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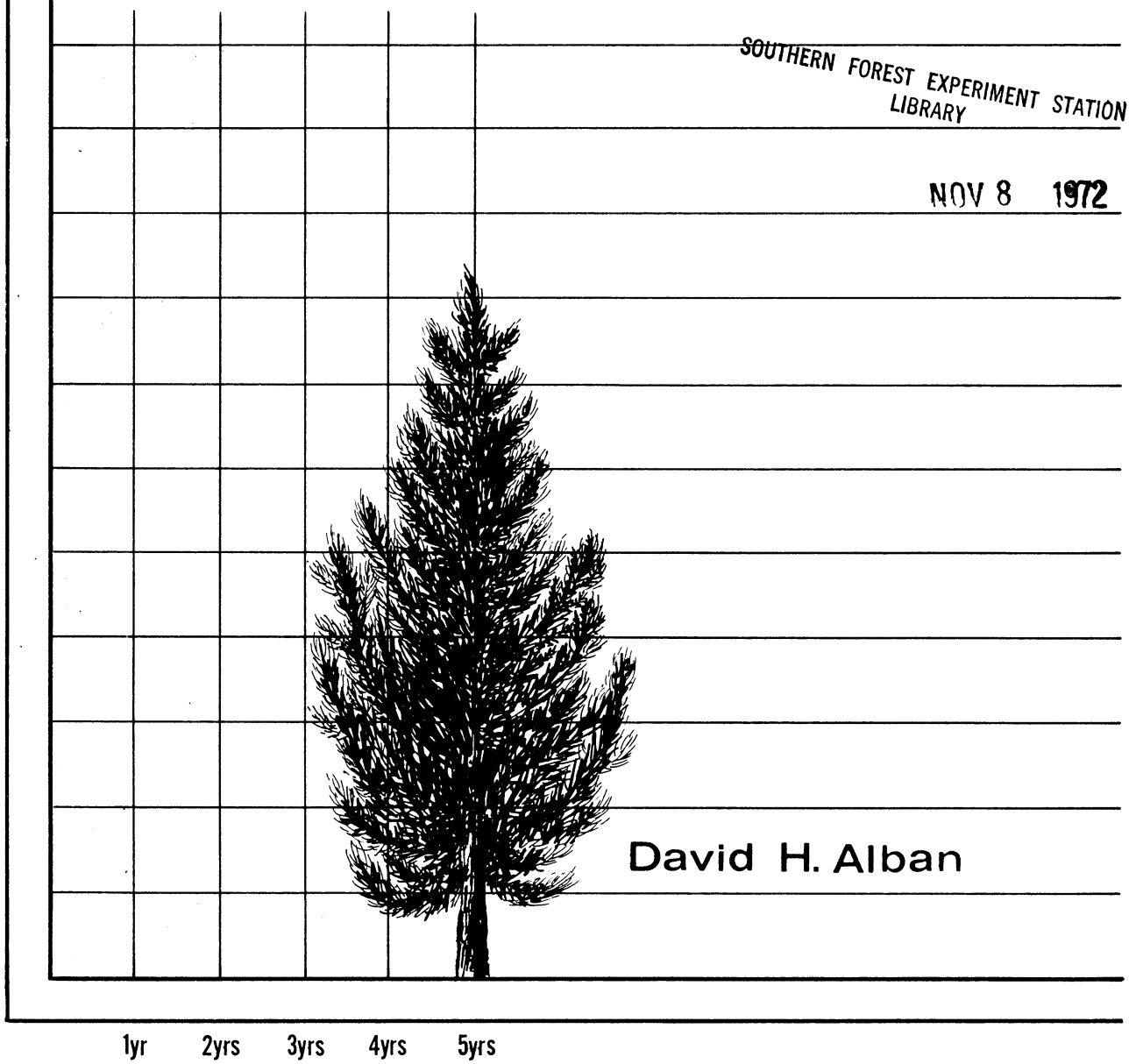

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An Improved Growth Intercept Method For Estimating Site Index of Red Pine

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For tree species that have limbs showing distinct annual whorls the cumulative length of three to five internodes beginning at breast height has been suggested as a measure of site quality, particularly for young stands (Ferree *et al.* 1958, Wakely and Marrero 1958, Warrack and Fraser 1955).

The advantages of such a method are: (1) it can be used in stands too young to be evaluated with standard site index curves; (2) it eliminates the need to measure total tree age or height, either of which can be a major source of error; (3) it can be measured easily and rapidly; and (4) by measuring internode lengths above breast height (BH) many of the variabilities associated with the establishment period can be reduced or eliminated. Disadvantages of the method include the effects of short-term climatic fluctuations, and the fact that sometimes early growth of a stand does not accurately reflect later growth (Wilde 1964).

Growth intercept (GI) has most commonly been defined as the total length of the first five internodes above BH, and this 5-year growth intercept has usually been a reliable predictor of height growth for the next 5 to 20 years. However, because most studies have been conducted using juvenile stands no direct comparison has been possible between growth intercept and dominant tree height at the site index reference age. In several studies the measured 5-year growth intercept in young stands has been correlated with site index estimated from standard site index curves using total height and age. But this approach must be used with caution because height growth curves may vary in shape from one site condition to another (Bull 1931, Carmean 1956, Husch 1956, Spurr 1955).

In the study reported here, older stands (with two exceptions noted under Methods) were used and the growth intercept was related to the actual height attained by dominant trees at age 50 (Ht_{50}). Particular attention was paid to selecting suitable starting heights from which to measure the growth intercept. Plantations were also sampled and the application of the growth intercept information (obtained from natural stands) to plantations is evaluated and discussed.

METHODS

As part of a study of the relationship between soil properties and the growth of red pine (*Pinus resinosa* Ait.), 69 plots were established in natural stands throughout the commercial range of red pine in northern Minnesota. Most stands occurred on well-drained upland soils of sand to sandy loam texture, but a few were on soils with silt loam to loam surface texture. Red pine growing on organic soils or on rock outcrops were not included.

The stands were selected carefully to ensure that fire or other severe environmental disturbances had not injured either the trees or the site. No stand was used if major insect or animal damage was apparent, or if the dominant trees took longer than 12 years to reach BH. One stand was 47 and another was 49 years old, the rest ranged in age from 50 to 95 years. The basal areas were from 75 to 175 square feet per acre (of which at least 75 percent was red pine). On each plot three to seven dominant trees were felled, the position of each whorl on the stem recorded, and the stems were sectioned as follows: 1-foot sections from the 6-inch stump to 6.5 feet; 2-foot sections from 6.5 to 20.5 feet; and 3-foot sections from 20.5 feet to the top of the tree. Total age was estimated by adding 2 years to the ring count at the 6-inch stump. On each section the annual rings were counted and from this data a single average

height growth curve was constructed for each plot. From this curve, total height at 50 and 25 years, and growth intercepts measured from numerous positions along the stem were determined.

Normally growth intercept is measured from actual internode lengths. In the present study growth intercept was estimated from the stem analysis data because the lower limbs were no longer visible in many of the older stands. Forty-nine of the plots used in this study had at least three sample trees with whorls extending lower than 8 feet from the ground. From these a comparison was made between the 5-year growth intercept determined from actual internode lengths above 8 feet and one estimated from the stem analysis data, which showed that the stem analysis method gave a good approximation of the growth intercept as measured from actual internode lengths. The average difference between the growth intercept measured by the two methods was only 0.27 feet.

RESULTS AND DISCUSSION

Natural Stands

The correlation between Ht_{50} and height growth during 5-year periods showed a rapid rise with increasing height above the ground (fig. 1). Thus a much better estimation of Ht_{50} will result from measuring a growth intercept starting at least several feet above BH.

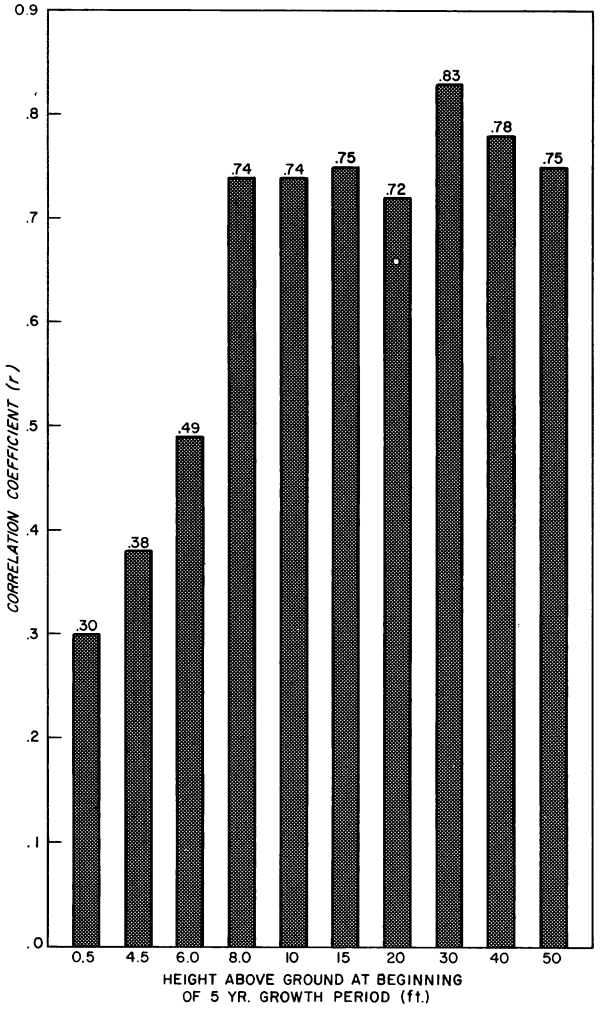

Figure 1. – Correlations between height at age 50 and 5-year growth intercepts.

Most studies in red pine plantations have found only a very weak relationship between the time required to reach BH and later tree growth (Day *et al.* 1960, Ferree *et al.* 1958, Husch 1956). The present study in natural red pine stands likewise showed a weak relationship between height at age 50 and the number of years to reach BH ($r = -0.29$). Seedling establishment and early growth are strongly affected by special factors such as seedling vigor, competition, animal and insect damage, etc., which have much less effect on later growth. Growth intercept, to be most reliable, must be measured above the height where the influence of these special factors becomes small, at about 8 feet in the present study.

The correlation coefficient between Ht_{50} and total height at age 25 (Ht_{25}) is 0.76. This is nearly the same value as obtained for the relationship between Ht_{50} and 5 years height growth beginning anywhere from 8 to 50 feet along the stem (fig. 1). Thus it is possible to predict Ht_{50} just as accurately using a carefully selected 5-year growth period as it is using the first 25 years height growth.

In order to decide on a suitable number of internodes to measure for growth intercept, the length of 3, 5, 10, and 15 internodes above 10 feet was correlated with Ht_{50}. The correlation coefficients were 0.56, 0.74, 0.81, and 0.86 respectively. Five internodes result in a reasonable compromise between ease of measurement and precision.

Measuring the 5-year growth intercept beginning 8, 10, or 15 feet above ground results in considerably better prediction of Ht_{50} than starting at 4.5 feet (BH) (table 1). In particular the number of plots estimated within 2.5 feet of the actual Ht_{50} is increased by about 50 percent, and the number of plots having an error greater than 7.5 feet is reduced to just a few percent. The fact that the equations derived for 5-year growth periods starting at 8, 10, or 15 feet are virtually identical means that any 5-year growth period beginning within these limits will result in nearly identical predictions of site index. Consequently, it is recommended that the growth intercept for red pine be measured as the five internodes starting from the first whorl above 8 feet. Site index can then be predicted by substitution of the 5-year growth intercept above 8 feet into the equation $Ht_{50} = 32.54 + 3.434\ GI_8$.

The substitution of growth intercept values from 3 to 12 into the above equation resulted in a range of values that covers nearly the entire spread of site index values for red pine in Minnesota.

Five-year growth intercept above 8 feet	*Predicted height at age 50*
Feet	*Feet*
3	42.8
4	46.3
5	49.7
6	53.1
7	56.6
8	60.0
9	63.4
10	66.9
11	70.3
12	73.7

During the course of this study several hundred red pine stands were examined and the highest site index for natural stands was about 70 feet. No stands except those with severe early suppression had site index values less than 42 feet.

The slope of the recommended equation (3.434) means that a 1-foot error in the estimation of stand growth intercept will contribute an error of 3.4 feet to the prediction of site index. In this study using three to seven trees per plot the maximum standard error of the mean for the measurement of growth intercept was 0.80 feet. This error corresponds to an error of about 2.7 feet in the estimation of site index. By increasing the sample size the error could be reduced, but the number of trees which should be sampled in a given case will depend on both the variability within the stand and the precision desired.

Table 1. – Precision of predicting height at age 50 using 5-year growth intercept beginning at four different heights above ground[1] (cumulative percentage of plots within specified error limits).

Ht_{50} error limits (feet)	Height above ground from which 5-year growth intercept measured			
	4.5 feet	8 feet	10 feet	15 feet
0 - 2.5	33	51	48	48
0 - 5.0	62	81	81	77
0 - 7.5	88	97	97	96
0 - 10.0	94	99	99	100
0 - 12.5	97	100	100	100
0 - 15.0	100	100	100	100

1/ The prediction equations and correlation coefficients are as follows:

4.5 feet	$Ht_{50} = 45.35 + 1.913\ GI_{BH}$	r = .38
8 feet	$Ht_{50} = 32.54 + 3.434\ GI_8$	r = .74
10 feet	$Ht_{50} = 33.54 + 3.264\ GI_{10}$	r = .74
15 feet	$Ht_{50} = 32.03 + 3.342\ GI_{15}$	r = .75

An average of 8.3 years was required for the trees in this study to reach BH. In applying the recommended growth intercept equation to stands taking greater or fewer years to reach BH, a certain amount of error is introduced into the estimation of Ht_{50}. However, by working with stands taking 6.3 to 10.3 years to reach BH (which includes 91 percent of the stands in this study) the maximum error in estimating Ht_{50} will be about 2 feet.

A comparison was made of actual Ht_{50} with Ht_{50} estimated by three methods: (1) the equation $Ht_{50} = 32.54 + 3.434\ GI_8$ and the 5-year growth intercept above 8 feet, (2) the equation $Ht_{50} = 45.35 + 1.913\ GI_{BH}$ and the 5-year growth intercept above breast height, and (3) total height at age 25 in conjunction with Gevorkiantz' site index curves (Gevorkiantz 1957). Of the three methods, the GI_8 method of estimating Ht_{50} deviated least from the actual in all measurements but one (table 2). The negative average deviation of the site index curve method indicates that it does not predict as rapid a height growth from ages 25 to 50 as found in this study. This underestimation is about twice as large for plots with site index over 55 as for plots with site index under 55.

Table 2. – Comparison of three methods of estimating height at age 50

Method of estimating site index	Deviations of estimated from actual Ht_{50}		Percent of plots[1] in which the estimated Ht_{50} deviates from actual Ht_{50}	
	Average absolute difference	Average difference	> 5 feet in error	> 10 feet in error
	Feet	Feet		
5 years growth above 8 ft. (GI_8)	± 2.9	0.0	19	1
5 years growth above BH (GI_{BH})	± 4.2	+ 0.1	38	6
Site index curve total height age 25	± 3.5	- 1.2	17	1

1/ Total number of plots was 69.

Application

For estimating red pine site index in our natural stands, the growth intercept method starting at 8 feet is clearly superior to growth intercept starting at breast height. Growth intercept above 8 feet is also somewhat better than measuring total height and age in stands 25 years or younger and estimating site index from the standard site index curves.

Best results in estimating Ht_{50} from GI_8 will be obtained in even-aged fully stocked red pine stands not affected by severe environmental disturbance (e.g., by fire or erosion). Only dominant trees without obvious insect, disease, or fire damage should be used, which are the same criteria to be applied when estimating site index by use of standard site index curves. It is also important that site index trees were not severely suppressed as seedlings. Trees requiring more than 11 years to reach BH are suspect and have probably been suppressed to some degree.

Using these criteria of stand and tree selection, Ht_{50} of red pine can be satisfactorily estimated by the following growth intercept method: the length of five internodes beginning at the first whorl above 8 feet is measured on individual trees, the number of which will depend on the variation between trees and the desired precision. Using only three to seven trees on a uniform one-tenth-acre plot resulted in an estimate of GI_8 with an average standard error of 0.45 feet. Measurement of more trees entails little additional work and it is anticipated that a minimum of 10 to 20 trees may be needed in most situations. However, in practice enough trees should be measured to reduce the error to an acceptable level. After GI_8 is estimated to a suitable level of precision, Ht_{50} is read from the above tabulation or by substitution in the equation: $Ht_{50} = 32.54 + 3.434\ GI_8$.

Using a 13-foot, two-piece, collapsible pole in young red pine stands, two workers can measure the 5-year growth intercept from either BH or 8 feet with nearly equal ease. Either can be measured at a rate of about 10 trees per 5 minutes. The average growth intercept of 10 trees measured with a pole will differ from taped measurements on the same 10 trees after felling by less than 0.1 foot.

Extension to Plantations

It is of considerable interest and importance to evaluate this method in plantations. Twenty 25- to 70-year-old plantations (average age 32 years) established primarily on abandoned agricultural land were sampled in the same manner as the natural stands.

Both plantations and natural stands were stratified into the "good sites" (those with $GI_8 \geq 8.5$ feet), and "poor sites" (with $GI_8 < 8.5$ feet). For both the good and poor sites the average height growth of plantations was slightly greater than for natural stands. Therefore, in order to facilitate comparison between height growth

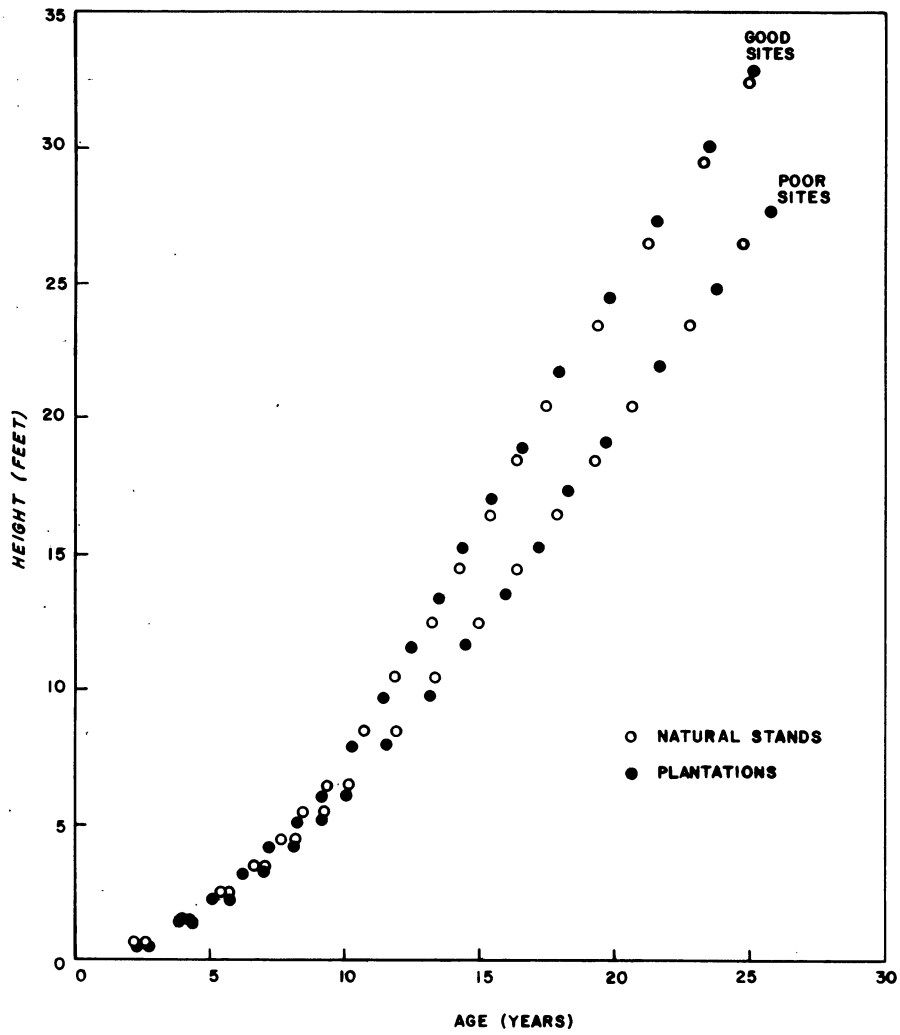

Figure 2. – Comparison of height growth patterns of plantations and natural red pine stands. (See text for details.)

patterns of natural stands and plantations, the plantations' height growth curves were adjusted downward to coincide with those of the natural stands at age 25:

$$\text{Adjusted Plantation Height at age X} = \left(\text{plantation height at age X}\right)\left(\frac{\text{natural stand } Ht_{25}}{\text{plantation } Ht_{25}}\right)$$

After this plantation adjustment it is clear that the height growth patterns of natural stands and plantations are nearly identical (fig. 2). Most natural stands were probably established after fire and the trees were free of overhead competition, as were trees in the plantations. Therefore dominant trees in natural stands and plantations required about the same number of years to reach BH (8.3 and 7.7 respectively).

Very few red pine plantations in Minnesota are older than 35 years, hence few direct measurements of Ht_{50} are possible. Consequently two measures of site quality were tested: (1) total height at age 25 and (2) total height growth for 20 years after attainment of BH (Ferree *et al.* 1958). These two measures of site quality were closely related to each other ($r = 0.90$ for natural stands and 0.97 for plantations), and each was closely related to GI_8. In the present study Ht_{25} was used as a measure of site quality for plantations. As with natural stands

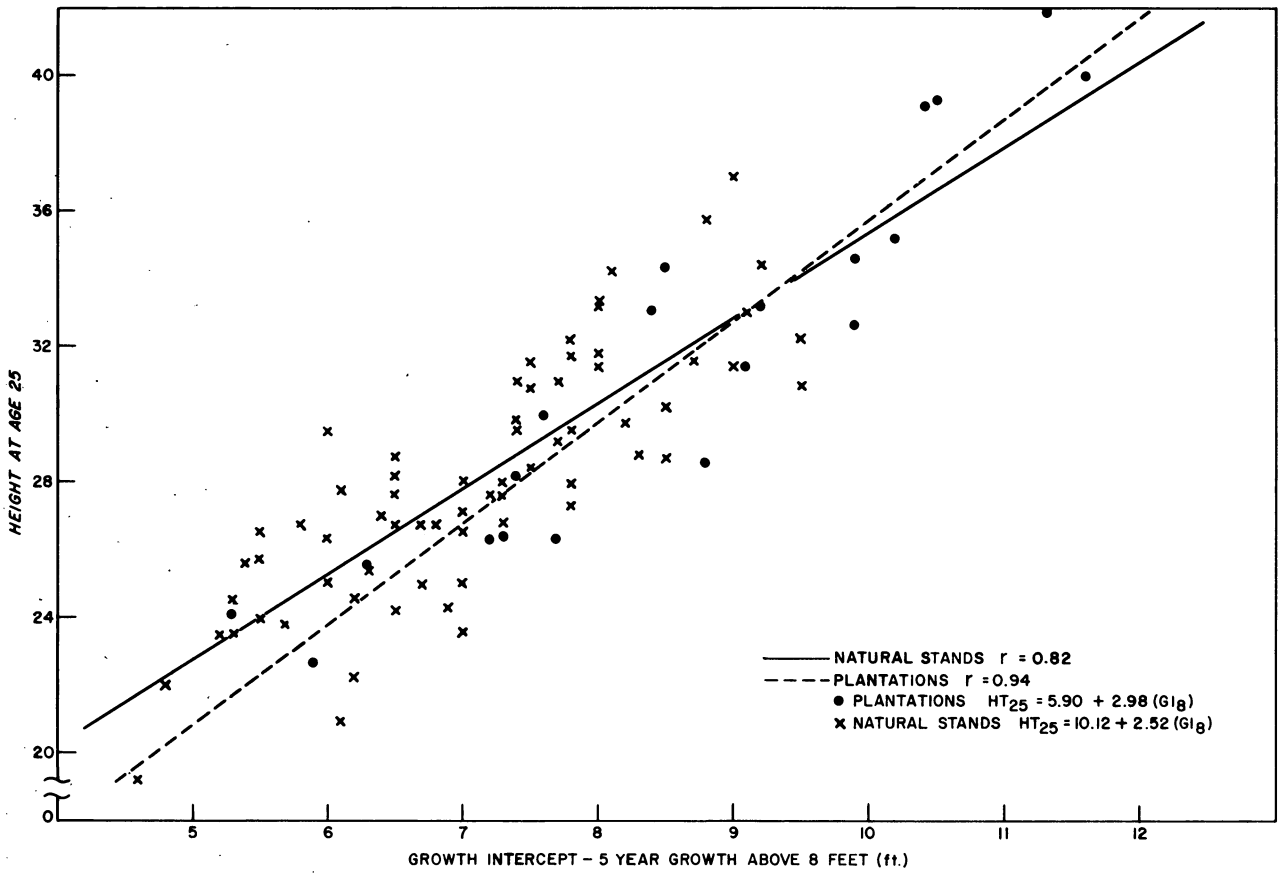

Figure 3. – Relationship between height at age 25 and 5-year growth intercept measured above 8 feet.

site quality was estimated more closely by using 5-years growth above 8 feet rather than above BH (r = 0.94 for GI_8, and 0.78 for GI_{BH}).

The relationship between GI_8 and the total height at age 25 for both plantation and natural stands shows that the plantations fit in with the general relationship quite well, although they were established on better sites than most of the natural stands (fig. 3). The equations for predicting Ht_{25} for plantations, and for natural stands are not significantly different at the 5 percent level in either slope or intercept. Within the limits of the GI_8 values commonly found in this study (5 to 11.5 feet) these two equations result in a maximum difference in estimated Ht_{25} of less than 2 feet. Hence the growth intercept equation developed for natural stands is also applicable to plantations in Minnesota.

A further check of the applicability of the equation was made utilizing red pine plantation height growth curves from Connecticut (Bull 1931) and New York (Richards *et al.* 1962). Three height growth curves corresponding to the best, poorest, and average sites were constructed from Bull's data. Three of Richards' height growth curves corresponding to site index values of approximately 46, 58, and 70 feet at 50 years were used. In each case the growth intercept (GI_8) and the Ht_{25} were read from the height growth curves. The Ht_{25} as read from the curves was then compared with and found to be slightly less than Ht_{25} estimated from the growth intercept and the equation developed for natural stands in Minnesota [$Ht_{25} = 10.12 + 2.52 (GI_8)$] (table 3).

These small differences are a reflection of the fact that the height growth patterns of red pine are quite similar over a wide geographic range (Spurr 1955). In spite of the similarity of red pine height growth curves

Table 3. – Application of recommended growth intercept method to plantation data from Connecticut and New York

Source of data	5 year growth intercept above 8 ft. Col. A	Ht_{25} estimated from growth intercept (Ht_{25} = 10.12+ 2.52 (GI_8) Col. B	Ht_{25} from Bull's or Richards' height growth curves Col. C	Difference Col. B-Col. C
	Feet	Feet	Feet	Feet
Bull (1931):				
Best sites	12.3	41.1	39.5	+ 1.6
Average sites	9.4	33.8	32.3	+ 1.5
Poorest sites	6.2	25.7	22.7	+ 3.0
Richards et al. (1962):				
Best sites (Ht_{50} ca. 70 feet)	10.8	37.3	36.9	+ .4
Average sites (Ht_{50} ca. 58 feet)	7.9	29.9	29.0	+ .9
Poorest sites (Ht_{50} ca. 46 feet)	4.5	21.4	20.4	+ 1.0

over a wide geographic range, individual stands may deviate considerably from the standard curves. In particular the time required to reach BH may be variable. For natural stands or plantations which have taken 8 ± 2 years to reach BH the equation reported in this paper will enable the prediction of Ht_{25} within reasonable limits. For stands falling outside of this range sizeable errors in the estimation of Ht_{25} may result. In Minnesota no stands were found in which red pine reached BH in less than 6 years. And most stands requiring more than 10 to 11 years to reach BH have probably experienced severe early suppression and so are not suitable for estimation of site index.

The evidence presented in table 3 and figure 3 strongly suggests that the recommended growth intercept method (GI_8) can be used to predict Ht_{25} in plantations as well as natural stands over a wide geographical range. Certainly if there are errors involved in extending the results to plantations they are not great. If plantations follow different growth patterns than natural stands the differences should be most pronounced at young ages and there is no reason to believe that plantations and natural stands on similar sites grow differently after 25 years. It follows, therefore, that the recommended growth intercept method which can be used to predict Ht_{25} in plantations and natural stands, and Ht_{50} in natural stands, can also be used to predict Ht_{50} in plantations.

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