A Survey of Thinning and Pruning Studies

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"Once a plantation has been established its welfare is chiefly determined by the skill with which it is thinned."
"The object of pruning is to secure clear timber."

W. E. HILEY.

THE theory and practice of thinning and pruning, which may be regarded as complementary sciences, constitute one of the most important phases of silviculture. When, as is the case in Ireland at present, they have become the major silvicultural operations, a knowledge of the behaviour of stands to different treatments should prove of value. It is with this thought in mind that a survey of the results of experiments carried out in other countries is presented, for even though growth conditions may be entirely different the same basic problems exist.

Thinning and pruning experiments are usually carried out separately, one of the main reasons being the avoidance of interactions. It is proposed to deal with pruning studies first as they are the least complicated.

In South Africa a large number of pruning experiments were initiated in the Transvaal and Natal in 1936 to test the effect of live-pruning on increment. The results of the investigations were analysed by Luckhoff and may be summarized as follows :

"(a) The retardation of diameter increment due to the pruning was considerably greater than the retardation of height increment.

(b) The removal of 25% of vigorous crown had no statistically significant effect on either diameter or height growth.

(c) The removal of 50% of vigorous crown had a significant effect upon subsequent diameter increment but not upon height increment.

(d) The removal of 75% vigorous crown had a significant effect upon both diameter and height increment.

(e) The recovery of normal increment was rapid and was usually regained by the fourth year after pruning, even in the case of the severest pruning.

(f) The loss in volume due to the pruning tended to be permanent, particularly in the case of the heaviest pruning and would probably never be regained."

In addition Luckhoff found that "where all the trees were live-pruned, the effect of the pruning was less severe and less lasting than where a selected number were pruned." He found also that older stands were less affected by pruning than the younger ones; that trees on poor sites were better able to withstand pruning than those on favourable sites and that the removal of 50 and 75% of crown improved the form (in Craib 1947).

These investigations were carried out in South Africa on *Pinus patula, P. taeda* and *P. caribaea.*

In the United States Bennett (1955) records an experiment on *Pinus Elliotii* where 35%, 50%, 65% and 80% of live crown was removed in two plantations one 5 years old, 15 ft. high, 3.9 in. diameter and spacing 10 ft. × 10 ft., and the other 11 years old 30 ft. high, 7.6 in. diameter and spacing 15 ft. × 15 ft. He uses the term "crown ratio" instead of "percentage live crown removed" to indicate the depth of crown in relation to the height of the tree. We may summarize his findings as follows:

"(1) Pruning up to 80% of the live crown has little or no effect on height growth.

(2) In the 5 years old plantation, with an average crown ratio of 89%, removal of 50% or more of the live crown resulted in a significant reduction in diameter growth.

(3) In the 11 years old plantation with an average crown ratio of 72%, removal of 35% or more of the live crown resulted in a significant reduction in diameter growth.

(4) Diameter growth increases rapidly with an increase from 10 to 50% crown ratio, but beyond 50% the increase is very gradual."

It is mentioned that this last observation agrees with findings by Bull, Henry in longleaf pine in 1943.

Bennett referring to the lay-out of his experiment on *P. Elliotii* says that treatment was replicated in five blocks of five randomised plots each. This can be interpreted as either a randomised block or a latin square depending on whether the treatments occurred more than once in the rows and columns.

Jacobs (1938) commenting on the use of replicated latin squares says: "In plantations where stocking is regular and serious site changes do not take place at short intervals, pruning experiments lend themselves quite well to a latin square treatment. The latin square treatment may be applied either to testing of the efficiency of the pruned tree in relation to unpruned neighbours, or to the testing of its efficiency in utilizing the factors of the locality to the full. The latin square is generally used for the latter purpose. The randomized individual tree method is considered sounder for the former."

The randomized individual tree method is the one considered most suitable when it is required to test the loss of efficiency of pruned trees in comparison with unpruned neighbours, or neighbours pruned to a different grade. In areas where stocking is irregular it may be the only satisfactory method of determining the effect of pruning. It should also prove useful in determining the effect of different pruning grades on the selected stems in the Scottish eclectic or crown thinning systems.

In the United States, Stein (1955) reports the results of an experiment in pruning Douglas fir. The randomized individual tree method was used along lines similar to those outlined by Jacobs. Stein, however, found a correlation between current diameter growth and initial diameter and between current height and initial height. In both cases the larger trees made the best growth. The problem was got over by correcting for initial diameter and height by covariance analysis before testing the significance of the difference between treatments. Jacobs also found "a strong correlation between current diameter increment and initial diameter on individual sites" and in one particular experiment got over the difficulty by restricting the diameter class range to ½ inch.

The effect of green pruning on the tree from the pathological viewpoint is something that cannot be ascertained from the behaviour of trees to green pruning under climatic conditions different to ours. Yet it is interesting to note that in South Africa and Australia the incidence of fungal diseases because of pruning is so small as to be discounted. Commenting on the subject Stein (1955) says: "A number of trees adjacent to the study plot boundaries were given the same crown removal treatment as the trees in the plots. Some of these trees have been dissected at periodic intervals: no decay has been found under pruning wounds and most wounds healed over in 13 years." Considering the slow growth rate and the consequent slow rate of occlusion it is remarkable that the trees escaped infection if they were in any way susceptible. Jacobs (1938) lists a number of factors in the time taken to occlude pruned branch stubs and says that growth rate "might be termed the only factor which determines rate of occlusion, the other factors influencing the time taken to occlude and the quality of the knots only." He, therefore, recommends pruning "before the rapid early diameter growth falls off."

Pruning is an essential operation following wide spacing or heavy thinning to avoid the production of coarse and knotty timber; on the other hand, pruning, without subsequent thinning to get maximum increment on the pruned stems, is a waste of time and money.

Thinning is carried out to improve the stand, either for hygienic purposes or the concentration of increment on the best stems in the stand. It has also a very important effect on financial returns and the quality of the crop.

Thinning may be broken down into a number of types or methods, e.g. (i) Stem or low thinning; (ii) Crown thinning; (iii) Selection thinning; (iv) Mechanical thinning. Thinning grades may be described either qualitatively, e.g. the removal of dead and dying, suppressed, sub-dominants, whips and defective co-dominants and dominants; and numerically, i.e. the reduction of the number of stems per acre to a certain number. The qualitative method offers a lot of scope as to the number of trees to be removed in a thinning. Hiley (1954) points out that in relation to the two editions of the Forestry Commission's publication, "The Thinning of Plantations", the instructions for the thinning of Japanese larch are the same for both editions, yet the number of stems left at all heights up to 60 ft. is almost halved in the second edition. Numerical thinning grades are more complicated than qualitative grades because, in general, a separate table has to be prepared, not only for each species, but for each quality class within a species. Hiley (1954) mentions that in most of the yield tables which he has examined, a lower quality class has more trees per acre at any given age, but fewer trees at any given height, than a higher quality class. There are exceptions, however, such as Moller's table for Norway spruce and the Forestry Commission yield tables in which all quality classes have the same relationship between height and number of trees. Numerical thinning should not be confused with mechanical thinning, nor is there any suggestion that the principles of qualitative selection are being abandoned. Rather the contrary. A numerical thinning will also aim at taking out the poor stems and leaving the best, with the additional stipulation that the number of trees per acre left after thinning will be approximately the same as given in the table. To quote Lewis "all thinning should be silvicultural. Expressing treatment in quantitative terms of any kind does not make it unsilvicultural. It merely expresses a treatment in figures from which local variations can be developed." (in Penistan 1960).

Much has been written about thinning, spacing and other density affecting treatments, but as Spurr (1952) points out, "a very large proportion of the literature deals with inconclusive experiments where the measurement data are not complete, where untreated stands were not measured for comparison or were located on dissimilar sites, or where the measurements were not sufficiently precise or sufficiently replicated to enable valid conclusions to be drawn. Only when the experiment is replicated, or when the control plot is closely comparable to the treated plot, and only when complete sets of measurements are carefully made at intervals of several years can really valuable information be obtained."

Before considering thinning and its effect on growth, it may be of interest to consider what constitutes growth in a stand.

The rate of growth of a stand is made up of the total growth rate of individual trees in the stand. The growth rate of each individual tree is determined by its genetic character, the quality of the site and its growing space. It is this last factor which is influenced by thinning.

While thinning will affect the growth of individual trees in the stand, there is a theory that every growing site has a certain growth potential, made up of nutrients, soil moisture, intensity of sunlight, etc. and that as long as these site factors are fully utilized, growth per stand will not vary for widely different degrees of stocking. This is referred to as Moller's theory by Heiberg (1954) "that within certain wide limits, the volume increment is not influenced by density of stocking." It will not obtain where density affects tree vigour, as when the stand is so overcrowded that "whipping" has damaged the crowns. In such a case growth will be retarded even though the site is fully utilized.

The effect on stocking on growth may be considered under four headings:

(1) Effect on height growth;
(2) Effect on diameter growth;
(3) Effect on form;
(4) Effect on Basal Area and Volume.

The findings by some of the leading investigators can be summarised under these headings.

(1) *Effect of stocking on height growth.*

Hawley conducted a thirty-year thinning experiment in white pine and found that the average height in the unthinned plot changed from 42 ft. to 73 ft., while that in the heavily thinned plot changed from 43 ft. to 75 ft. The difference of a foot is not significant. Schantz-Hansen found that no difference in height could be attributed to different thinning treatments of four plots, although height growth was retarded by overstocking prior to thinning. (in Spurr 1952).

It should be remembered that different thinning methods may change the average height of a stand without actually affecting height growth. A low thinning which removes the smaller trees will increase the average height, while a crown thinning is apt to decrease it. Hummel records that in the Bowmont plots the average height of all trees was greater for C and D grade low thinning than for B grade low thinning and crown thinning. There was no significant difference, however, between the average height of the 100 largest trees per acre, and it was concluded that the different thinning grades had no effect on height growth (Hiley 1954). In South Africa, research along the lines suggested by O'Connor indicates "that the density of the plantations has no significant influence on the mean height of the dominant trees" (Hiley 1959). If a constant relationship between stocking and height is accepted, it could have considerable influence in thinning experiments because it would mean that any difference in height between treatments is due to site and not to treatment.

(2) *Effect of stocking on diameter growth.*

The one outstanding result of practically all experiments where stocking is varied, is that diameter growth of the individual trees is closely related to the growing space. Most investigators have agreed, however, that 25% or more of the basal area must be removed before substantial increases in diameter growth will occur. The ability of a tree to respond to increased growing space is dependent on its age and vigour. Younger trees respond better than older trees and trees with good healthy crowns better than ones with small unhealthy crowns. It should be borne in mind that growing space includes soil space as well as air space. Even ground vegetation may reduce diameter growth. Gabrielson showed that *Vaccinium* and heather, coming in after a heavy thinning of Scots pine, in Sweden, resulted in decreased diameter growth. This should be remembered in experiments involving heavy thinning grades and all vegetation would have to be removed from the plots before it affected growth. Another aspect of the problem, commented on by Craib (1939, 1947) and Hiley (in Spurr 1952) is that the largest trees in a dense stand are smaller than the largest trees in an open stand. In other words, they are suppressed by lack of growing space and, once suppressed, they will never catch up on unsuppressed dominants. Craib also refers to the effect of site on the amount of growing space needed to obtain a given rate of diameter growth; the poorer the site the more space must be allowed.

(3) *Effect of stocking on tree form.*

Dense stands have less taper than open-grown stands. The longer and wider the crown, the greater will be the percentage of increment laid down in the crown rather than in the stem, and the greater the rate of taper. Regarding change in form following thinning: Moller and Holmsgaard found no change; Hagburg and Bickerstaff found that thinning increased diameter growth at breast height more than in the upper stem, resulting in more taper, and Meyer and Behre suggest that the cylindrical stems become more tapered, and the conical stems become more cylindrical; all trees tend to end up with the same taper. In general, it would appear that variation in form is sufficiently related to height and basal area to be ignored in volume computations if these two variables are used. (in Spurr 1952).

(4) *Effect of stocking on Basal Area and Volume Growth.*

Most workers, including Wiedemann, Moller and Holmsgaard, Hawley, Chapman, Eyre and Zehngraff, agree that thinning does not materially affect nett basal area or nett volume growth. In some experiments, nett growth of thinned stands was found to be greater than that of control stands. The difference in most cases, however, was due to mortality. Where mortality is salvaged in the control plots, it is found that gross volume production is not affected by thinning. In most cases mortality is so low that nett growth is not affected either (in Spurr). Notable exceptions to the general rule are the Bowmont plots and thinning experiments in South Africa. Hummel found that the heavily thinned plots (grade D) grew 30% more in basal area and attained a total cumulative production 25% greater than the lightly thinned plots (grade B). However, as the plots got older, the differences were not so marked. In South Africa the reverse occurred. Lightly thinned plots gave greater total cumulative volumes than heavily thinned plots. Attempts to explain these variations have been made by Braathe, (in Moller 1954) and by Hiley (1959). Braathe points out that the differences found by Hummel between degrees of thinning would probably not be significant if allowance were made for the fact that only volumes over 3 inches d.b.h. were dealt with. Regarding the South African experiments, Hiley suggests that the loss of increment is due to the free growing conditions in the heavier thinnings. This simply means that thinnings were so heavy as to leave open spaces in the stand, which were not immediately availed of by the surrounding trees with resultant loss of total increment and volume.

Before dealing with thinning experiments as such, a few words on thinning methods might be appropriate.

1. *Low Thinning:* This thinning method is familiar to all of us as it is the usual way of thinning in this country and in England. The Forestry Commission specify five thinning grades from A to E with combinations of any two consecutive letters to indicate intermediate grades. It means that when a thinning is marked, the smaller trees are removed first and if the thinning is heavy (E grade) little more than dominants and co-dominants are left. Incidentally, E grade was introduced to try and obtain results comparable to those obtained by Craib (1939) in South Africa.

2. *Crown Thinning:* A limited number of the best dominants are isolated and given sufficient room for rapid development while the spaces between them are occupied by smaller trees. The selected trees are usually marked with paint and high pruned. Under this heading might come the Scottish Eclectic thinning, where 50 to 60 trees per acre are marked for very special treatment, and the Queensland Eclectic method when 160 stems per acre are selected.

3. *Selection Thinning:* This method originated in European and Scandanavian farms and is practised particularly where small produce is unsaleable. It can be conducted extensively or intensively. The extensive form is practised where small dimensions are unmarketable, or where labour costs are high and the increment small. It consists of the removal of trees which are saleable and only where smaller trees will take their place. The intensive form requires markets for smaller trees, available manpower for thinning and C.A.I. of at least 150 cu. ft. per acre. Thinning would be carried out annually in stands less than 50 years of age. The dominant trees are gradually removed and are replaced by the trees which were sub-dominant. It is suggested that this method gives trees of a much better quality and grade than originally dominant trees would have given had they been allowed to remain. The method, however, is difficult to administer and Juncker (1954) who is an advocate of this method in Denmark, warns that it is also dangerous especially "when the method results in cutting to a diameter limit in which the criterion for the removal of the tree is placed entirely

on a certain dimension instead of the development possibilities for the entire forest."

4. *Mechanical Thinning:* It was used extensively in England during the war years, when every second or third line was removed. This method was adopted, firstly because of the lack of skilled personnel to mark thinnings and, secondly to facilitate extraction.

While the thinning methods mentioned may differ in that the approach to the problem of thinning is different in each case, it will be found that the choice of thinning method is not limited to any geographical region or country, rather it is that a particular method has been adopted to fit a certain set of circumstances, or maybe because of reluctance to change from a known system as in this country. There are countries, such as Denmark, which employ a combination of three methods, i.e. *Low, Crown,* and *Selection* as Moller (1954) points out "the typical Danish thinning cannot be classified under any of these categories. It is a free cutting that in reality comprises all three systems but is closest to crown thinning."

A thinning experiment which investigates differences between thinning methods is the Frazer study in the United States. (Alexander 1956). Six separate 2¼ acre blocks were divided into ¼ acre plots, each surronded by a 35 ft. isolation strip that received the same treatment as the plot. One plot in each block was left unthinned, one was given a low thinning treatment called single tree thinning, and the third plot was given a type of crown thinning or crop tree thinning. Two methods of assessing the growth response are given—

(1) Total stand method;

(2) Comparable tree method.

(1) *Total stand method*—A comparison of the growth of all trees in the stands during a seven year period after treatment showed that all diameter classes were about equally stimulated by both kinds of thinning. Mean annual diameter growth per tree was three times greater in the low thinning plots than in the unthinned, and five times greater on the selected trees in the crown thinning than in the uthinned, but when the selected trees and remaining trees were combined, the diameter growth was only slightly greater. The mean annual basal area growth per acre was not significantly different between thinned and unthinned plots. There was no significant difference in volume growth between the two thinning methods.

(2) *Comparable tree method*—The removal of suppressed and slow-growing trees raises the average rate of growth regardless of the effect of thinning in the plot, so it was felt that a comparison between selected trees of comparable size and condition in the thinned and unthinned plots would be a fairer comparison. A number of trees were selected (100 per acre) in each treatment, and increment borings were made at breast height to determine rate of growth prior to thinning.

The mean diameters of individual plots and treatments were ascertained. The response to thinning was obtained from measurements taken a number of years after thinning had been completed. In this instance, both thinning treatments gave a definite growth response, the increase in diameter growth being better for the low thinning than the crown thinning. This difference was significant at the 1% level, even after the variation of growth rates before thinning had been eliminated by covariance analysis. This method of analysis is almost identical with the individual tree method already described for pruning.

Carbonnier reports on a thinning method of experiment in Norway Spruce in Sweden, planted between 1878 and 1891, (in Holmsgaard 1958). One thinning series was established in 1906 and four others in 1911, 1924, 1925 and 1927 and all have been measured for at least 25 years. The experiment consists of :

(i) 5 control plots (no thinning);
(ii) 7 low thinning plots—5 of which are heavily thinned and 2 extra-heavily thinned;
(iii) 6 crown-thinning plots—5 of which are heavily thinned and 1 extra-heavily thinned.

It is mentioned that the uneven ground of the region causes variations within individual series on which it would have been interesting to have information, but which cannot be explained on the basis of this otherwise very extensive material. This points to the need of uniformity in growing conditions. The experiments "treat the thinning problem on the basis of direct observations of the course of increment, with no adjustment whatever of the tree measurement figures." All the data is given, however, to enable "the reader to form his own judgment of the reliability of the conclusions." This experiment, and indeed most European experiments, are aimed at investigating the increment, yield and financial return from different thinning methods and grades. Henriksen reports the results of a thinning experiment which commenced in a 35-year-old Sitka Spruce stand in Denmark in 1936. (in Moller 1954). The plots are located in the same plantation but are separated. Four degrees of thinning grade are involved, and increments are determined with four intervals between thinning for all degrees. The table below shows the average annual increment in cu. ft. of stem volume per acre from 1935-1951.

Degree of thinning	A	B	C	D
Approx. B.A. per acre (sq. ft.) 1951	350	220	175	145
Plots a, b, c, d	585	532	545	519
e, f, g, h, i, j, k, m	576	549	498	466
n, o, p	—	507	454	474

The fact that increment looks exceptionally good does not affect the comparisons. Henriksen suggests that the 5% difference between B and D grades may be due to an attack of *Hylesinus micans* on the heavier thinned plots. He also calls attention to the large basal area in the A grade, where only dead trees were cut.

An experiment combining thinning grades and methods was conducted by the Forestry Commission in 20 year-old Norway spruce at Bowmont in Scotland (Hiley 1954). There are 16 plots in the experiment arranged in Latin square design with four treatments, i.e. *B grade:* light low thinning; *C grade:* moderately heavy low thinning; *D grade:* heavy low thinning; *L.C. grade:* light crown thinning. Each plot is 0.1 acre and the plots are separated by 28 ft. isolation strips. The stand is on fine sandy loam overlying Old Red Sandstone, and is Q.C. 111 according to British Forestry Commission yield tables for Norway spruce. Hummel published the results of the experiment for the period 1930-1945, and Hiley has brought them up to 1950. The general results (from Hiley) are as follows :—

"(1) The number of trees per acre, which was just over 3,000 before the first thinning, now ranges from 1,333 under the B grade thinning down to 272 under the D grade.

(2) Height growth has been much the same in all the plots. The average height of the 100 largest trees was about 25 ft. at 20 years and about 47 ft. at 40 years.

(3) At 40 years, the average length of crown expressed as a percentage of the total height, was $41\frac{1}{2}\%$ in D grade and $31\frac{1}{2}\%$ in B grade.

(4) The form factor, or taper is about the same in all the plots.

(5) Girth increment has been greatly stimulated by heavy thinnings. The growth from $3\frac{3}{4}$ inches Q.G. at 20 years to 8 inches Q.G. at 40 years in D grade is equivalent to 8 annual rings to the inch, whereas corresponding growth in the B grade, from 4 inches to $6\frac{1}{4}$ inches, is equivalent to about 12 annual rings per inch.

(6) The B grade thinning contains about 100 dominants to the acre which have good crowns and well shaped stems. The corresponding numbers for the other grades are 130 for C grade, 180 for D grade and 170 for L.C. grade.

(7) Heavy thinning has yielded a far larger volume of thinnings than light thinning, but it has left a smaller standing volume.

(8) The total production is greater with heavy thinnings than with light thinnings and this difference is statistically significant. This is contrary to many experimental results, most of which show that the grade of thinning has no significant influence on total production."

By reducing the number of plots while catering for extremes of stocking at the same time, and correlating the information gained from each plot, forecasts for any degree of stocking between the two extremes can be made accurately. This is the basis of O'Connor's Correlated Curve Trend (C.C.T.) experiments. E. K. March, Assistant Chief

Research Officer, Department of Forestry, South Africa, in a recent (1957) paper explains the C.C.T. method :—

"In essentials, the C.C.T. method as originally developed by O'Connor, consists in maintaining 8 plots representing densities of 1,200, 600, 400, 300, 200, 150, 100 and 50 stems per acre at these densities, or their nearest feasible equivalent, for the period of a full rotation. In addition, other plots are allowed to become suppressed to varying extents and their response to thinnings of varying degrees is then observed.

The plots representing densities of 1,200 to 50 stems per acre cannot be grown at these densities from the start, because they will not fully occupy the site in the early stages and it would thus become an impossible task to keep them free of weed competition at this stage. Consequently all these plots are established at an espacement of 6 ft. × 6 ft. (1,200 S.P.A.) and thinned in steps in advance of competition to their final espacements.

O'Connor suggested a unique means of ensuring that competition was not permitted to take effect in these plots prior to thinning. In the second year, before there is any sign of competition, plots 2 to 8 are thinned from 1,200 to 600 stems per acre. The mean D.B.H. of these plots is determined and 600 trees on Plot 1 (1,200 S.P.A.) are selected to give the same mean D.B.H. as that of plots 2 to 8. When the mean D.B.H. of the selected 600 trees falls below that of plots 2 to 8 by $^1/_{10}$th inch, competition is considered to have commenced in 1,200 S.P.A. (plot 1) and thereupon plots 3 to 8 are thinned to 400 S.P.A. The mean D.B.H. of plots 3 to 8 is then determined and 400 stems in plot 2 (600 S.P.A.) are selected to give the same mean D.B.H. When the mean D.B.H. of the selected 400 S.P.A. falls behind that of plots 3 to 8 by $^1/_{10}$th inch, plots 4 to 8 are thinned to 300 S.P.A. In a similar manner, it is determined when thinnings to 200, 150, 100 and 50 S.P.A. are due."

In his paper, Marsh (1957) concludes that :—

(a) "The C.C.T. projects are, contrary to the expectations of Wicht (1952) capable of yielding all the results claimed for them by O'Connor (1935). In effect, these experiments will end the necessity for further thinning experiments.

(b) That the method of analysis of these projects suggested by O'Connor (1935) should be replaced by that suggested by Craib (1947) with the modification indicated therein.

(c) That this method of experimentation can be confidently recommended for general adoption and that it yields results of wide practical application."

The method of analysis suggested incorporates the use of a total volume per acre—age in years graph, a mean height in feet—DBH in inches graph, and a mean height in feet—age in years graph, and the use of volume tables or alignment charts, where necessary. The age at which competition starts is almost identical when calculated by O'Connor's method and that suggested by Craib.

The above-mentioned experiments give the required information from observations over a number of years, but some worthwhile guides may be obtained from existing or easily procured data. Hiley and Lehtpere (1955) have calculated thinning grades, based on the thickness of annual rings, by making use of existing yield tables for the species. The calculations are based on Moller's theory and, although the calculated yield tables may not be entirely accurate, they are useful in that they give an idea of the size of tree which can be grown for various thinning grades.

Three Americans—J. E. Krajicek, K. A. Brinkman and S. F. Gingrich (1961)—have published a report on the relationship of crown width to D.B.H. in open-grown trees and have calculated the number of open-grown trees of a specific diameter that can be grown per acre. Diameter and crown width are measured on trees of a particular species which have been open or free-growing all their lives. Since the relationship of crown width to D.B.H. is linear, a simple regression equation is calculated for each species. All the field work required is the measurement of a number of trees of various sizes for each species.

It is not a simple matter to find answers to the questions, when and how heavily should one thin and prune. The answers may be partly conditioned by factors of site and locality, but mainly by the uses to which the end product is put. Knottiness, a high degree of taper, and wide rings may not materially affect conversion into pulpwood, but would be unacceptable for veneer purposes. This in turn raises the question of the revenue obtainable from the various forest products for it is the revenue over the rotation that really determines the profitability of one thinning regime over another.

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