Effects of Nursery Density on Shortleaf Pine[1]

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Abstract.--A technique to determine the effective nursery bed density of individual seedlings was developed and then used to evaluate density influence on shortleaf pine (*Pinus echinata* Mill.) bare-root seedlings. At lifting, mean height had increased while mean root collar diameter and root volume had decreased with increasing effective density. After the first growing season, seedlings produced at lower effective densities exhibited greater height and diameter growth than seedlings grown at higher effective densities.

INTRODUCTION

Sbortleaf pine (*Pinus echinata* Mill.) is the most important species used for artificial regeneration on the Ouachita and Ozark National Forests (Kitchens 1987). Approximately 12 million seedlings are planted annually on about 7,000 hectares of the two forests. Although artificial regeneration of shortleaf pine represents a large investment on the two forests, success of the program has been limited by poor seedling survival and growth. Excluding the severe drought year of 1980, seedling survival has averaged about 50 percent since large-scale planting was begun in the 1970's. The reasons for poor seedling performance are not clear. The planting sites are harsh, the soils are rocky, and the south and west aspects are exposed to hot, droughty conditions throughout the summer. However, many forest managers do not think that difficult site conditions alone explain the poor seedling performance. They note that seedling quality also must be considered. Consistent production of quality planting stock requires a thorough knowledge of seedling development in the nursery and an understanding of how nursery culture impacts field performance.

In a recent review, Barnett and others (1987) found few references to shortleaf pine stock quality. Two of the most enlightening items were by Chapman (1948) and Clark and Phares (1961). The earlier paper dealt with the effects of morphological characteristics on the survival and initial growth of seedlings planted on old field sites in Arkansas, Missouri, Indiana, and Ohio. The later paper dealt with survival and growth of the plantations in Missouri and Indiana at age 19 and 20. In general, larger diameter seedlings performed better initially, and that early superiority was maintained over time.

One of the most critical factors determining seedling quality is seedbed density. Density is a. measure of competition among seedlings for growing; space and relates to their ability to receive light, water, and nutrients. As density increases, yield of cull seedlings increases and average root collar diameter decreases (Shoulders 1961). Seedling weight also decreases with increasing density. In loblolly pine (*P. taeda* L.), root weight is reduced proportionately more than shoot weight, resulting in a corresponding decrease in root-to-shoot ratio (Harms and Langdom 1977). Mexal (1981) concluded that the biological) optimum density for growing loblolly pine seedlings is 200/m^2.

With the mechanical sowing methods in use, and less than perfect germination, nursery bed density is seldom uniform. Although bed density is a useful criterion for evaluating average seedling characteristics on a plot basis, bed density consequence on individual seedlings is difficult to determine.

In 1985 a study was established at Weyerhaeuser Company's Magnolia Forest Regeneration Center in southwest Arkansas to address the quality of shortleaf pine planting stock used to reforest Ouachita and Ozark Mountain sites. The effects of nursery bed density and fertilization on the morphology, nutrient status, and root growth potential of seedlings from that

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study were reported previously (Brissette and Carlson 1987). Objectives of this paper are to describe a method of determining the effective density of individual seedlings and to compare the morphology and subsequent first-year field performance of seedlings grown at a range of effective densities.

MATERIALS AND METHODS

This study was part of one designed to evaluate nitrogen (N) and phosphorus (P) fertilization as well as seedbed density. The design and installation of the experiment were described in a previous paper (Brissette and Carlson 1987), and will be only briefly reviewed here. There were two levels of P, five levels of density, and four levels of N applied in a split-split plot design with four replications. The levels of P were the level in the soil before the experiment and enough 0-300-0 fertilizer incorporated prior to seedbed formation to theoretically raise the level 150 percent. No significant effects were attributed to the P treatments (Brissette and Carlson 1987).

Ammonium sulphate was applied in five biweekly topdressings at levels ranging between 55kg N/ha and 170kg N/ha. The effect of N on morphological attributes peaked at an intermediate level, and interacted with mean seedbed density in its effect on root growth potential (Brissette and Carlson 1987).

The study was sown on April 16, 1985, with Weyerhaeuser-designed precision vacuum equipment that sowed eight double rows of seeds. The five target densities of living seedlings were: (1) $160/m^2$, (2) $230/m^2$, (3) $295/m^2$, (4) $360/m^2$, and (5) $430/m^2$.

Actual average seedbed densities were lower than the target densities because germination was poorer than expected. Average density for each level in the stud was: $141/m^2$, $218/m^2$, $269/m^2$, $296/m^2$, and $296/m^2$, Note that the two highest levels were the same. Although the highest density was well below the sowing target it was higher than the operational level ($270/m^2$) recommended by Chapman (1948) but much lower than the density ($540\text{-}590/m^2$) suggested as a maximum by Wakeley (1954).

Early in the study a transect was taken across the center of each plot and one seedling from each double drill row was permanently tagged as a measurement tree. Thus, 1280 identified seedlings were followed throughout the study. Those seedlings are the basis for this paper.

To determine effective density we reasoned that seedling shoots are most affected by other seedlings that are closer than about 15 cm. Root competition probably occurs at greater distances, but we assumed that most water and nutrient uptake is also within 15 cm. Thus, seedlings sown in conventional drills on 15 cm spacing compete within their own drill row and with seedlings in adjacent drill rows. To determine the effective density of each of the labeled seedlings the number of seedlings in the double drill row for 15 cm on either side was added to the similar number obtained on adjacent drill rows. The total is an estimate of the number of seedlings with which the measurement tree was competing.

Because competition is usually expressed as the number of seedlings per unit area, the number of competing seedlings was converted to number per square meter, i.e., the effective density for each measurement tree. The conversion was based on the area included in obtaining the number of competing seedlings. The measurement area was 30 cm long, the nursery beds were 1.2 m wide with eight drill rows. Since the seedlings from the six interior drill rows are competing with those on either side (three rows total-) the area was calculated to be $3/8 \times 1.2\ m \times 0.3\ m = 0.135\ m^2$. The effective density was then calculated as the number of competing seedlings/$0.135\ m^2$--for example, 36 seedlings/0.135 m = 267 seedlings/m^2. Because the seedlings on the outside of the nursery bed only have one adjacent drill row (two competing rows) their area of competition was calculated to be $1/4 \times 1.2\ m \times 0.3\ m = 0.09\ m^2$. Thus for a seedling on the outside drill row competing with 19 additional seedlings, its effective density is 20 seedlings/$0.09\ m^2$ = 222 seedlings/m^2.

Each of the 1280 measurement seedlings was labeled with an aluminum tag attached to the stem with a wire. When the beds were laterally root pruned prior to lifting the tags and wires caused extensive stem damage. When the seedlings were hand-lifted on January 20-21, 1986, 970 of the original 1280, were undamaged. These undamaged were measured for root collar diameter, height (shoot length), and root volume, using the displacement method (Burdett 1979). The seedlings were kept in cold storage between lifting and planting except when they were being measured. The measurements were made in a laboratory and required less than 5 min per seedling.

On February 7, 1986, the seedlings were machine-planted on a sod-covered site at the J. K. Johnson Tract of the Palustris Experimental Forest west of Alexandria, LA. On March 5-6, 1987, the total height and ground line diameter of all living trees were measured. Relative growth rates (RGR) were calculated as percent change in height and diameter between the nursery and first-year field measurements (field measurement-nursery measurement/nursery measurement X 100).

Seedling morphology and first-year field performance data were analyzed by regression techniques. The 970 trees were subdivided in 10 density classes of 97 observations each and the means were used in the analyses.

RESULTS AND DISCUSSION

The effective densities for the 970 seedlings ranged from 55 to 431 seedlings/m^2 with a mean of 246/m^2 and a coefficient of variation (CV) of 30 percent. When divided into 10 subclasses of 97 seedlings each, the mean densities ranged from 123 to 365/m^2 (table 1). The amount of N available per seedling was computed by dividing the total N applied by the effective density. It ranged from 13 to 260 mg/seedling with a mean of 47 mg/seedling. Within the density classes, mean N ranged from 30 to 87 mg/seedling (table 1).

With density as the independent variable, regressions with the three morphological characteristics as dependent variables were all significant (p<.001). Coefficients of determination (r^2) were 0.78, 0.92, and 0.98 for height, diameter, and root volume respectively. field performance. Under operational conditions where the rate of N application is usually more uniform than bed density, this relationship may be even more important.

Nursery bed density clearly had affected seedling morphology at time of lifting (table 1).

Table 1.--Nursery bed density effects on shortleaf pine seedling morphology and first-year field performance

Density	Mean	Mean	Nursery			First-year field		Relative growth	
class	density	N [a]	Ht	Dia	RV [b]	Ht	Dia	Ht	Dia
	--/m2--	-mg/tree-	--mm--		--cc--	-------mm-------		-------%-------	
1	123	87	163	4.8	4.1	357	6.8	124	42
2	155	65	167	4.7	3.9	373	6.8	130	47
3	188	59	181	4.7	3.5	356	6.5	100	41
4	217	46	182	4.6	3.3	353	6.2	100	36
5	237	43	183	4.6	3.2	356	6.1	100	36
6	261	39	181	4.4	2.8	348	5.9	94	38
7	282	38	182	4.4	2.7	328	5.8	86	37
8	303	33	183	4.3	2.7	328	5.8	82	38
9	331	32	187	4.3	2.6	335	5.7	83	35
10	365	30	190	4.3	2.5	328	5.6	76	32
r^2 [c]		.98	.78	.92	.98	.75	.97	.88	.68

[a] N = nitrogen

[b] RV = root volume

[c] r^2 = coefficient of determination with mean effective density as the independent variable, see text for individual regression equations

Determination of nutrient uptake in fertilizer experiments requires destructive sampling. For this study concentrations of N, P, and K in seedling shoots were reported previously (Brissette and Carlson 1987). Although a theoretical amount of N was calculated for each seedling on the basis of effective density, it cannot be confirmed. Therefore, this paper's discussion is confined to the effects of density. Differences due to the four N rates applied are taken into account by analyzing the means of the density classes that are made up of approximately equal numbers from each N treatment. As shown in table 1, the average amount of N available per seedling decreases as density increases. Thus the effects of density on an individual seedling cannot be totally separated from the effects of N. This relationship should be kept in mind during the following discussion about morphology and field performance. Under operational conditions where the rate of N application is usually more uniform than bed density, this relationship may be even more important.

As mean density increased, mean height increased while mean diameter and root volume decreased. With density as the independent variable, regressions with the three morphological characteristics as dependent variables were all significant (p<.001). Coefficients of determination (r^2) were 0.78, 0.92, and 0.98 for height, diameter, and root volume respectively.

Nursery managers seldom have a seedlot or even a species growing at the range of densities represented in this study. For pines, managers are most interested in densities between 215 and 325/m^2. To evaluate this range in more detail, we selected two of our density classes and compared them with analysis of variance (ANOVA). The classes selected from table 1 were 4 and 8. Class 4 had a mean density of 217/m^2. It had a relatively narrow range of densities of from 204 to 226/m^2. Class 4 is the one just above the biological optimum density recommended for loblolly pine by Mexal (1981). At most nurseries it would be considered low density. Class 8 had a mean density of 303/m^2 and a range (between 292 and 316/m^2) nearly as narrow as Class 4. Class 8 would be considered moderately high density.

Seedlings from Classes 4 and 8 did not differ significantly in height (MSE=1521, p =.905). Although the difference in mean diameters was only 0.3 mm, it was significant (MSE=0.96, p = .020). The 0.6 cc difference in root volume was also significant (MSE=1.33, p< .001).

Nursery managers often evaluate their crop quality as the percentage of seedlings that exceeds some minimum standard. For the southern pines, morphological seedling grades were developed by Wakeley (1954), drawing on several years of research results and operational observations. These grades are still recognized as the standard measure of southern pine seedling quality. Three grades are defined, two plantable and one cull, based primarily on root collar diameters of undamaged seedlings. For shortleaf pine the minimum diameter for plantable seedlings (Grade 2) is 3.2 mm while the minimum for premium seedlings (Grade 1) is 4.8 mm. In our density Class 4, only 3 percent of the seedlings were less than 3.2 mm and would have been considered culls, while in Class 8, 12 percent were culls. In Class 4, 40 percent of the seedlings were Grade 1, while in Class 8, 30 percent were Grade 1.

Root volume is seldom evaluated operationally but is considered one of the most important morphological characteristics. During the period between planting and elongation of new roots, root volume largely determines the level of plant moisture stress that can develop (Carlson 1986). Larger root volumes also provide more sites for new root growth, thus root volume has been positively related to root growth potential in both loblolly pine (Carlson 1986) and shortleaf pine (Brissette and Carlson 1987). For these reasons large root volumes are especially important when seedlings are planted on droughty sites. However, root volume is extremely sensitive to nursery bed density. Across our 10 density classes, root volume decreased sharply as density increased (fig. 1).

First-year field survival was excellent, being 98 percent overall. Among seedbed density classes, first-year survival was between 96 and 99 percent. Field growth was statistically related to nursery bed density (table 1). The regression between first-year field height and seedbed density was significant (p<.005, r^2 = 0.75). But, unlike nursery height, field height decreased as the density at which the seedlings were grown increased (fig. 2). That is, the shortest trees from the nursery were the tallest in the field after the first growing season. First-year field diameter was also significantly related to nursery density (p< .001, r = 0.97). Like nursery diameter field diameter decreased with increasing seedbed 'density (fig. 3).

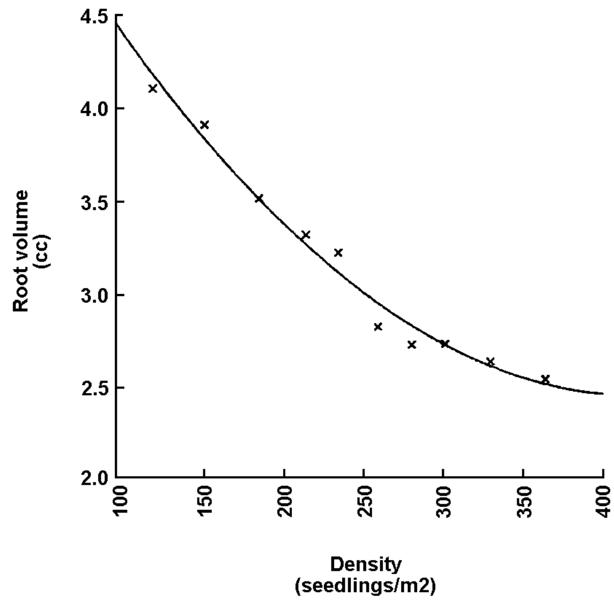

Figure 1.--Relationship between mean effective density and mean root volume of shortleaf pine seedlings, n=97.

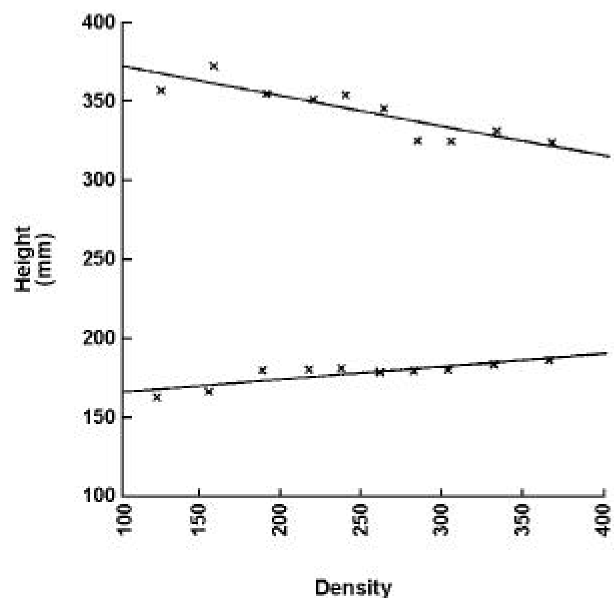

Figure 2.--Relationship between mean effective density and mean shortleaf pine seedling height at lifting (lower curve, n=97) and after one year in the field (upper curve, n=93-96.

In terms of RGR, changes in heights and diameters between the nursery and the field were also related to nursery density (table 1). For the 970 trees, the mean RGR for height in the field was 97 percent; 100 percent represents a doubling in size. When regressed with seedbed density the relationship was significant ($p<.001$, r^2 - 0.88). Diameter RGR was not nearly as great with an overall mean of 38 percent, but was also significantly related to nursery density ($p< .005$, r^2 - 0.68). For both height and diameter, RGR in the field declined with increasing nursery density (fig. 4).

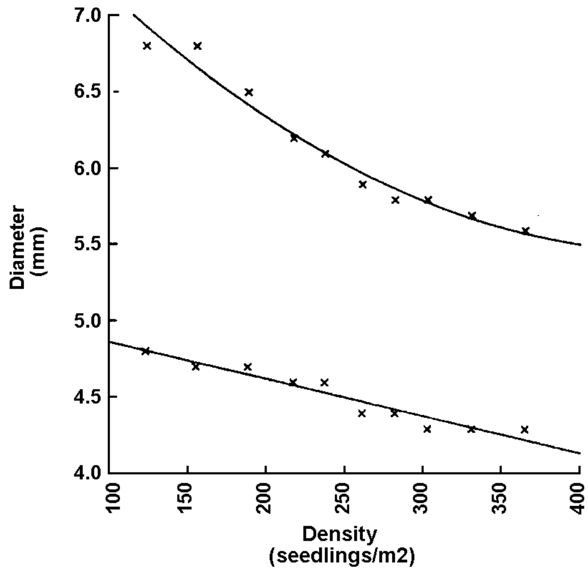

Figure 3.--Relationship between mean effective density and mean shortleaf pine seedling root collar diameter at lifting (lower curve, n=97 and ground line diameter after one growing season (upper curve, n=93-96).

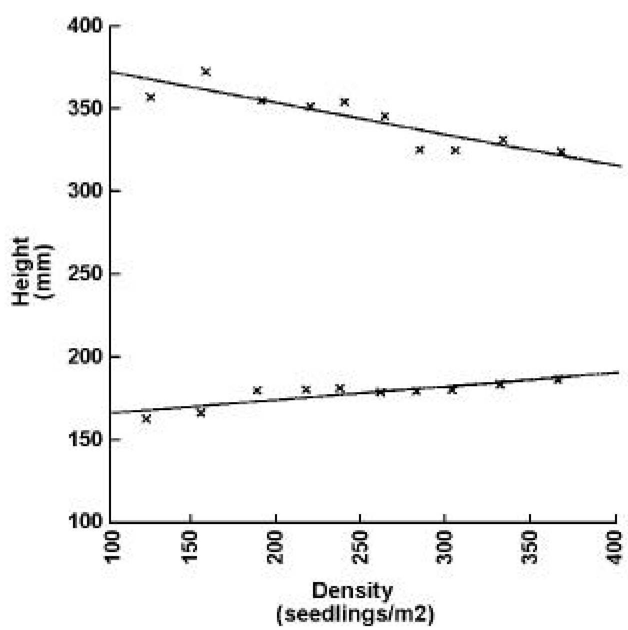

Figure 4.--Relationship between mean effective density and mean relative first-year growth rates (field measurement-nursery measurement/nursery measurement X 100) for seedling height (upper curve, n=93-96) and diameter (lower curve, n=93-96).

Both nursery managers and foresters benefit when they agree on a set of specifications for a target seedling that will give the desired performance on a particular planting site. Target seedling specifications differ somewhat from seedling grades because targets are based on performance goals. Thus target specifications are often more stringent than morphological grades, which are usually based on a minimum performance level. One proposed goal for southern pines is a doubling in height during the first growing season in the field (Brissette 1985). Data from this study can be used to help specify a target seedling that will meet that goal. The regression equation for relative height growth in terms of nursery density (X = seedlings/m^2) is:

$$RGR\ HT = 150.5 - 0.21537X,\ r^2 = 0.88$$

To achieve a doubling in height (100 percent change), the equation predicts a density of 235/m^2. The equations for nursery height (HT), diameter (DIA), and root volume (RV), in relation to density are:

$$HT = 156.2 + 0.09608X,\ r^2 = 0.78$$

$$DIA = 5.1 -0.00237X,\ r^2 = 0.92$$

$$RV = 5.9 -0.01648X + 0.00002X2,\ r^2 = 0.98$$

These equations predict that a seedling capable of doubling in height under the conditions of this study: (a) is no more than 179 mm tall (minimum mean height in the data set was 163 mm), (b) is at least 4.5 mm in root collar diameter, and (c) has a root volume of at least 3.1 cc. These specifications could also be estimated graphically from figures 1-4.

These specifications are based on seedlings grown on a less droughty site than those typically found in the mountains. However, the height suggested by the analysis is at the low end and the diameter is at the high end of the range of specifications given for an initial target seedling to be planted on Ouachita and Ozark Mountain sites (Barnett and others 1987). Therefore, we think that the root volume suggested by this analysis is an appropriate addition to those target specifications. Note that 3.1 cc is the target root volume, the minimum acceptable would be somewhat less and would depend on what was defined as a minimum performance level.

SUMMARY AND RECOMMENDATIONS

This study was designed to evaluate the effect of nursery bed density on the morphology and subsequent field performance of shortleaf pine seedlings. Because seedling morphology is so strongly related to seedbed density, it was not possible to separate the effects of density and morphology on field performance in this study. However, based on the above results and discussion the following recommendations are made:

1) To produce shortleaf pine seedlings with the morphological characteristics for rapid first-year growth in the field, nursery bed density should be kept below 235/m^2.

2) For any species, root volume should be included in the development of target seedling specifications. While not as easy to measure as shoot length or diameter, root volume determination is not excessively difficult nor time consuming.

3) Because density can influence seedling nutrient status, it should be remembered that the effects of density on growth and performance are confounded by the effects of fertilization.

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