United States
Department of
Agriculture

Forest
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North Central
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Research
Paper **NC-280**

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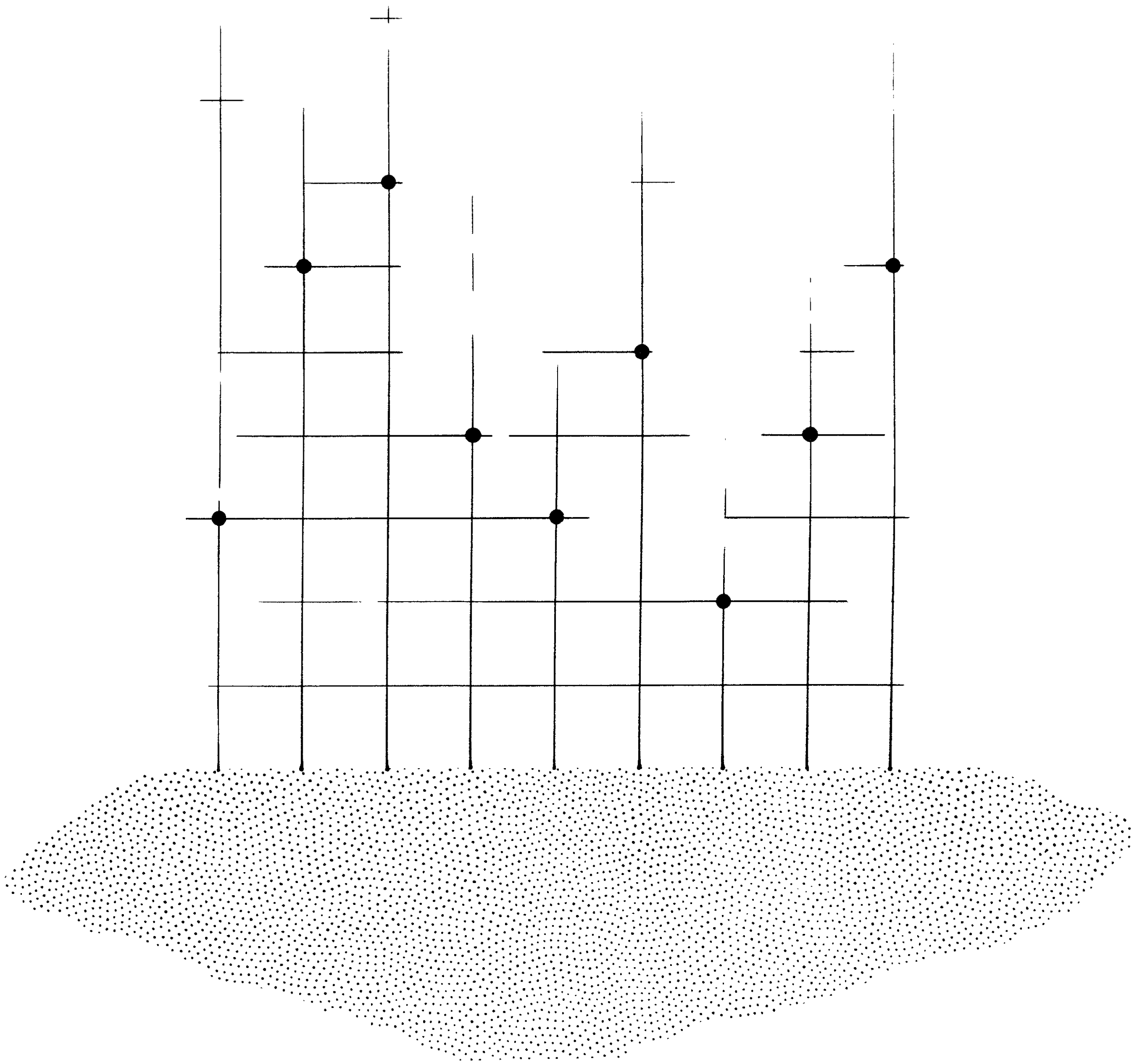

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Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication May 14, 1987
1987

GROWTH PATTERNS OF RED PINE ON FINE-TEXTURED SOILS

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Naturally occurring red pine (*Pinus resinosa* Ait.) in the Lake States and throughout its range is largely restricted to sandy soils (Fowells 1965). On finer textured soils (greater than 30 percent silt plus clay in the surface soil), intense plant competition probably restricts the natural establishment of red pine. But red pine plantations have been established on fine-textured soils in the Lake States (Rudolf 1950), perhaps in the expectation that red pine growth on these soils would be very high. Many of these stands have now reached the age where their growth potential can be realistically appraised.

We hypothesized that red pine growth should be greater on fine-textured soils because of increased availability of moisture and nutrients, as is the case for agricultural crops (Russell 1973) and many forest trees (Carmean 1975). Results for red pine, however, have not shown this to be true. Both Alban in Minnesota (1974) and Wilde *et al.* in Wisconsin (1965) reported red pine growth on well-drained fine-textured soils to be little different from growth on the better sandy soils. No significant relationship was found between red pine site index and soil texture in New York (DeMent and Stone 1968) or Massachusetts (Mader and Owen 1961). In all of these studies, excellent growth with a maximum site index of about 70-75 feet was observed on some well-drained fine-textured soils, but equally high site indices were found on some of the sandy soils.

Because most red pine stands occur on sandy soils, existing site index curves, yield tables, and growth prediction models have been developed for these kinds of sites, and their applicability to fine-textured soils is largely unknown. If volume growth of red pine on fine-textured soils were to differ from that on sandy soils, it could be because of differences in height growth, diameter growth, or bole form.

Height growth is particularly important because, through site index, it is the most commonly used indicator of site quality and is therefore a major variable in nearly all growth prediction models. For most species, the pattern of height growth varies with extreme soil conditions (polymorphism), and different site index curves have been developed to represent these conditions (Carmean 1975).

Red pine appears nearly unique in the rareness of polymorphism it exhibits (Alban 1985). In 165 red pine stands—both natural and plantation—growing on a wide range of sites throughout the Lake States, height growth in nearly all cases followed the pattern expected from the site index curves (Alban 1979). Nor was any evidence of polymorphism beyond breast height detected in 21 stands of red pine growing on well-drained fine-textured soils in Minnesota (Alban and Prettyman 1984). Thus, the standard site index curves (Gevorkiantz 1957) accurately describe the height growth of red pine on these fine-textured soils.

But even if the height growth pattern of red pine on fine-textured soils is the same as on other soils, it does not necessarily follow that diameter or volume growth are also identical. For example, Hoyle and Mader (1964) found that red pine height growth, which occurs primarily early in the season, is less sensitive to drought than diameter growth, which occurs well into the fall when droughts are more likely. Thus, the relationship between height and diameter growth may differ among soils that have different water storage capacities. Consequently, the use of site index (height growth) curves to predict yields could result in significant errors, unless the yield equations were modified to take storage capacity into account.

The purpose of the current study was to examine growth of red pine on fine-textured and sandy soils to see if it differed significantly from that predicted by two commonly used growth projection systems, both of which were developed primarily from red pine growing on sandy soils.

METHODS

Nine red pine plantations in northern Minnesota on fine-textured soils were sampled (table 1). The stands, which were nearly pure red pine, had been established at 4 × 4- to 8 × 8-ft spacing, and three had been thinned about 15 years prior to the study. For two of the stands, two measurements of tree diameter (d.b.h.) and height (ht) were made 8 or 10 years apart so that stand net growth and mortality was estimated directly.

In the other seven plantations, d.b.h. of every tree on a 0.3-A plot was measured and ht was measured on 30 trees to develop a ht-d.b.h. relationship. In each plantation, nine trees representing the full range of diameter and height were felled. Current d.b.h. as well as d.b.h. at 5-year intervals for the last 20 years were determined by stem analysis, resulting in a measure of periodic diameter growth of individual trees over the last 20 years. The linear relationship between current and past d.b.h. was very good. For example, r^2 for current d.b.h. vs d.b.h. 10 years ago ranged from 0.96 to 0.99 for the seven plantations. This relationship was used to determine the past d.b.h.'s of every tree on the plot, which allowed calculation of stand basal areas in the past.

Past stand volumes were calculated from the relationship: volume = 0.4085(BH) (Buckman 1961), where B is stand basal area as determined above and H is the height of dominant and codominant trees as determined from site index curves (Lundgren and Dolid 1970). Current stand volume from Buckman's equation was compared with stand volume calculated by summing the current volumes of individual trees for each of the nine plantations. Agreement was very close, with an average difference of only 1 percent and a maximum difference of 2.6 percent. Thus, the relationship between B and H and stand volume as established in 1961 by Buckman primarily for sandy soils works well also for fine-textured soils.

Table 1.—*Stand and site characteristics*

Stand number	Total tree age	Site index	Trees per acre	Basal area	Silt and clay	Soil
			FINE-TEXTURE SOILS			
	Years	Feet	Number	Ft^2/acre	Percent	
1[1]	48	69	417	187	52	unnamed (Glossic Eutroboralf)
2	48	66	417	188	55	"
3	49	65	413	200	57	"
4	46	62	943	222	59	"
5	46	63	853	224	58	"
6[1]	44	66	583	147	61	"
7[1]	44	65	560	157	62	"
8	49	71	658	255	36	Warba (Glossic Eutroboralf)
9	49	64	775	233	34	unnamed sandy loam over loam
Mean	47	66	615	201	53	
			SANDY SOILS			
10	35	69	680	217	11	Rubicon (Entic Haplorthod)
11	28	68	937	163	8	Menahga (Typic Udipsamment)
12	37	71	920	179	22	Zimmerman (Alfic Udipsamment)
13	35	65	847	196	10	Rubicon (Entic Haplorthod)
14	42	62	503	178	14	Vilas (Entic Haplorthod)
15	33	72	453	160	25	Padus (Alfic Haplorthod)
16	39	67	747	171	19	Vilas (Entic Haplorthod)
17	37	74	830	214	27	unnamed sandy loam over loamy sand
18	29	65	1,067	138	24	Zimmerman (Alfic Udipsamment)
Mean	35	68	776	180	18	

[1] Thinned stands.

Table 2.—*Sample tree characteristics (averages, with ranges in parentheses)*

Soils		Age	D.b.h.	10-yr d.b.h. growth	Live crown ratio	Form quotient
		Years	— — — — *Inches*	— — — —	*Percent*	
Fine-textured	(n= 63)	47	8.3	1.2	49	0.71
		(44-49)	(3.8-12.7)	(0.3-2.5)	(25-54)	(0.60-0.83)
Sandy	(n= 26)	35	6.5	1.3	48	0.72
		(28-42)	(4.2-8.5)	(0.5-2.2)	(38-58)	(0.63-0.81)

Nine additional red pine plantations growing on sandy soils in northern Minnesota and northwestern Wisconsin, which were used in a previous study (Alban 1978), were also utilized in this study (table 1). Tree d.b.h. and ht were measured as on the fine-textured soils. Stem analysis was also done as on the fine-textured soils, but on only three (in one case two) trees of mean basal area per plantation. This sampling scheme precluded determining past diameters for all trees in the plantation, but did allow an estimate of past stand basal area (the past basal area of mean trees was multiplied by the number of trees per acre, assuming no mortality).

The stands and trees on the sandy soils were similar in most characteristics to those on the fine-textured soils (tables 1 and 2). Trees on sandy soils were somewhat younger, but for the tree ages of this study (about 30-50 years), periodic basal area and volume growth in fully stocked stands were relatively constant and near maximum (Buckman 1962, Benzie 1977, Berry 1984). At this high growth rate, nutrient and moisture demands would also be high, and differences in the ability of fine- and coarse-textured soils to provide these materials should show up clearly.

The two growth projection models used in the study were STEMS (Belcher *et al.* 1982, Miner and Walters 1984) and REDPINE (Lundgren 1981)[1] . STEMS, an individual tree growth model updated and verified in 1985 (Holdaway and Brand 1986), is based on measurements of more than 92,000 trees of many species throughout the Lake States. STEMS estimates potential growth using tree d.b.h., site index, and live crown ratio. The potential growth is then adjusted based on the mean stand diameter, the ratio of tree d.b.h. to mean stand diameter, stand basal area, and the maximum possible stand basal area (350 ft^2/A for red pine). Thus, STEMS estimates diameter growth of individual trees. Stand basal area growth is obtained by summing individual tree growth after adjusting for mortality (Buchman 1983). Total cubic foot volume is estimated from the relationship: volume = 0.4085(BH), where B is stand basal area as determined by STEMS and H is the height of dominant and codominant trees as determined from age and the site index curves (Lundgren and Dolid 1970).

REDPINE is a stand projection model that projects basal area growth based on initial stand basal area, site index, and stand age with a constraint imposed on the maximum diameter growth allowed and with a reduction for mortality (Lundgren 1981). As with STEMS, volume equals 0.4085(BH).

For this study, growth comparisons were based on periodic growth over the last 10 years. This is a long enough interval to average out short-term climatic variation and to reduce measurement errors, while lessening problems associated with mortality and possible effects of past thinning.

Diameter growth of sample trees for the last 10 years (n = 63, fine-textured soils; n = 26, sandy soils) was compared with diameter growth predicted by STEMS. Stand basal area and volume growth as measured (or predicted from growth of sample trees) was compared with that predicted by STEMS and REDPINE. Growth predicted by STEMS or REDPINE was statistically compared with measured growth by a program developed by Rauscher (1986). The program determines a confidence interval for the differences between measured and predicted values based on the Student's t statistic. If the differences are not normally distributed, an approximate confidence interval is calculated by the jackknife procedure (Rauscher 1986). If the confidence interval includes zero, the differences between measured and predicted growth are not significant. For this paper all testing was done at the alpha = 0.05 level.

[1] *The STEMS version used in this study was one (GROBACK) developed for microcomputers by Gary J. Brand, North Central Forest Experiment Station; the REDPINE version was one (RPAL) developed by Carl W. Ramm, Michigan State University.*

RESULTS AND DISCUSSION

Bole Form

The form quotient, defined as the diameter outside bark at half the total tree height over d.b.h., was used as an indicator of bole form (Gevorkiantz and Olsen 1955).

The form quotient of the 63 trees growing on fine-textured soils (0.71) did not differ significantly from that of the 26 trees on sandy soils (table 2). Average form quotient on the sandy soils (0.72) was identical to that of 57 red pine plantation trees growing on mostly sandy soils throughout the Lake States from lower Michigan to northern Minnesota (Alban 1978).

Similarly, a volume prediction equation developed for the 63 trees on fine-textured soils (volume = 0.424(BASAL AREA × HEIGHT) R^2 = 0.998) did not differ significantly (95-percent level) from an equation developed for red pine on mostly sandy soils throughout the Lake States (Alban 1978). It is nearly identical to the composite equation (volume = 0.42 × BASAL AREA × HEIGHT) developed by Gevorkiantz and Olsen (1955) for many Lake States species.

The evidence is clear that the shape of red pine boles does not differ between fine-textured and sandy soils. Thus, knowing a red pine's basal area and height allows an accurate calculation of its bolewood volume, regardless of the kind of soil on which the tree is growing.

Tree Diameter Growth

For the 63 red pine trees on fine-textured soils, STEMS overpredicted the 10-year diameter growth by an average of 18 percent (1.42 vs 1.20 inches), which is statistically significant at the 95-percent level. (STEMS also significantly overpredicted the diameter growth for the last 5- and 20-year periods.) STEMS overpredicted diameter growth in 53 cases, underpredicted in 10 cases, and tended to overpredict most for the slowest growing trees (fig. 1). The STEMS overprediction (error) was not significantly related to tree d.b.h. or live crown ratio, or to stand basal area or site index. Slower growth than predicted on the fine-textured soils is the opposite of what we initially hypothesized.

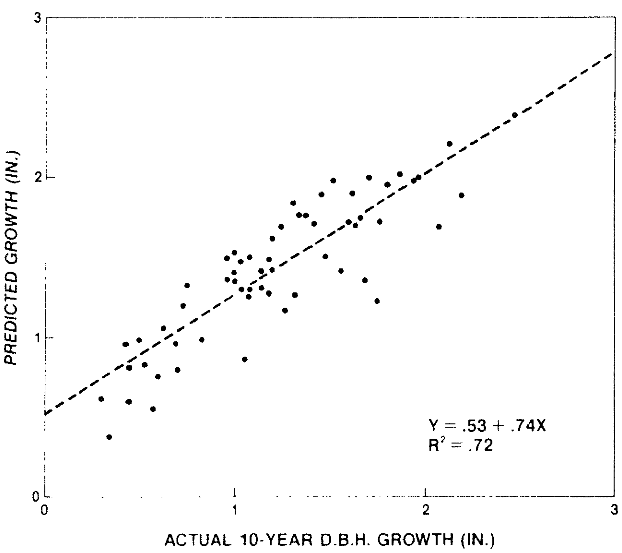

Figure 1.—*Actual 10-year diameter growth on fine-textured soils vs growth predicted by STEMS.*

For the 26 red pine trees on sandy soils, STEMS overpredicted 10-year d.b.h. growth by an average of 21 percent (1.62 vs 1.34 inches) (statistically significant). The nearly identical overprediction of STEMS for fine-textured and sandy soils (18 and 21 percent, respectively) further indicates that diameter growth rates on sands and fine-textured soils are similar as long as age, site index, crown ratio, and basal area are similar (as they were in this comparison). Thus, we found no evidence that diameter growth on fine-textured soils behaves differently from that on sandy soils. Growth prediction models should work similarly for both kinds of soils.

Tree Mortality

Both STEMS and REDPINE estimate tree mortality to be very low for red pine at the densities and ages in this study (table 3). This is in agreement with the number of standing dead trees actually observed, which averaged 35 per acre for the fine-textured soils and 40 per acre for the sands. The basal area of the standing dead trees averaged less than 2 percent that of live trees (table 3). Ring counts on a few standing dead trees indicated that dead trees remained standing for roughly 10 years; a similar estimate was obtained by comparing standing dead trees with annual mortality in the two stands (8 and 9) for which mortality was directly measured (table 3).

Dividing the standing dead trees by 10 gives mortality estimates of 3.5 and 4.0 trees per acre per year for the fine-textured and sandy soils, respectively. These estimates are higher than those derived from STEMS or REDPINE, but still very low. Because mortality is concentrated on the smaller trees, it can be disregarded for short-term growth projections with only small error. This is important because, in this study, our estimates of stand growth are based on measurements of currently live trees assuming no mortality.

Mortality in the two stands in which we measured it directly was higher than predicted by STEMS or REDPINE and is reflected in the number of standing dead trees. The reason for the high mortality in these stands is unknown, but they were the oldest stands in the study, had the highest basal area, and were established at 4 × 4 spacings. The mortality in stand 8 was similar to that found by Beckwith and Roebbelen (1983) for unthinned red pine at close spacing in Ontario. The very high mortality in stand 9 is unexplained, but we have no reason to expect that it is related to soil texture.

Table 3.—*Tree mortality and standing dead trees*

Stand	Age	Mortality: Measured	Mortality: Predicted STEMS	Mortality: Predicted REPINE	Standing dead trees: Number per acre	Standing dead trees: Percent of live basal area
FINE-TEXTURE SOILS						
		— — Number/acre per year — —				
1	38-48		0.3	0	20	1.0
2	38-48		.2	0	0	0
3	39-49		.4	0	7	.6
4	36-46		.7	3.1	17	.2
5	36-46		.8	1.9	30	.9
6	34-44		1.0	0	23	1.0
7	34-44		1.1	0	17	.7
8	39-49	6.2	.5	3.4	61	3.6
9	41-49	18.8	.5	5.2	144	5.3
Mean			.6	1.5	35	1.5
SANDY SOILS						
10	25-35		.3	0	0	0
11	18-28		2.6	0	63	2.1
12	27-37		1.9	0	80	.9
13	25-35		1.5	0	53	1.4
14	32-42		2.9	0	90	5.0
15	23-33		.6	0	0	0
16	29-39		.4	0	27	1.4
17	27-37		3.0	0	47	1.2
18	19-29		2.1	0	0	0
Mean			1.7	0	40	1.3

We found no evidence to indicate that mortality in successful plantings differs between red pine or fine-textured and sandy soils, at least up to an age of 50 years. Mortality is low on both kinds of soil, even in unthinned stands; we anticipate that it would be even lower under normal management, which includes thinnings (Lundgren 1981).

Stand Growth

Both STEMS and REDPINE use basal area as the basic measure of growth (STEMS uses individual trees and REDPINE uses the entire stand). Because height growth on fine-textured soils follows height growth patterns on sandy soils (Alban and Prettyman 1984), because bole form does not depend on soil texture, and because mortality is a minor factor in these stands, basal area growth should be an excellent indicator of whether stand growth on fine-textured soils behaves differently from that on sandy soils.

Both STEMS and REDPINE overpredicted basal area growth for red pine (table 4). The STEMS overpredictions of 1.4 and 1.0 ft^2 per acre per year for the fine-textured and sandy soils, respectively, are statistically significant. However, the REDPINE overpredictions of 0.3 and 0.4 ft^2 per acre per year are not statistically significant.

Volume predictions followed the same pattern. The 36 and 21 ft^3 per acre per year overpredictions by STEMS for fine-textured and sandy soils, respectively, are statistically significant, whereas the REDPINE overpredictions of 8 ft^3 per acre per year for both soils are not statistically significant.

It appears that STEMS overestimated red pine growth for these stands and that the error was most severe for stands with very high basal area (tables 1 and 4). Lundgren (1983) also found that STEMS gave higher estimates for red pine growth than did REDPINE.

But the most important observation is that REDPINE overpredicts red pine volume growth by amounts which do not differ for fine-textured and sandy soils (table 4). With the exception of the very high basal area stands, the same can be said for STEMS. This strongly suggests that red pine growth patterns are similar on both kinds of soils and that the same growth models will apply equally on both kinds.

Table 4.—*Ten-year current basal area and total cubic foot volume growth*

Stand	Basal area growth: Actual	Basal area growth: Predicted from STEMS	Basal area growth: Predicted from REPINE	Volume growth: Actual	Volume growth: Predicted from STEMS	Volume growth: Predicted from REPINE
	FINE-TEXTURE SOILS					
	——— Ft^2/acre/year ———			——— Ft^3/acre/year ———		
1	4.8	5.4	5.6	199	215	220
2	4.3	5.3	5.4	181	205	209
3	4.8	5.4	5.1	196	211	203
4	4.1	6.6	4.1	180	240	181
5	5.0	6.4	4.4	199	234	186
6	5.2	5.6	6.0	173	182	191
7	5.6	5.6	5.9	184	185	191
8	3.0	5.6	2.9	199	272	196
9	2.4	6.1	2.8	159	254	169
Mean	4.4	5.8	4.7	186	222	194
	SANDY SOILS					
10	5.6	7.1	5.9	210	240	216
11	8.0	7.8	8.2	180	177	184
12	4.1	7.4	6.4	173	246	224
13	5.2	6.9	5.9	179	212	193
14	6.8	7.2	5.7	201	209	178
15	6.7	6.5	6.8	193	190	195
16	6.2	7.0	6.1	196	213	194
17	6.4	7.2	6.3	239	256	237
18	6.5	7.9	7.8	145	167	166
Mean	6.2	7.2	6.6	191	212	199

These results are, of course, most reliable for Minnesota and northwestern Wisconsin. But the fact that plantation height growth patterns and bole form are constant throughout the Lake States suggests that the same principles may apply throughout the region. More testing would be necessary to verify this.

The fact that the same growth models can be used on both kinds of soils makes the observation of similar site index values for red pine on fine-textured soils and some of the better sandy soils (Alban 1974, DeMent and Stone 1968, Wilde *et al.* 1965) applicable as well to volume growth. Very high growth rates for red pine can occur on sandy soils as well as on fine-textured soils, and very poor growth can also occur on both kinds of soils. Clearly, soil texture *per se* is not a strong determinant of red pine growth.

SUMMARY AND CONCLUSIONS

We found no consistent differences in growth pattern of red pine on fine-textured and sandy soils. The height growth pattern of red pine has been shown previously (Alban and Prettyman 1984) to be similar for fine-textured and sandy soils. In this study, we were unable to find differences in mortality, bole form, or live crown ratio between red pines growing on these two kinds of soils, nor did we find differences in the pattern of individual tree diameter growth or stand basal area and volume growth. Thus, growth models developed from stands on sandy soils should be applicable to stands on well-drained fine-textured soils.

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Compares growth of 28- to 49-year-old red pine plantations on sandy and fine-textured soils. Red pine growing on these two contrasting soils did not differ in bole form, live crown ratio, or mortality, and tree growth predicted by models (STEMS and REDPINE) developed from trees growing on sandy soils worked equally well for trees growing on fine-textured soils.

KEY WORDS: *Pinus resinosa*, STEMS, REDPINE, plantations, height growth, diameter growth.