SEEDLING BED DENSITY INFLUENCES SEEDLING YIELD AND PERFORMANCE

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Abstract. The growing density in the seedbed impacts not only the yield, but also the grade and morphology of southern pines. The biological optimum appears to be a density of about $200/m^2$. This density optimizes the balance between individual seedling biomass and total biomass production. Morphological advantages at time of lifting which are attributable to density will result in long-term growth advantages expressed as increased individual tree volume.

Additional key words: *Pinus taeda*, *Pinus elliotii*, dry weight, grade, plantation performance.

The nurseryman is charged with the responsibility of optimizing and/or maximizing nursery production given certain economic constraints. Through his cultural practices ultimately he is responsible for successful seedling performance in the plantation. An important factor influencing nursery production as well as field performance is growing density. The relationship between growing density or plant population and crop yield is very strong regardless of the crop under study, and over the years, scientists have endeavored to define the optimum growing density. Studies with southern pines generally have focused on maximizing seedling numbers in the nursery. However, some studies have attempted to define the optimum population based on certain morphological standards, i.e. seedling grade or, in some cases, on the performance following outplanting. Regardless of the study objective, crop yield frequently is defined as the number of seedlings attaining a minimum size. Size is usually defined in terms of height and caliper, but also can be defined in terms of individual seedling biomass. An alternative method used by some is to define the population in terms of total biomass per unit area.

The objective of this paper is to address the impact of seedling density on crop yield and field performance. Yield, in this case, will be defined both as the number of seedlings attaining a minimum size or grade and as total biomass production. First, I will explore the interaction between density and yield in the conventional sense, i.e. seedling number, and second, the interaction of density and total biomass production. Then, I will examine the relationships between seedling density and field performance.

The relationship between density and yield is not simple. These two factors are influenced by other nursery practices such as fertility, irrigation, and seed quality. However, this paper will be limited primarily to the relationship between these two factors while holding other parameters fixed.

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SEEDLING GRADE

Many investigators have examined the relationship between density and seedling yield, but there is little agreement among those offering recommendations; recommended densities range from $215/m^2$ to $480/m^2$ (Table 1). Clearly, there is disagreement over optimum density, but probably because the authors may have used different definitions of a seedling acceptable for outplanting. Wakeley's original grading criteria are used frequently, in spite of the reported inadequacies of this grading scheme (Wakeley 1954).

Table 1. Recommended seedling bed densities (no./m^2) for Southern pines.

Reference	Seed Bed Density (no./m^2)	
	Loblolly	Slash
Burns and Brendemuehl, 1971	---	430-480
Foster, 1956	430	430
Muntz, 1944	---	320
Shipman, 1964	215 - 270	215 - 270
Shoulders, 1961	430	430
Range	215	265

The relationship between seedling density and grade is shown clearly in a study by Hansbrough (1957). As density increased from $320/m^2$ to $645/m^2$ the ratio among grades decreases from predominantly grade 1 seedlings to predominantly grade 2 seedlings; the proportion of grade 3 seedlings increases from 6% to 22%. A closer examination of these seedlings demonstrates the overall superiority of the higher grades. The dry weight of grade 1 seedlings averaged about 7.7 g regardless of density. However, grade 2 seedling dry weight averaged 2.7 g, while grade 3 averaged 1.2 g. Relative to grade 1 seedlings, these are reductions of 65% and 85%, respectively. Root weights were reduced proportionately more than shoot weight and the R/S ratios decreased from 0.26 to 0.22 and 0.22 for grades 1, 2 and 3, respectively. Based on biomass and R/S ratios, grade 2 seedlings resemble grade 3 more than grade 1. However, the seedings were not outplanted to determine potential performance differences.

BIOMASS PRODUCTION

The problems associated with visually assessing seedling grade are avoided by examining biomass production either on a individual seedling basis or on a unit area basis. This eliminates the need to categorize the trees based on arbitrary criteria, and allows examination of the entire population.

Both individual seedling biomass and total plot biomass have been used successfully to describe agronomic crop yields (Willey and Heath 1969). However, only the former has been used to date to characterize southern pine crops. Simple transformation of the data will convert one to the other. Possibly the best information to illustrate this point comes from a study by Harms and Langdon (1977) installed at the Westvaco nursery in Summerville, South Carolina. They reported that seedling dry weight decreased markedly as seedling bed density increased (Fig. 1). Concomitant with the biomass decrease was a shift in biomass partitioning. The ratio of root weight to shoot weight decreased about 25% over the densities tested. The shift toward a greater imbalance between root and shoot weight with increasing density conceivably could result in reduced field performance.

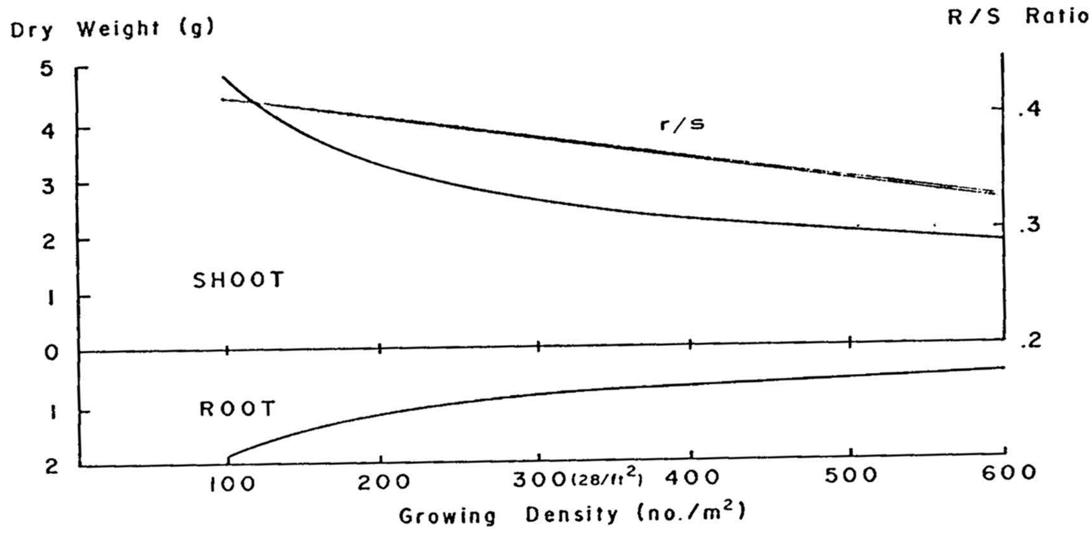

Figure 1.--The effect of growing density on root and shoot weight and root/shoot ratio of loblolly pine (Harms and Langdon 1977).

The question of "optimum" density cannot be resolved simply by examining Figure 1; unless it is known that a particular range of seedling dry weights or R/S ratios is preferable to another. I doubt that this information is available. An alternative approach is to transform the data and examine total yield *per* unit area as a function of density (Willey and Heath 1969). To accomplish this, the reciprocal of seedling density or growing area/plant is plotted against the reciprocal of biomass per unit area (Fig. 2). This relationship generally is linear and extrapolating to the intercept yields the theoretical maximum yield or "P" value (Willey and Heath 1969). In this study, the maximum amount of biomass that could be produced is 1.9 kg/m^2. This value appears to be consistent with other studies (Hansbrough 1957, Switzer and Nelson 1963).

Given the maximum yield of approximately 2 kg/m^2, the nurseryman must decide whether to concentrate that growth on a few large seedlings or spread it over many small seedlings. As nursery densities are lowered seedling size increases, but outplanting becomes more difficult. As densities increase, a larger proportion of the crop may be culled due to small size and field performance again may suffer due to an inability of small seedlings to get to compete with the weeds.

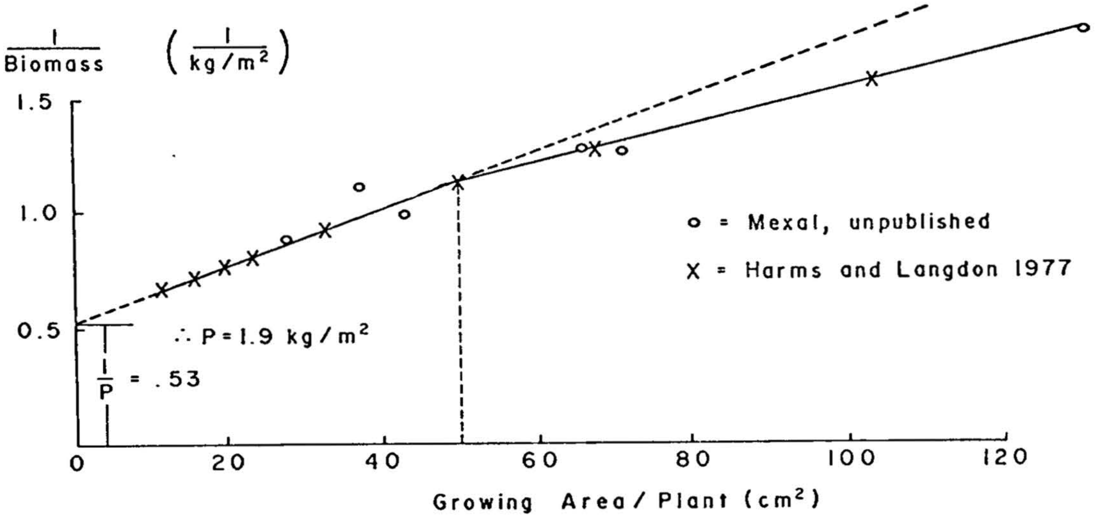

Figure 2.--Relationship between growing area and the reciprocal of total biomass production in loblolly pine.

The generally linear relationship between growing area and the inverse of biomass does not appear to hold for loblolly pine. The response is linear up to about 50 cm^2/plant; as the growing area increases beyond this point, the reciprocal of biomass diverges from the predicted line. The reasons for this are not entirely understood, but the relationship held in two studies of two nurseries (Harms and Langdon 1977, Mexal, unpublished results). A possible explanation for this divergence involves competition among plants. Below a growing area of 50 cm^2/plant, the seedlings are experiencing competition and the resultant biomass production per plant is linearly related to density. Competition is restricting growth and the site is underutilized on an individual seedling basis. Above 50 cm^2/plant, competition is not limiting and other factors limit growth. In this case the site is under-utilized on a unit area basis. This reasoning suggests that the biological optimum growing area for loblolly pine which maximizes both total biomass production as well as individual seedling biomass is about 50 cm^2/plant. This translates to a growing density of 200 plants/m^2 or 19 plants/ft^2.

There is an opportunity to shift total biomass production through the judicious use of fertilizers. Switzer and Nelson (1963) were able to increase pine seedling biomass production significantly by increasing fertilization rates. However, in their study, seedlings grown at a density near the biological optimum were much less responsive to changes in fertility levels than seedlings grown at higher densities. Apparently, seedlings grown at the biological optimum are less sensitive to the vagaries of nursery management practices.

FIELD PERFORMANCE

Describing the optimum growing density on a biological basis is intriguing. However, the decision to alter nursery management practices should be based on its ultimate effect on field performance; whether it be survival, height growth, or volume production. Few studies have addressed the subject of field performance of seedlings grown at various densities, and most of these studies have examined only short-term performance (Burns and Brendemuehl 1971, Shipman 1964). Many studies have emphasized seedling grading criteria in long-term performance evaluations, and most grading schemes are fraught with problems as Wakeley (1959) discovered. Therefore, it probably is unwise to assume that all grade 1 seedlings are equivalent regardless of growing density, cultural regime, etc. Likewise, the field performance of all grade 1 seedlings will not be equal even given identical field environments.

The data in the previous section suggests that seedling dry weight is very sensitive to growing density and may be a better, more reliable index of field performance than grade. Seedling dry weight is a reliable indicator of growing density and it also can be an index of future performance. Dry weight appears to integrate such factors as density, fertility, etc., into one common measure. Switzer and Nelson (1963) found seedling dry weight at time of lifting to be an excellent predictor of seedling height after three growing seasons in the plantation by the following equation:

$$\text{Ht (ft)} = 3.74 + 0.253\ (\text{D.W.}) \qquad r^2 = 0.79$$

This equation describes the relationship between dry weight and growth for three studies spanning three consecutive years. Autry (1972) reported the long-term effects from two of these studies, and found that individual tree volume was correlated with seedling dry weight at time of lifting (Fig. 3). It is evident that individual tree volume production is maximized by low nursery seedling density since the largest seedlings are produced at the lowest densities. The question now becomes what is the optimum growing density to maximize nursery bed utilization and yet realize maximum plantation performance? It would appear from the studies by Autry (1972) and Switzer and Nelson (1963) that future tree volume production in the plantation is inversely related to nursery density. The lower the density the greater the volume production. From studies by Harms and Langdon (1977) and Mexal (unpubl.) the biological optimum nursery density is known (see above). These two factors taken together point to a growing density of $200/m^2$. This density optimizes nursery production and also returns long-term growth benefits in terms of increased volume production.

Clearly, reduced bed densities offer many advantages. Culls should be practically eliminated and therefore the cost of removing them can be eliminated. Seed costs will also be reduced because of the elimination of cull seedlings. Growth regulation should improve as it is usually seedlings grown in dense beds which have a propensity to grow tall and spindly. This should result in savings in culture expenses. Seedling survival following outplanting is not likely to be impacted except where cull seedlings from dense beds are not removed prior to shipping (Burns and Brendemuehl 1971, Shipman 1964). Increased growth and volume production in the plantations are long-term gains to be realized. On the negative side, the nursery land base will have to be increased substantially and therefore growing costs will increase. Lifting and planting difficulties are likely to arise as seedlings from low density beds have larger, more fibrous root systems. All these factors will have to be considered collectively before the decision to alter growing density can be reached. Unfortunately, the question cannot be answered here, but will have to be answered based on each land manager's particular regeneration objectives, economic constraints, of course, experience. The objective of this paper was to present the biological side of the coin, and others will hopefully provide the economic side.

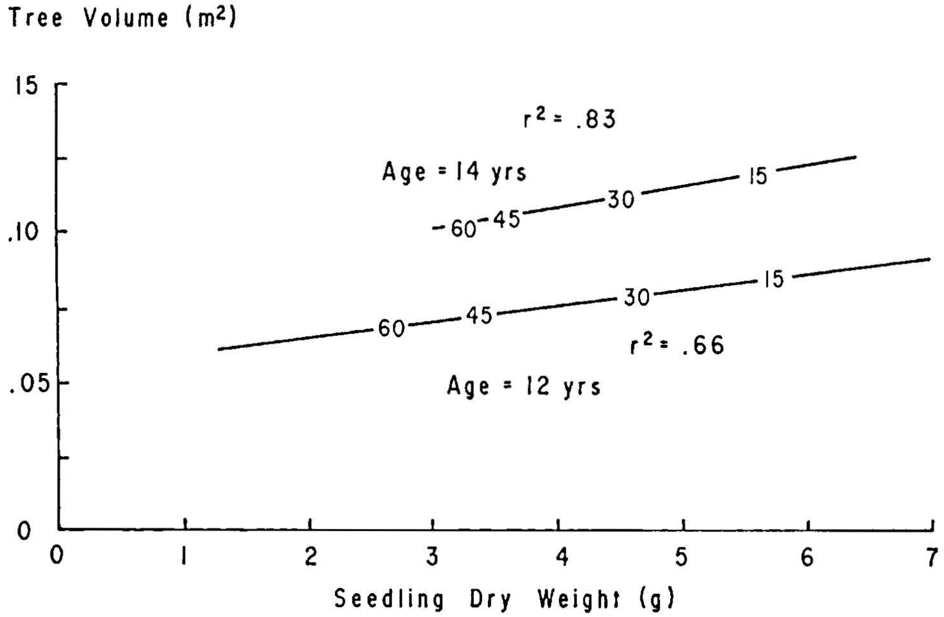

Figure 3.--Relationship between growing density, morphology, and volume yield in the plantation (Switzer and Nelson 1963, Autry 1972). The numbers in the figure refer to growing density (no./ft^2) yielding a particular mean dry weight

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