-
cifically, the following model was fitted to the branch diameter data:

\[ BD_{ij} = \mu + S_i + Q_j + (SQ)_{ij} + \epsilon_{ij} \]

where \( \mu \) is the overall mean, \( BD_{ij} \) is branch diameter for the \( i \)th spacing treatment and the \( j \)th branch quadrant, \( S_i \) is the \( i \)th spacing treatment (\( i = 1 \) for the 3:4 spacing and \( i = 2 \) for the 1:3 spacing), \( Q_j \) is the \( j \)th branch quadrant (\( j = 1 \) for within rows and \( j = 2 \) for between rows), \( (SQ)_{ij} \) is the interaction between spacing treatment and branch quadrant, and \( \epsilon \) is the error term.

Another model was considered to investigate the possibility of differences in branch diameters resulting from orientation (between or within rows):

\[ BD_i = \mu + Q_i + \epsilon_i \]

where \( \mu \) is the overall mean, \( BD_i \) is branch diameter for the \( i \)th quadrant, \( Q_i \) is the \( i \)th quadrant (\( i = 1 \) for the within-row 1:3 spacing, \( i = 2 \) for the between-row 1:3 spacing, \( i = 3 \) for the within-row 3:4 spacing, and \( i = 4 \) for the between-row 3:4 spacing), and \( \epsilon \) is the error term.

Hypothesis 4 was tested by applying ANOVA procedures to the within-row and between-row DBH measurements in the 3:4 and 1:3 spacing treatments of the Piedmont location. The model tested was

\[ CD_{ij} = \mu + S_i + M_j + (SM)_{ij} + \epsilon_{ij} \]

where \( \mu \) is the overall mean, \( CD_{ij} \) is the caliper DBH measurement for the \( i \)th spacing treatment and the \( j \)th measurement direction (within or between rows), \( S_i \) is the \( i \)th spacing treatment (3:4 or 1:3), \( M_j \) is the \( j \)th measurement direction (within or between rows), \( (SM)_{ij} \) is the interaction between spacing treatment and measurement direction, and \( \epsilon \) is the error term.

### Results and discussion

The \( P \) value associated with the \( \chi^2 \) test for hypothesis 1 was 0.356. Thus, the hypothesis that there is no difference in the mortality of the two spacing treatments could not be rejected. The \( P \) value associated with the \( \chi^2 \) test for hypothesis 2 was 0.272, so hypothesis 2 could not be rejected.

For testing hypothesis 3, model 1 had an overall \( F \) value of 3.29 and a \( P \) value of 0.020. The \( P \) values associated with the main effects of spacing treatment and branch quadrant were 0.010 and 0.127, respectively. The \( P \) value for the interaction term was 0.338. For evaluating model 2, Tukey’s pairwise comparison test on the means found significant differences (\( P < 0.05 \)) between the between-row 1:3 spacing and the within-row 3:4 spacing. All other comparisons were not significant at the \( \alpha = 0.05 \) level. Thus, hypothesis 3 could be rejected at the \( \alpha = 0.05 \) level.

For testing hypothesis 4, model 3 had an overall \( F \) value of 0.13 and a \( P \) value of 0.945. The \( P \) values associated with the main effects of spacing treatment and measurement direction as well as the interaction term were all greater than 0.5 (not significant). A t test comparing the within-row with between-row caliper measurements using only the 1:3 spacing treatment was not significant (Wilcoxon one-sided \( P = 0.4 \)). Therefore, hypothesis 4 could not be rejected.

The analyses performed here suggest that rectangular spacings up to at least 1:3 in loblolly pine plantations have little effect on stem characteristics affecting the butt log. Up to age 19, there were no significant differences in survival or in the proportion of potential sawtimber quality trees in the 3:4 and 1:3 spacing treatments. There was a significant difference in mean maximum branch diameter between the two spacing treatments, with the 1:3 spacing having larger maximum branch diameters in the butt log than the 3:4 spacing. However, the mean maximum branch diameter in the 1:3 spacing was less than 2.5 cm (Table 1), well under the 5-cm maximum for dead branches in the butt log to receive a grade 1 classification (Clark and McAlister 1998). It should be noted, however, that the planting density tested here (2242 trees/ha) is relatively high. Mean branch diameter should be greater in plantations established with fewer trees per hectare.

While Sharma et al. (2002b) found that 1:3 rectangularity had produced asymmetric crowns through age 12, this study suggests that the eccentric crown shape has not resulted in branch diameters that are detrimentally large (at 2242 trees/ha) or stems that are unusually asymmetric. This may be due, in part, to the heliotropic movement of some within-row branches into between-row growing space to capture additional sunlight. While it is not possible from this study to anticipate the effect of stretching rectangular spacings beyond 1:3, it is clear that some detrimental effects on butt log quality will be encountered by establishing loblolly pine plantations at rectangular spacings up to 1:3 in stands planted at approximately 2242 trees/ha.

### References


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