Chapter 15
Initial Spacing: How Many Trees To Plant

William D. Smith and Michael R. Strub

Abstract

The best initial spacing at which to plant the southern pines is primarily a function of the product desired and is based on both biological and operational factors. Long-term spacing studies over a wide range of initial densities and tree species demonstrate that for rotations beyond approximately 20 years, initial density has little effect on total net wood yield. However, it has a pronounced effect on product size and distribution, value, cost and on harvesting and cultural treatments. Planting seedlings on 2.4 x 2.4 to 3.0 x 3.0 m or equivalent spacing provides good flexibility for plantation management under most landowner objectives and current market conditions.

15.1 Introduction

The decision on how many trees to plant depends on several factors: (1) the product or products desired, (2) the likelihood and intensity of intermediate stand treatments, and (3) the expected initial survival and spatial distribution of seedlings. The effect of initial spacing on both biological (height, diameter, crown, quality, basal-area, and volume development) and operational (harvesting, thinning, site preparation, and other cultural treatments) factors, must be considered.

15.2 Relationships Among Growth, Yield, and Density

Empirical evidence of the relationship between initial spacing (which determines initial density) and pine plantation growth and development is consistent within and across southern pine species. Examination of these relationships has been limited to long-term spacing studies which provide side-by-side comparisons of stocking levels unconfounded by differences in climate and soil type. More importantly, the results of short-term studies can be very misleading. When trees are young and before the onset of intertree competition, individual tree growth is accelerating. At this stage, volume per hectare is proportional to the number of trees. However, once trees begin to compete, this relationship no longer holds, and the effect of initial number of trees per hectare on total productivity diminishes with age.

Loblolly *(Pinus taeda* L.) and slash *(Pinus elliottii* Engelm.) pine are the most commonly planted southern pines and the species for which the greatest number of spacing studies have been established. Spacing studies that are old enough to give meaningful results regarding growth, yield, and density relationships include Sprinz et al. [16], Hafley and Smith [unpubl. data, 7], Arnold [1], Feduccia [5], and Buford [3] for loblolly and Jones [8] and Bowling [2] for slash. Spacing-study results have been published for shortleaf *(Pinus echinata* Mill.) [1], Virginia *(Pinus virginiana* Mill.) [13], and Choctawhatchee sand *[Pima clausa* Chapm. ex Engelm) Vasey ex sarg.] [12] pine. In the following discussion, results from species other than loblolly or slash are presented when their growth habit deviates from that of those two.

15.2.1 Dominant-Height

It is commonly accepted that dominant height growth is unaffected by spacing unless the stand is either extremely crowded or open [14]. Height growth is retarded at extremely high or low densities. Most decisions on how many trees to plant have been made based on the assumption that "normal" densities are within a range at which dominant height is not affected. Although a rigorous test of this assumption has for the most part not been possible, several long-term controlled-spacing studies in southern pines provide insight into the soundness of this assumption and a clearer determination of what constitutes "crowded" and "open."

The relationship between dominant height and initial planting density for loblolly [3] and slash [8] pine is illustrated in Figure 15.1. The studies represent an overlapping range of densities, the first from 1.8 x 1.8 to 3.7x 3.7 m, the second from 1.8x 1.8 to 4.6x 4.6m, for trees 15 and 30 years old. Similar patterns are exhibited in both cases: dominant height growth decreases at closer spacings, with the differences in height increasing as trees mature. For loblolly, the difference in dominant height between the 1.8 x 1.8 and 3.7 x 3.7 m spacing was 1.1 m at age 15 and 1.5 m at age 30. For slash, the difference between 1.8 x 1.8 and 4.6 x 4.6 was 1.5 m at age 15 and

M.L. Duryea & P.M. Dougherty (eds), Forest Regeneration Manual, pp. 281–289.

Table 15.1. Percentage by which growth is overestimated when the density-height effect is ignored [101.

Period (years)	Planting spacing, m							
	4.6 × 4.6	2.3 × 4.6	3.0 × 3.0	1.8 × 3.7	2.4 × 2.4	1.5 × 3.0	1.8 × 2.4	1.8 × 1.8
				– % –				
10–15	2	–4	2	15	9	24	23	34
10–20	0	1	2	21	17	28	24	37
10–25	–2	3	3	19	19	28	18	38
10–30	6	7	9	22	24	31	27	46

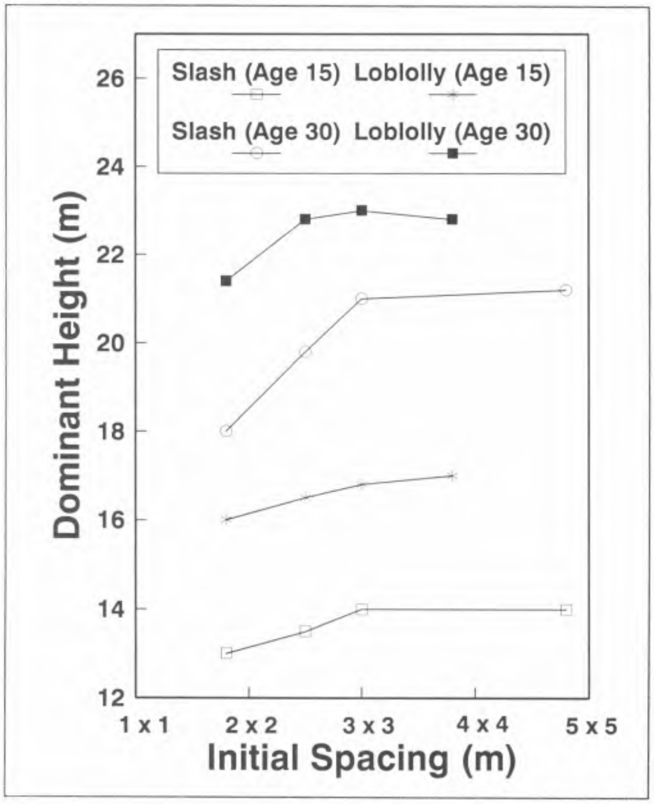

Figure 15.1. Relationship between initial planting spacing and dominant height of two southern pine species at two ages.

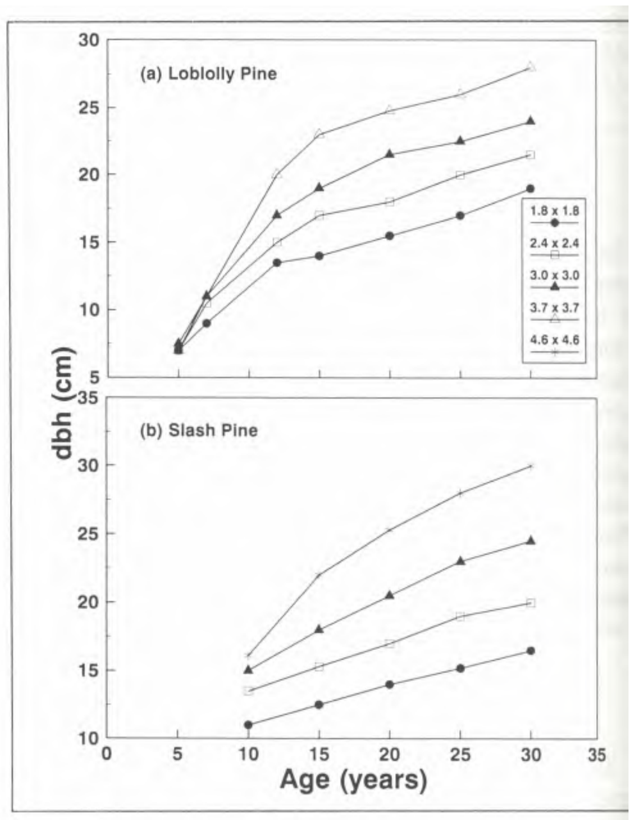

Figure 15.2. Relationship between planting spacing and quadratic medIan dbh over time for (a) loblolly and (b) slash nine.

3.4 m at age 30. The difference between 2.4 x 2.4 and 3.0 x 3.0 at age 30 was 0.3 m for loblolly and 1.5 m for slash. These results suggest that the threshold spacing at which height growth begins to be significantly retarded is closer than 2.4 x 2.4 m for loblolly and 3.0 x 3.0 m for slash. The characteristic lack of expression of dominance of slash pine makes it more sensitive than loblolly to overcrowding. Dominant height at age 20 was not affected by spacing in either Virginia pine [13] or sand pine [12].

The impact of ignoring the effect of density on site index when determining the best initial spacing was demonstrated by Lloyd and Jones [10]. They developed a yield function from the slash data and then projected growth using the actual basal-area at each spacing and age, but assumed a constant site index based on the mean dominant height at age 10 across all spacings. Ignoring the impact of density on site index resulted in significant overpredictions in growth for all spacings 1.8 x 3.7 and closer (Table 15.1). Overprediction in volume growth from age 10 to 30 ranged from 22% for the 1.8 x 3.7 spacing to 46% for the 1.8 x 1.8 spacing.

15.2.2 Diameter

Diameter growth before the onset of intertree competition is generally unaffected by spacing; however, once competition begins, it is reduced. The period of fast, early growth before competition is longer at wider spacings, resulting in larger trees. Once competition has begun, the

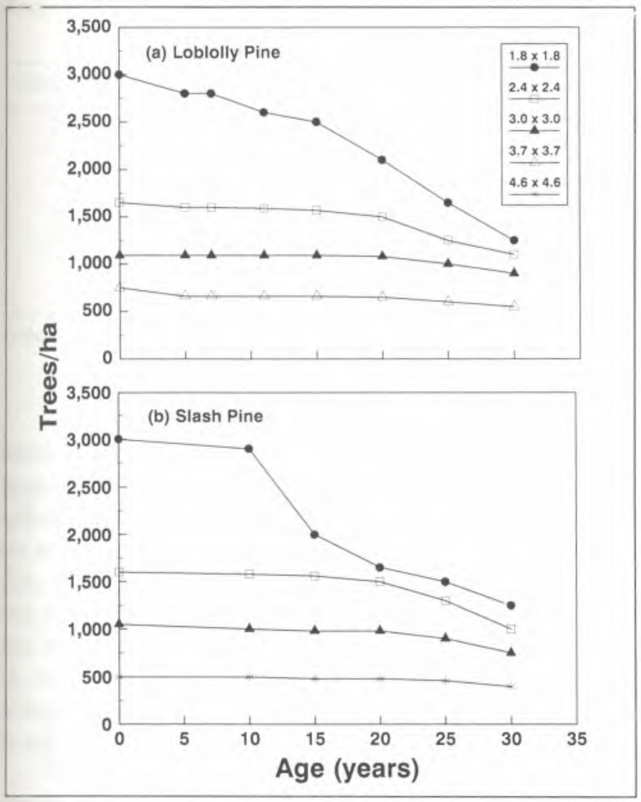

Figure 15.3. Relationship between planting spacing and number of trees per hectare over time for (a) loblolly and (b) slash pine.

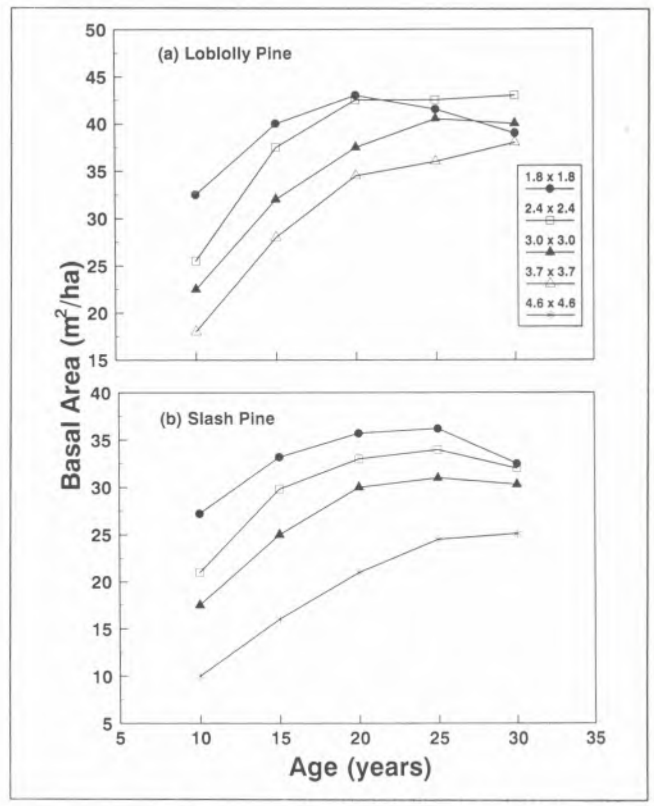

Figure 15.4. Relationship between planting spacing and basal-area over time for (a) loblolly and (b) slash pine.

rate of increase in mean dbh (diameter at breast height, 1.37 m above ground) appears to be independent of spacing (Fig. 15.2). This apparent equal diameter growth across spacings is a consequence of disproportionately greater mortality of trees planted at narrow spacings and the geometrical relationship between diameter and diameter growth. At narrow spacings, much of the increase in average diameter is due to the mortality of small trees. At wider spacings, with less mortality, most of the change is due to actual growth. In addition, the early diameter advantage of trees planted at wider spacings provides a larger base for radial increment.

15.2.3 Mortality

Mortality in plantations occurs in two phases: that related to establishment and that due to intertree competition. Establishment-related mortality is a function of seedling quality, planting practice, intensity of site preparation, and weather conditions, not number of trees planted. Planting more seedlings to compensate for poor handling, planting practice, or site preparation typically results in stands of overstocked clumps and understocked openings, not the desired number of well-distributed trees.

Early in stand development, before the onset of intertree competition, mortality is largely unaffected by initial tree spacing. As competition between trees intensifies, trees begin to die, and at a much faster rate at close spacings (Fig. 15.3). After a period of precipitous mortality, the number of dominant trees at all spacings is close to the same. Ultimately, when most of the intermediate and suppressed trees die, the number of trees per hectare at all spacings approaches the same level. For example, by age 40 on the Hill Farm [16] and the Hofmann Forest [unpubl. data, 7] spacing studies, the difference in number of surviving trees between 1.8 x 1.8 and 2.4 x 2.4 m spacing was less than 30 trees/ha.

15.2.4 Basal-Area

Basal area is a product of quadratic mean dbh and survival. Before trees begin competing and when diameter is largely unaffected by spacing, basal-area is proportional to number of trees per hectare. Trees spaced close together have more rapid basal-area growth at these early ages (Fig. 15.4). Once competition begins, diameter growth is retarded at close spacings, slowing basal-area growth. Once competition becomes severe enough to cause mortality, basal-area growth is further reduced, and ultimately total basal-area declines. Basal area culminates earliest and at higher levels at close spacings. (see Fig. 15.4).

15.2.5 Volume

Before the onset of competition — when diameter growth

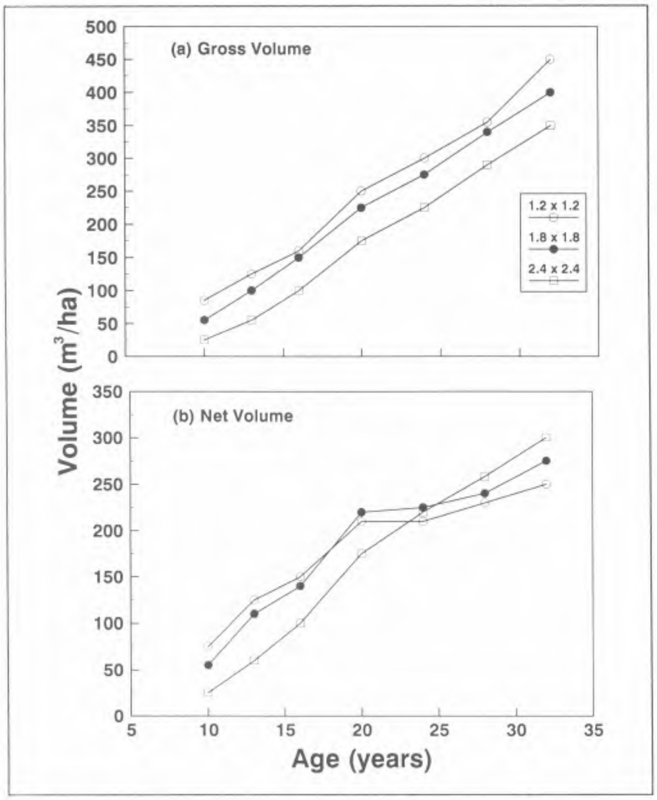

Figure 15.5. Relationship between planting spacing and (a) gross and (b) net volume over time for loblolly pine.

is fastest, when basal-area growth is proportional to the number of trees per hectare, and when height growth is not yet inhibited — trees initially planted at narrower spacings produce greater gross volume. However, after that period, gross volume production is independent of initial spacing. Net volume, unlike gross volume, is not independent of initial spacing. Mortality occurs earlier at successively narrower spacings, decreasing net volume growth. This pattern of mortality leads to the crossing of net volume curves at successively earlier ages as initial spacing is decreased. (Figs. 15.5a, b) [unpubl. data, 7]. In the example presented, the spacing with the maximum net volume changes with age. On the basis of net volume, the best spacing is 1.2 x 1.2 m before age 16, 1.8 x 1.8 m at ages 20 to 24, and 2.4 x 2.4 m at ages 28 and older.

15.2.6 Species

The choice of which species to regenerate with also influences the initial number of trees to plant. The main characteristics that differentiate the species are relative shade tolerance (Table 15.2), growth pattern, and product limitations.

Slash is the most shade tolerant of the southern pines, and the weakest in expression of dominance, as demonstrated (see Fig. 15.4b) in the study by Jones [8]. Basal area per hectare increases directly with initial number

Table 15.2. Characteristics differentiating the southern pines (from [15]).

Pine species	Shade Tolerance	Expression of dominance
White[1]	Intermediate	Pronounced
Slash	Intermediate	Slow
Sand	Intolerant	Very little
Virginia	Intolerant	Slow
Shortleaf	Intolerant	Slow
Loblolly	Intolerant	Early and rapid
Longleaf[1]	Very intolerant	Early

[1] White pine, *Pinus strobus* L.; longleaf pine, *Pinus palustris* Mill.

of trees per hectare, culminating at age 25 at all initial spacings. In contrast, loblolly is shade intolerant and most rapid and strongest in expression of dominance (see Fig. 15.4a). As a result, the relationship between basal-area and initial number of trees per hectare changes rapidly with time. By age 20 to 25 with spacings of 3.0 x 3.0 m and narrower, there is no association between basal-area and initial number of trees per hectare in loblolly pine. In general, closer initial spacings reach maximum basal-area and volume earlier and at a slightly greater level, but at older ages fall below the basal-area of wider spacings.

The other species of similar shade tolerance (shortleaf, sand, and Virginia) exhibit less pronounced expression of

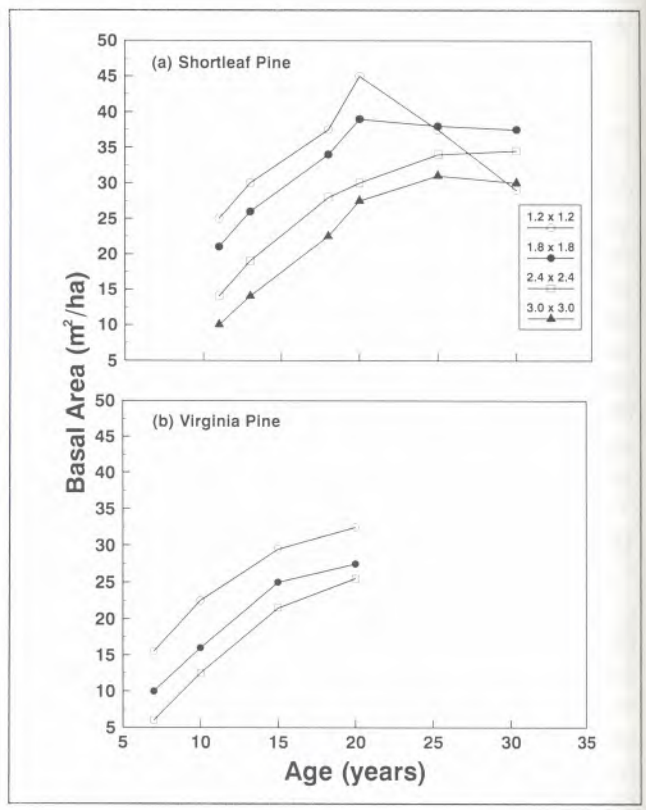

Figure 15.6. Relationship between planting spacing and stand basal area over time for (a) shortleaf and (b) Virginia pine.

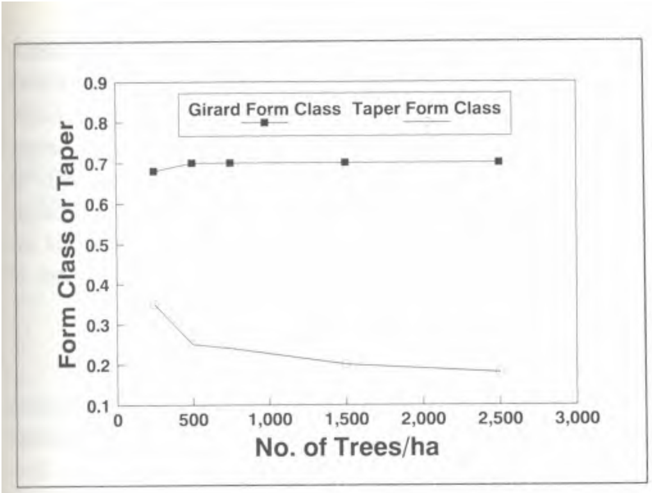

Figure 15.7. Relationship between stocking and Girard form class and stem taper for loblolly pine.

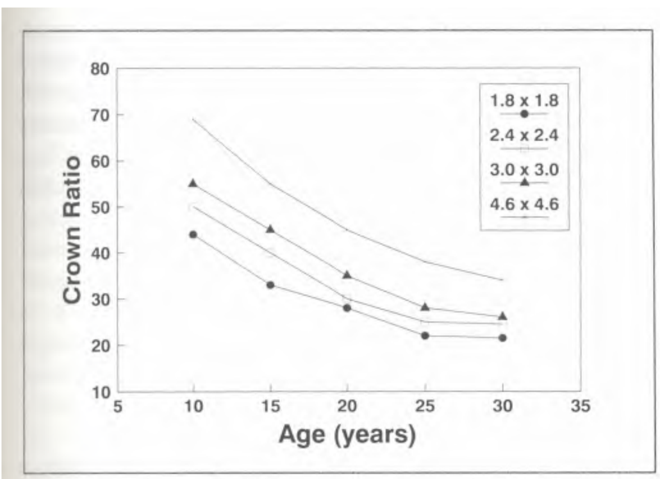

Figure 15.8. Relationship between planting spacing and crown ratio over time for slash pine.

dominance. As a result, the pattern seen for loblolly (earlier culmination of basal-area and volume at closer initial spacings) develops more slowly in these species. For example, Arnold [1] found that basal-area of shortleaf pine planted at a 1.2 x 1.2 m spacing declined below that at all other spacings by age 31 (Fig. 15.6a).

15.3 Mensurational Relationships

15.3.1 Tree Form

The choice of initial planting spacing has a larger impact on tree diameter than on height. Wider spacings produce trees with larger diameters but with heights similar to those of trees planted at narrow spacings. Such growth results in more absolute taper (change in diameter per change in length) in trees from wider spacings. When tree taper is measured relative to tree diameter, as in the case of Girard form class, it is similar in wide and narrow spacings

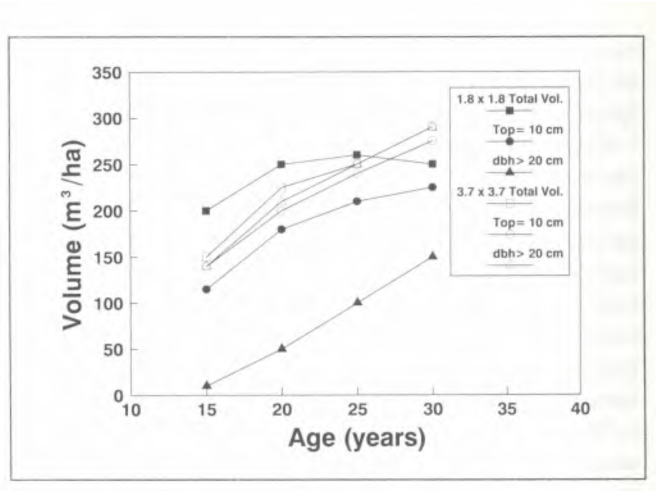

Figure 15.9. Relationship between planting spacing and merchantable volume over time for loblolly pine.

because taper is roughly proportional to dbh. These concepts are illustrated in Figure 15.7 for the Mutual Competition Study at the Hill Farm [16]. Although trees in this study were planted at a constant spacing, they were thinned early enough to simulate variable spacing.

Tree form is influenced by the development of the tree crown. Cross-sectional area growth is proportional to the volume of tree crown above it. This means that the tree produces a strongly tapered sheath of wood in the live crown and a relatively constant sheath of wood below the crown. Wider spacings maintain a long crown, resulting in a strongly tapered stem, whereas narrow spacings cause the crown to recede quickly, resulting in less taper. Figure 15.8 shows the relationship between spacing and crown ratio in slash pine [8].

15.3.2 Merchantability Limits

Merchantability limits reduce total recoverable volume when trees are grown at narrow spacings more than at wide spacings. Since narrow spacings produce smaller trees, imposing a top-diameter limit results in a proportionately greater reduction in volume of the small trees from the narrow spacings, as illustrated in Figure 15.9 for loblolly pine.

When only trees meeting a dbh limit are considered, even larger penalties are applied to those planted at narrow spacings. Trees at narrow spacings require more time to reach the dbh limit than do those at wide spacings; thus, merchantable volume is greater on wider spacings at all ages (Fig. 15.9).

15.3.3 Weight

Tree weight is strongly influenced by specific gravity. Wood of low specific gravity has low dry weight. Megraw [11] demonstrates that, below the live crown, specific gravity is strongly affected by ring age but is not affected by stocking level. This indicates that initial spacing will have little effect on specific gravity because the proportion of earlywood and latewood is constant across initial spacings in this area of the bole.

Larsen [9] suggests that juvenile wood is produced in the tree crown and that mature wood is only produced below the crown. As was illustrated in Figure 15.8, wider spacings produce trees that maintain longer live crowns than do narrow spacings, resulting in production of juvenile wood over a greater portion of the tree bole. Juvenile wood has a lower specific gravity than does mature wood, so trees grown at wider spacings will have lower dry weight than trees grown at narrow spacings.

Wood with low specific gravity contains more space for water than that with high specific gravity. When water fills this additional space, wet weight of the former approaches that of the latter. For this reason, wet weight per cubic meter will not vary greatly across spacings. Wet weight per hectare is closely related to volume per hectare since specific gravity is constant across spacings. Spacings that produce more volume will produce more wet weight. (The relationship between spacing and volume per hectare has been discussed in 15.2.5.)

15.4 Influence on Tree Quality

15.4.1 Knots

Knot size is strongly influenced by initial spacing. Wide initial spacing allows branches to live longer and grow larger, producing larger diameter knots. This effect has not been documented for southern pines, but is discussed for 22-year-old jack pine *(Pinus banksiana* Lamb.) by Godman and Cooley [6], who found that average branch size was 0.5 0.5 cm larger at 2.7 x 2.7 m spacings than at 1.5 x 1.5 m spacings. In addition, the largest branch on the largest trees on each plot averaged 1.3 cm larger at the widest spacings. The largest live branch averaged 2 cm larger on the widest spacing. Similar trends likely exist in southern pines, suggesting that pruning may be required if wide initial spacing regimes are to be considered for producing quality sawtimber.

15.4.2 Sweep

The propensity for the main tree stem to sweep is primarily a genetic characteristic and is generally not directly affected by initial spacing. However, initial spacings with many trees per hectare provide greater opportunity for selecting straight residual trees when thinning.

In planted stands, sweep often results from poor planting technique, damage from ice, tip moth *(Rhyacionia frustrana* Comstock), or wind, and irregular spacing. Placing roots improperly in the planting hole (J-rooting) inhibits the development of the supporting root system, often resulting in seedlings that lean; planting at a severe angle will cause sweep due to the geotropic response of the tree to lean. Ice can bend trees, which are often slow to straighten, producing permanent sweep. When the leader is killed by the tip moth or broken by ice or wind, a branch assumes apical dominance and a crooked tree results. Irregular spacing creates asymmetric crowns with larger, heavier, more numerous limbs on open sides than on crowded sides; this unequal distribution of weight causes sweep. Sweep and crook reduce lumber yields, and the compression wood associated with the development of sweep has many undesirable wood properties.

15.4.3 Selection Opportunities

Precommercial and commercial thinning can be used to remove poorer quality trees. Although very wide spacings provide little selection opportunity for removing low-quality trees, narrow spacings, with many more trees per unit area, allow trees containing defects such as forks, broken tops, fusiform rust *[Cronartium guercuum* (Berk.) *fusiforme],* sweep, and heavy limbs to be eliminated from the stand. However, the degree to which selection opportunity can be realized is limited by the thinning method used. In a simulation study, Watson et al. [18] found that, when thinning with feller bunchers, the ability to actually remove marked trees and leave desired trees was significantly reduced when the distance between trees was less than 2.1 m and row width was less than 3.4 m.

15.5 Operational Considerations

15.5.1 Cultural Treatments

15.5.1.1 Thinning

Initial spacing has a substantial impact on thinning - primarily on the volume and value of products, the harvesting cost, and ultimately the age at which initial thinning can take place.

The obvious advantage of a greater initial number of trees per hectare is that larger volumes are accumulated at earlier ages. For example, at ages 16 and 20 on the Hofmann study [unpubl. data, 7] volume of trees at the 1.8 x 1.8 m spacing was 146 and 218 m ^{3}/ha, respectively; that at the 2.4x 2.4m spacing was 101 and 177 m ^{3}/ha. If trees growing at both spacings were thinned to the same residual density, the 1.8 x 1.8 would yield an additional 41 m ^{3}. Assuming a delivered price of \$20/m ^{3} the 18 x 18 spacing would yield an additional \$820. However, tree diameter influences logging costs (Table 15.3). The average diameters of trees at age 20 were 16 cm for the 1.8 x 1.8 spacing and 18 cm for the 2.4 x 2.4 spacing. Assuming a d/D (diameter removed/diameter before thinning) ratio of 0.95, the average diameter of trees removed would be 15 and 17 cm for the 1.8 x 1.8 and 2.4 x 2.4 spacings, respectively. Net stumpage value would be \$3/m ^{3} for the 1.8 x 1.8 and \$7 for the 2.4 x 2.4. If trees at both spacings were thinned to 18 m ^{2} (about 84 m ^{3}/ha), the dollar yields would be \$402/ha for the 1.8 x 1.8 and \$651/ha for the 2.4 x 2.4. Although the volume yield for the narrow spacing

Table 15.3 Logging cost in dollars per cord and dollars per cubic meter as a function of dbh (from [4]).

dbh, cm	Logging-cost $/cord	Logging-cost $/m^3
13	56	26
15	37	17
18	28	13
20	23	11
23	21	10
25	20	10
28	20	9
30	19	9

would be 44% greater, the dollar yield would be 38% less. Thus, a simplistic decision based solely on volume production would impose a substantial economic penalty.

The residual stand would be different for each spacing. The 1.8 x 1.8 spacing would have 697 trees/ha with an average diameter of 18 cm. The 2.4 x 2.4 spacing would have 581 trees/ha with an average diameter of 20 cm. Because 605 more trees would be removed from the 1.8 x 1.8 than the 2.4 x 2.4 spacing, opportunity for selecting higher quality residual trees would be greater on the narrower spacing. However, the narrower spacing is more difficult to thin without damaging the residual stand; thus, the advantage of more trees per unit area may not be realized because of operational limitations (see 15.4.3).

As discussed above, logging costs decrease with tree size-favoring wider spacings. This concept can also be used to plan thinnings. Precommercial thinnings, or thinnings that result in a net loss, represent a cost that must be compounded and subtracted from later revenues. Insuring that all thinnings break even or return a profit helps insure the financial success of a plantation. Initial spacing should be wide enough that the stand does not stagnate before the first thinning and that tree size is large enough to at least break even on the first thinning. Thinning levels should be planned to insure the profitability of subsequent thinnings and final harvest.

15.5.1.2 Weed control

When trees are initially planted at wider spacings, hardwood encroachment must be controlled (see chapters 13 and 19, this volume). At narrow spacings crowns close early and subsequently shade out competing hardwoods. Wide initial spacings, however, provide a long period of time before crowns close during which competing hardwoods may become established. Planting at wide spacings may require the application of selective herbicides or mechanical methods to control competition before crown closure.

15.5.1.3 Fertilization

Fertilization accelerates the development of plantations (see chapter 14), and initial spacing influences its time of application. If the plantation is approaching the stand density at which competition-related mortality is imminent, fertilizing may accelerate croptree mortality. Stands planted at narrow spacings become crowded more quickly than those planted at wider spacings. For this reason, fertilizer should be applied at an earlier age. In addition, as described in 15.5.1.2, wide spacings provide a longer time period for development of competing species before crown closure. If competitors are not controlled, application of fertilizer may enhance their growth as well as that of the planted pine. Full benefit from fertilizer by pines is not likely until crown closure.

15.5.1.4 Tree improvement

Planting genetically improved stock, like fertilization, may accelerate the growth of pine plantations (see chapter 11, this volume). The faster growth of improved seedlings results in earlier crown closure and shading of competing vegetation. In addition, planting families with small branches may offset the effect of larger knots associated with wider spacings. For this reason, wide spacings may be more appropriate for genetically improved seedlings. Furthermore, growing fewer trees per hectare allows planting the best families on more hectares.

Planting fewer genetically improved trees may result in better tree quality at rotation age than can be achieved by planting unimproved stock at narrow spacings and then precommercially and commercially thinning. However, tree improvement does not insure against poor quality due to damage from ice, fusiform rust, and tip moth.

15.5.2 Establishment Costs

Certain site-preparation operations can be affected by the selected planting spacing (see chapter 13, this volume). Ripping soils in rocky areas and bedding in wet areas must be done in accord with the planned spacing. Distance between subsoil rips and beds must correspond with between-row spacing. Narrowly spaced rips or beds increase site-preparation costs.

Closer initial spacings result in higher planting costs. The cost of seedlings and of planting those seedlings increases as the number of trees planted increases — although this cost is relatively small compared to potential costs and revenues accruing from planting trees at the wrong spacing.

Straka and Watson [17] give the cost of planting seedlings by hand or machine as approximately 5.5 cents/seedling (1984 dollars). The average cost of seedlings is about $25/1,000, bringing the total cost of one seedling to 8 cents. This can be used as a guide to the added expense of planting closer spacings.

15.5.3 Logging and Hauling Costs

Logging costs decrease with larger tree size. This tends to favor wider spacings up to the point that the volume loss per hectare due to wider spacing results in a penalty greater than the reward from harvesting larger trees.

Hauling costs are related to the amount of weight a truck can carry. With small material the amount of solid wood per stacked volume is often so low that volume, rather than weight, limits the amount that can be transported in a single load. The amount of fiber transported is related to weight, and many mills in the South buy timber by weight; hence, it is profitable to transport as much weight as possible. Larger material results in reaching the weight limit of a truck. This situation also favors larger tree sizes associated with wider spacings.

15.6 Other Considerations

15.6.1 Wetland Sites

On poorly drained wetland sites, planting at wider initial spacings produces lower levels of transpiration. The resultant higher water table inhibits tree growth at young ages — an effect ameliorated with time as crown closure restores normal transpiration and height growth is no longer inhibited. In contrast, on upland sites, at young ages trees have sufficient moisture at all spacings, but as they grow larger competition for moisture becomes more limiting at narrower spacings. As a result, height growth is reduced. This is illustrated in Figure 15.10 with spacing-study data from a wetland site [unpubl. data, 7] and an upland site [3]. At age 10 on the wetland site the dominant height of trees at the narrow spacing was 1.5 m greater than that of tress at the wide spacing. By age 20 and thereafter, the dominant height was nearly equal. On the upland site, there was little difference in dominant height between the two spacings at age 15, but by age 30 the trees at the wide spacing were 1.3 m taller.

15.6.2 Insects and Diseases

Susceptibility to many insects and diseases is related to stand vigor. Fast growing, open stands are less susceptible than crowded, stagnated stands. In addition, spot growth after southern pine beetle *(Dendroctonus frontalis* Zimm.) attacks is directly related to distance between trees. Initial spacing, thinnings, and final harvests should be planned to avoid crowded conditions.

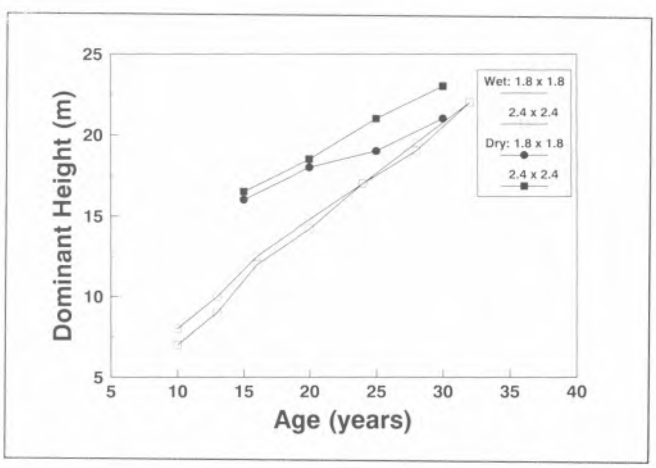

Figure 15.10. Relationship between planting spacing and dominant height on wetland and dry upland sites.

15.6.3 Legal Requirements

Some states require a minimum number of surviving trees per hectare after one growing season to meet the requirements for landowner assistance. To qualify, landowners must plan initial spacing to meet such requirements and include reasonable allowance for initial mortality.

15.7 Conclusions and Recommendations

The decision on "how many trees to plant" is a function of several factors: species, establishment cost, plantation health, and product objective. Expected survival is often considered.

Except where related to product objective, species has little impact on the decision. The major differences between southern pine species occur when stands become crowded, and sound management regimens avoid such situations.

Establishment cost has two components: site preparation and planting. Site-preparation costs are affected only if planting sites are ripped or bedded. As row spacing narrows, ripping or bedding costs increase. Planting costs are generally less than 10 cents/tree. Moreover, the increase in establishment cost is usually small compared to other future costs and returns.

The potential health of the plantation is an important factor in determining planting density. Plantations are susceptible to infestation from insects and disease when they become crowded. Most infestations can be prevented by maintaining vigorous trees through stocking control. Either wide initial planting spacing or intermediate thinning should be used to insure that good growth and stand vigor are maintained over the life of the plantation.

The desired final product should determine planting spacing. If pulpwood grown on a short rotation is desired, close spacing will insure high volume per hectare. Such a management regime results in small tree size and associated higher logging costs.

If sawtimber-sized material grown on a relatively short rotation (with no intermediate thinnings) is desired, wider spacings should be used. Such a management regime results in large tree size and lower associated logging costs. Disadvantages of such a regime include a long period before crown closure when competing species may flourish, larger knot size of lumber produced from trees grown under relatively open conditions, and limited opportunity to remove poorer quality trees through intermediate thinnings.

If a mixture of pulpwood from thinnings and sawtimber from final harvest is desired, closer spacings may be warranted. The poorer quality trees could be removed via intermediate thinnings for use as pulpwood where quality is of little importance and the higher quality trees reserved for final harvest as sawtimber. The viability of such a regime depends on the existence of a pulpwood market close to the plantation, because low product value prohibits long haul distance.

Flexible planting spacings, in the 2.4 x 2.4 to 3.0 x 3.0 m range, provide 1,000 to 1,600 trees/ha if initial survival is good. Such stocking levels are low enough to produce good tree size and volume per hectare with rotations of 20 to 30 years on good sites without thinning, but are high enough to allow one or two thinnings if market conditions so warrant. This spacing range also has the advantage of allowing access by small- to medium-sized equipment for cultural operations such as weed control, fertilization, and thinning.

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