Silvicultural Basis for Thinning Southern Pines: Concepts and Expected Responses

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By
Timothy B. Harrington[1]

Cover Photograph - A 13-year-old plantation of loblolly pine near Athens, Georgia that was thinned to a basal area of 80 ft² per acre (top photograph) and the same stand after five years of complete weed control and annual fertilization with nitrogen (bottom photograph). In the fourth year after thinning, cumulative volume growth (standing trees plus those removed in thinning and mortality) of this stand has exceeded that of a nearby unthinned stand, indicating that total productivity has been increased with intensive silviculture.

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Introduction

Thinning is a silvicultural treatment that reallocates stand growth throughout an evenly spaced population of crop trees. These crop trees can be identified by their dominant or co-dominant position in the stand, superior form and vigor, and lower incidence of disease or injury. If done properly, thinning can increase stand value in two ways: 1) by merchandizing trees that would otherwise die and decay, and 2) by focusing volume production on the trees that are most likely to increase in value.

Thinning can be used to accomplish a variety of landowner objectives, such as maximizing the net present value of a stand, providing periodic cash flows throughout the rotation, and improving health, wildlife habitat, and aesthetics of forest stands. However, generally thinning cannot be used to increase per-acre production of pulpwood, because a given site has a finite productivity that limits the final yield a forest stand can achieve.

This report presents an overview of the silvicultural basis for thinning stands of loblolly (*Pinus taeda*), slash (*P. elliottii*), shortleaf (*P. echinata*), and longleaf pine (*P. palustris*). The discussion is divided into two parts: 1) concepts of stand development relevant to thinning, and 2) thinning responses of individual trees and stands. For information on application of thinning, please refer to the companion report entitled, *Silvicultural Approaches for Thinning Southern Pines: Method, Intensity, and Timing* (8).

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Concepts of Stand Development Relevant to Thinning

Four stages of forest stand development occur following a regenerative disturbance, such as a crown fire or a clearcut harvest: stand initiation, stem exclusion, understory re-initiation, and old growth (10). The stand initiation stage, which occurs prior to complete occupancy of growing space, is characterized as a period of free growth in which all trees grow at approximately the same rate, regardless of stand density. Early in this stage, competition is perceived by pine seedlings as equivalent among species of woody and herbaceous vegetation because of similarities in their height and rooting depth. Later, other pines, hardwood sprouts, and tall shrubs are the chief competitors with a pine sapling, and light becomes a growth-limiting resource.

At crown closure, the stem exclusion stage begins, and pine becomes its own worst enemy as the effects of inter-tree competition begin to dominate. Tree shape changes during this stage of stand development. With increasing intensity of competition, diameter growth declines before height growth, because cambial growth is believed to have a lower priority for photosynthate than shoot growth (14). Ultimately, inter-tree competition will cause a tree to become top heavy and unstable, as indicated when the ratio of its height to stem diameter exceeds 100 (with both variables expressed in the same units) (Figure 1).

Figure 1 - A 21-year-old natural stand of loblolly pine located near Eatonton, Georgia. This stand developed from seed of adjacent stands following abandonment of farmland. Because of the excessively high density at which it developed, stem diameter growth suffered while height growth was maintained at a relatively normal rate. As a result, the average ratio of height to stem diameter exceeds 100, making the trees top heavy and extremely susceptible to damage from wind or ice storms. In addition, the crown ratio (ratio of crown length to total height) of most trees in this stand is less than 30%, indicating depressed vigor and low potential responsiveness to thinning.

Under prolonged and severe competition, smaller trees become suppressed and eventually die. The probability of mortality is related to a tree's carbohydrate balance, which is proportional to the ratio of its leaf area to weight of respiring tissue. An easily measured index of a tree's carbohydrate balance is crown ratio, because it indicates the proportion of a tree's stem (i.e., much of its respiring tissue) covered in leaves (i.e., photosynthetic tissue) (Figure 2).

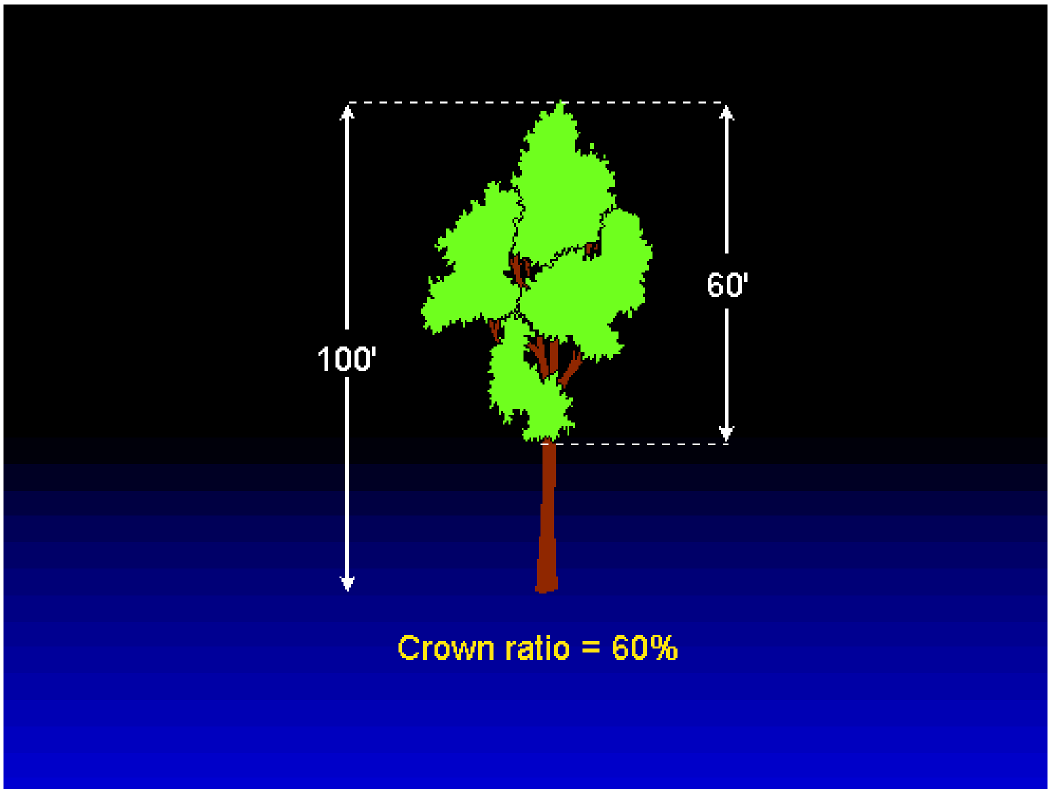

Figure 2 - Crown ratio, or crown length expressed as a percentage of total height, is a good index of a tree's carbohydrate balance. To provide an objective, reproducible measurement of crown height (height to base of live crown), it is best to sight at the point at which the lowest branch of continuous live crown intersects the stem of the tree.

Ideally, a visual estimate of foliage density should be multiplied by crown ratio to provide the best index of a tree's carbohydrate balance (2). In general, a crown ratio of 40% or greater is considered desirable for maximizing growth and vigor of southern pines (5). As an analogy, artificial pruning of loblolly pine from a crown ratio of 50% to one of 35% or less has been shown to cause substantial reductions in diameter growth, but it had little effect on height growth (12).

The death of individual trees within a stand in response to over-crowding is often referred to as self-thinning. In general, self-thinning begins earlier and proceeds at a faster rate for stands of greater initial density (13) (Figure 3). Rather than being gradual, mortality of southern pines during self-thinning is episodic, and is often precipitated by extreme weather or pest outbreaks, such as drought and associated infestations of southern pine beetle (*Dendroctonus frontalis*) (Figure 4).

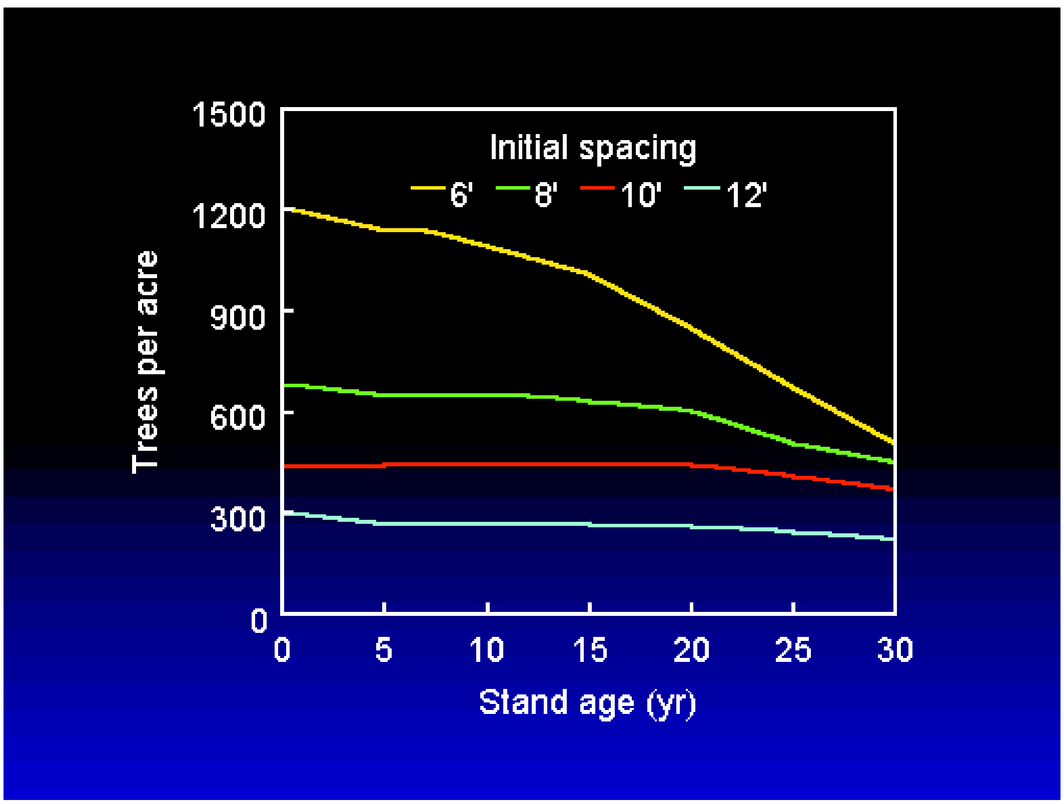

Figure 3 - Changes in stem density with time for plantations of loblolly pine established at spacings of 6', 8', 10', and 12'.[2] Self-thinning, or natural mortality of trees within a stand in response to crowding, begins earlier and proceeds at a faster rate for stands of greater initial density. Note the large differences in initiation and rates of self-thinning for a stand planted at a 6' spacing versus those of stands planted at an 8' or greater spacing.

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[2]Adapted from *Forest Regeneration Manual* edited by M. L. Duryea and P. M. Dougherty, ©1991. Reprinted by permission of Kluwer Academic Publishers.

Figure 4 - A 16-year-old plantation of loblolly pine near Juliette, Georgia that was attacked by the southern pine beetle following a lightning strike. The stand, which is part of a larger study (7), contained about 1800 pines per acre at 12 years of age as a result of dense natural regeneration following chain-saw cutting of residual hardwoods. This excessive density probably reduced tree vigor and facilitated attack by the beetles because surrounding areas of the study that were not attacked averaged 1200 pines per acre.

Differentiation of trees into crown classes (i.e., overtopped, intermediate, co-dominant, and dominant) during the stem exclusion stage allows some trees to occupy growing space at the expense of their neighbors. Lack of differentiation into crown classes results in similar growth for all trees, leading to either growth stagnation of the stand or the onset of a wave of mortality. In general, stands of either loblolly or longleaf pine are known to differentiate early in their development, and thus, avoid growth stagnation; however, overstocked stands of slash pine can be susceptible to growth stagnation (3).

During the understory re-initiation stage, voids left by mortality are filled by crown expansion of surviving trees or by new stems of understory hardwoods. For initially-dense stands of loblolly pine (over 1000 trees per acre), increment in stand biomass cannot immediately compensate for this mortality because suppressed trees in a growth-stagnant stand have only a limited capacity to expand their crowns to fill the growing space made vacant by the death of neighboring trees. As a result, growth in stand biomass slows after 20 years of relatively linear development (13)

(Figure 5). Thus, the persistence of a high density early in a stand's development can greatly restrict its future responses to thinning. In time, even stands with extreme crowding will respond to the release provided by an episode of mortality, and their stand biomass will begin to increase again (Figure 5).

For a given site quality, forest stands of various initial densities generally have rates of volume growth that converge with time, eventually resulting in similar final yields. Stands of higher initial density have the most rapid rates of volume growth at young ages, but later their growth is surpassed by stands of lower initial density, a process known as the "crossover effect" (10) (Figure 5). If a pine stand is thinned at the appropriate time, it will escape self-thinning and maintain a steady rate of growth.

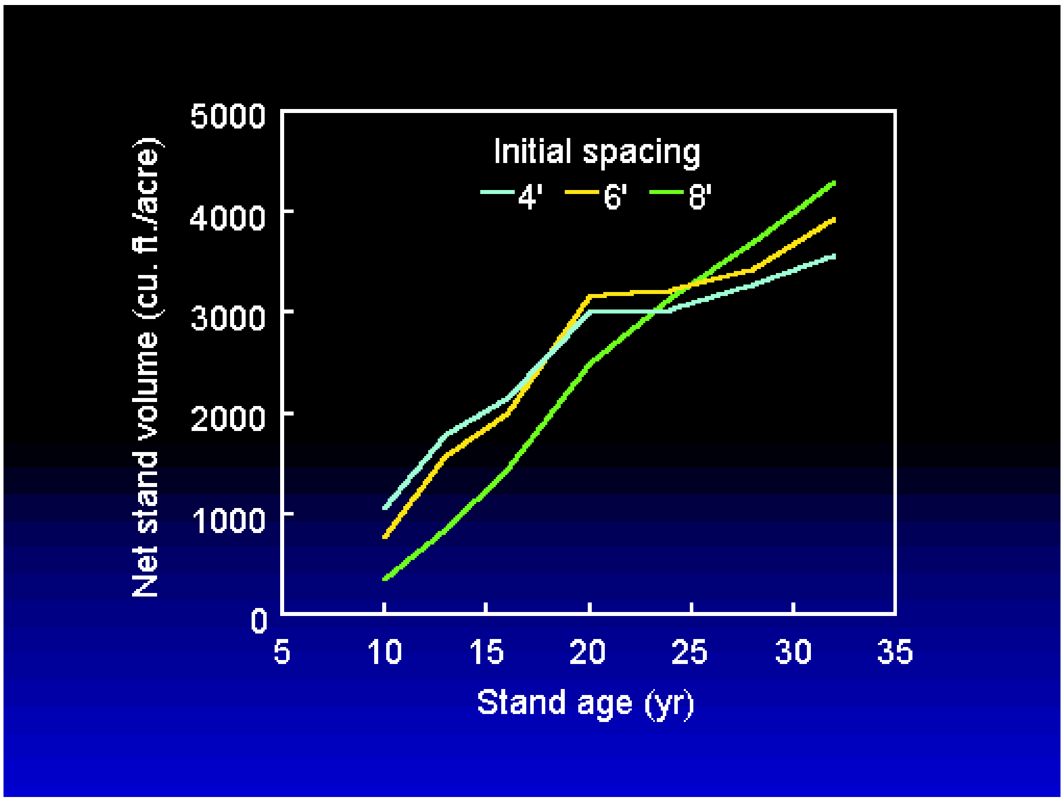

Figure 5 - Changes in net stand volume (not including mortality) with time for plantations of loblolly pine established at spacings of 4', 6', and 8'.[3] For the first 20 years of stand development, volume growth is linearly related to time. Volume accumulates most rapidly in stands established at the closest spacings (4' and 6'). Later, volume lost to self-thinning equals volume growth (the horizontal portions of the growth curves), and no volume is accumulated during this period. At 23 and 25 years of age, volume of the stand established at an 8' spacing surpasses those of stands established at 4' and 6' spacings, respectively (the crossover effect). Note that growth of the overstocked stands eventually begins to increase in response self-thinning (their growth curves begin to rise after 25 years of age).

[3] Adapted from *Forest Regeneration Manual* edited by M.L. Duryea and P.M. Dougherty, ©1991. Reprinted by permission of Kluwer Academic Publishers.

Thinning Responses of Individual Trees and Stands

Increases in individual-tree growth following thinning generally are not detected until one to two years after treatment. This is because a tree must first improve its carbohydrate balance through increases in leaf area before it can increase its volume growth. The additional growing space made available by thinning will stimulate a tree to increase its crown diameter as well as retain its lower branches, resulting in a larger crown volume and leaf area (Figure 6).

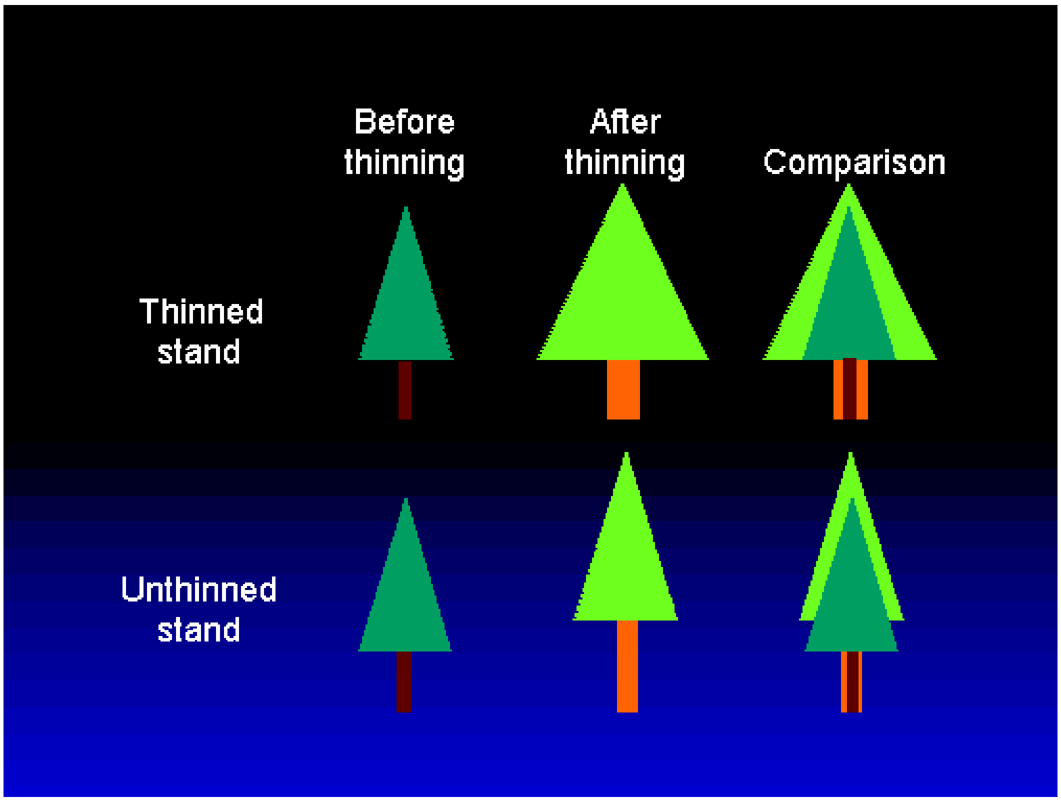

Figure 6 - Generalized comparison of changes in crown shape of southern pines that occur during the first 2 to 3 years after thinning. Three types of crown responses occur: increased growth in crown diameter, decreased growth in height (because of re-allocation of photosynthate to crown diameter), and decreased rate of shedding of lower branches. These responses in crown volume and leaf area of a tree will improve its carbohydrate balance and support sustained increases in stemwood growth.

For example, six years after thinning 8-year-old loblolly pine (average basal areas of 77 and 41 ft^2 per acre before and after thinning, respectively), crown diameter of individual trees averaged 7.4 ft. more than that in unthinned stands (11). Thinning also reduced the rate of decline in average crown ratio (-10% vs. -21% for thinned and unthinned stands, respectively) by slowing the rate at which lower branches were shed. Decreases in height growth often are observed during the first two years after thinning (9), a response that has been mislabeled as "thinning shock." However, it is now believed that these temporary reductions in height growth result when allocation of photosynthate is redirected to sustain increases in crown diameter growth (6).

Thinning responses are not limited to crown and stem growth of a tree but also can include changes in physiology associated with increased availability of light, water, and nutrients. In a six-year study (11), the lower canopy in thinned stands of loblolly pine had average rates of photosynthesis that equaled those of the upper canopy. In contrast, the lower canopy of unthinned stands had photosynthesis rates that were only about half of those of the upper canopy. Therefore, based on the foregoing discussion, individual trees can respond to thinning in two ways. First, they can increase their leaf area through expansion of crown diameter and length, often at the expense of height growth (Figure 6). Second, increased availability of light, water, and nutrients following thinning may support similar rates of photosynthesis for foliage throughout the entire length of the crown. Note, however, that these physiological responses are relatively short-lived (6 years or less) and eventually return to pre-treatment levels following crown closure (11).

The following generalizations are based on a review of research pertaining to the effects of thinning on mortality, growth, and yield of loblolly and slash pines (4).

<u>Mortality</u> of trees tends to be lower in thinned stands than in unthinned stands, but the magnitude of this response will depend on the method of thinning. Selective thinning (removal of the smaller and poorer trees) reduces mortality more than row thinning (removal of entire rows of trees) because selective thinning removes overtopped and diseased trees likely to die soon anyway.

<u>Average stem diameter</u> (usually expressed as the diameter of the tree of mean basal area) of thinned stands is greater than that of unthinned stands. Diameter growth also increases inversely with stand density, but this increase declines as the stand reoccupies vacant space. The percentage of trees in a stand that exceeds a threshold size, such as a minimum diameter for sawlogs (8" for chip-n-saw and 12" for sawtimber), is greater in thinned stands than in unthinned stands. This feature of thinned stands can result in substantial increases in economic value. For example, the current price of a cord (i.e., a stack of wood 4' x 4' x 8' in dimension) of chip-n-saw material in Georgia is over four times that of pulpwood. Average-diameter responses are usually more pronounced and prolonged when the first thinning occurs early in stand development (e.g., 10 to 15 years after planting) and when thinning intensity (proportion of the stand removed) is relatively high.

Dominant height is affected very little by thinning, except for short-term reductions in growth that result from reallocation of carbohydrates to crown width growth (discussed previously). This is because height growth is relatively insensitive to changes in stand density, except at extremely low or high densities, because it has a high priority for allocation of photosynthate (14).

Stand volume of thinned stands is often less than that of unthinned stands; however, merchantable volume, especially sawtimber, can be greater. For example, 12 years after thinning loblolly pine to remove approximately half of the basal area, gross volume (standing trees plus removals from thinning and mortality) was about 200 ft^3 per acre less than that of unthinned stands (1) (Figure 7).

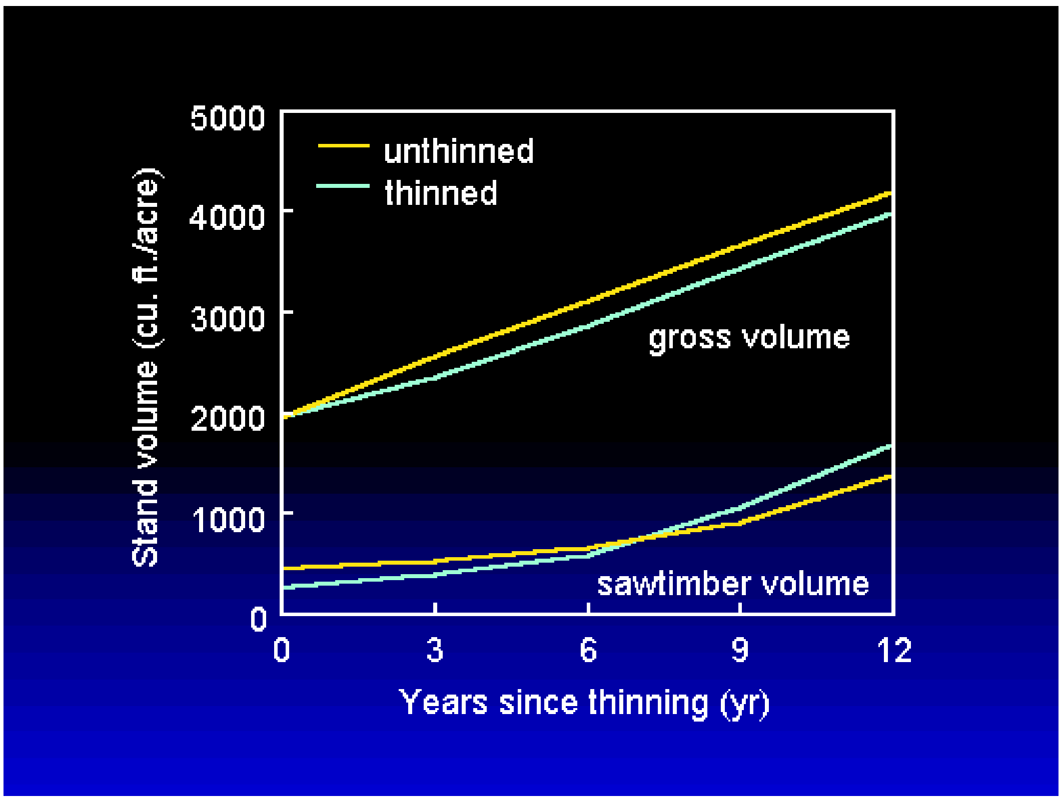

Figure 7 - Changes in gross stand volume (standing trees plus those removed in thinning and mortality) and sawtimber volume (trees 10" in diameter and greater to a 6" top) during 12 years after thinning 8- to 25-year-old plantations of loblolly pine in the Coastal Plain and Piedmont.[4] At 12 years after study establishment, gross volume of unthinned stands exceeded that of thinned stands by about 200 $ft.^3$ per acre, a result of the brief period of understocking that occurred immediately after thinning. In contrast, sawtimber volume of thinned stands exceeded that of unthinned stands by about 300 $ft.^3$ per acre, a result of the reallocation of stand growth to the larger and more valuable trees.

[4] Adapted from *Growth and Yield of Thinned and Unthinned Plantations* by R.L. Amateis, P.J. Radtke, and H.E. Burkhart, *Journal of Forestry*, ©1996. Reprinted by permission of Society of American Foresters.

However, volume of sawtimber (10" diameter and greater) in thinned plots exceeded that of unthinned plots by about 300 ft^3 per acre. Although the total volume of a thinned stand may eventually exceed that of an unthinned stand, such a yield may not be achieved for several decades.

Growth responses are greater for selective versus row thinning methods because row thinning removes a fixed proportion of the best trees in the stand. In addition, thinning with excessive frequency and intensity may prevent stands from achieving high volumes. Because tree size is an integration of its competitive status throughout stand development, trees that are released during thinning approach, but do not reach, the size of those that were planted at the same density as the thinned stand (10).

In general, the greatest growth responses occur when thinning is done at relatively young stand ages (i.e., 10 to 15 years). During this time, the crowns of individual trees are relatively large (crown ratios $\geq$ 40%), vigorous, and able to respond with increased shoot growth. Stands that are slow to reoccupy growing space after thinning include those that are growing on poor sites, are older than 30 years, were thinned to an excessively wide spacing, or have small crowns and a mean height-to-stem diameter (H:D) ratio exceeding 100. In addition, thinning a stand that has a high H:D ratio will make the residual trees particularly susceptible to uprooting and breakage from wind and ice because of the top-heaviness of their crowns and the inadequate support and strength provided by their small, non-tapering stems.

Our understanding of thinning responses is still far from complete. Information from a field demonstration at Whitehall Forest, University of Georgia, Athens, suggests that when thinning is combined with repeated applications of weed control and fertilization, stand volume production will exceed pre-thinning levels within four years (Figure 8). These results indicate that a potential opportunity may exist for landowners to invest some of their thinning revenues into stand treatments that both accelerate sawtimber production and maintain total stand production at rates equal or greater than that of unthinned stands.

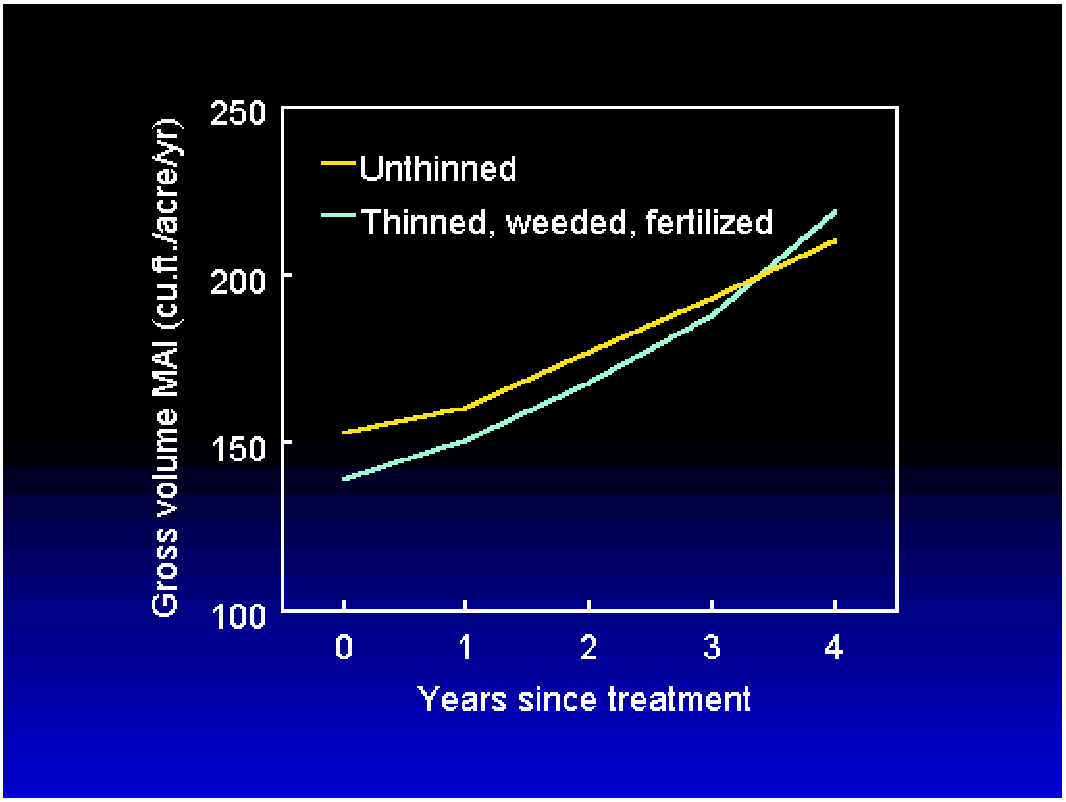

Figure 8 - Mean annual increment (MAI, or average annual growth) in gross volume (standing trees plus those removed in thinning and mortality) of two demonstration stands of loblolly pine near Athens, Georgia as they developed from age 13 to 17 years (see photographs on cover). During the fourth year after treatment, average growth of the intensively managed stand began to exceed that of the unthinned stand, despite the fact that it started at an initially lower value. This demonstration suggests that a combination of thinning, fertilization, and weed control will both accelerate sawtimber production and maintain total stand production at rates equal or greater than that of unthinned stands.

Summary

Thinning can be used to accomplish a variety of stand management objectives, including accelerated production of sawtimber, improved cash flows, and enhanced forest health, aesthetics, and wildlife habitat. An understanding of stand dynamics relevant to density management can be useful for predicting responses to thinning, as well as for selecting the appropriate timing and intensity of thinnings.

High stand densities cause mortality to occur at an earlier age and at a faster rate than low stand densities. Average stem diameter declines consistently with increasing density, but dominant height is influenced very little by stand density except at extremely low or high densities. Stand volume accumulates faster with increasing stand density; however, later in stand development, volume of a moderately dense stand will equal and often exceed that of a high-density stand (the crossover effect). These stand dynamics are the basis for applying thinning at the appropriate timing and intensity (8).

Southern pines are most responsive to thinning at young ages (10 to 15 years), when the trees are able to rapidly increase their crown size to fill vacant growing space. Also, if the first thinning occurs at an advanced age (20+ years), the potential yield for a given crop-tree density probably will not be achieved because of earlier losses due to growth stagnation and mortality. Thinning is most effective at accelerating production of sawtimber when it is done at a relatively high intensity to young stands soon after crown closure, when crowns are large and vigorous.

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