Thinning Planted Red Pine in Michigan
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by Victor J. Rudolph, Maurice W. Day, Walter A. Lemmien, John N. Bright and Jan J. Hacker[1]

Introduction

Periodic thinning is a necessary cultural practice in managing red pine *(Pinus resinosa)* plantations for sawtimber and other products in which fairly large tree diameters are important. Because red pine is the most frequently planted species in the Lake States, thinning procedures are of particular interest to forest managers.

Several methods may be used to thin red pine plantations. This report presents the results of applying three thinning methods to planted red pine in Michigan:

1. The residual basal area method — the stand is thinned periodically to leave a desired basal area. The residual basal area may be increased slightly in successive thinnings as the stand age increases.
2. The row thinning method — every other row, every third row, or every fourth row is removed. Usually row thinning is used only for the initial thinning, and some other method is applied in subsequent thinnings. However, in a stand initially thinned by removing every fourth row, a second row thinning is possible by removing the center row of the three remaining rows.
3. The percent of height method — the stand is thinned periodically so that the average spacing between residual trees is a specified percent of average dominant stand height.

Two of the red pine plantations used for this study are located in Michigan's upper peninsula, and a third is located in the lower peninsula. One plantation was thinned using the percent of height method. The other plantation was thinned using all three methods. The third plantation was thinned using residual basal area and row thinning methods.

Although the study areas are located in different climatic regions, on different site qualities, and differ somewhat in age and duration of thinning treatments, results are combined to present a comprehensive assessment of the three thinning methods and their applicability in managing planted red pine in Michigan.

Objectives

The three thinning methods applied in these plantations are compared with respect to:

1. Yield and income from the thinnings;
2. Stand structure by number of trees and size distributions; and
3. Growth, yield and value of the residual stands.

Silvicultural and economic aspects are integrated to indicate the best of the three methods and its level for thinning planted red pine.

The Plantations and Their Thinning Treatments

Dunbar Plantation

This plantation is located in the Dunbar Forest Experiment Station near Sault Ste. Marie, and is owned and operated by Michigan State University. The plantation was established in May 1927 on a field with Brimley fine sandy loam soil. The spacing was 6x8 feet, using 2-0 planting stock. The site index for red pine on this area ranges from 65 to about 75, and averages near 70. This plantation has a higher soil moisture regime than most typical red pine sites, with the water table at a depth of about six feet most of the year.

Five levels of the percent of height thinning method were applied in this plantation. In this method, the number of trees per acre in the desired residual stand was determined by the formula:

$$n = \frac{43{,}560}{(hf)^2}$$

Where n = the desired number of trees per acre after thinning

h = the total height in feet of the average dominant stand

and f = the desired average spacing in the stand after thinning,

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Cover photo — The south edge of the Dunbar Forest red pine plantation. Established in 1927 and 55 years old in 1981, it has been thinned nine times since 1953 by the percent of height method.

expressed as a percent of average dominant stand height (15).

For example, if the average dominant stand height is 50 feet and the average spacing after thinning is to be 20% (10 x 10 feet), then the number of trees per acre is 436. The desired number of trees in the residual stand should not include suppressed trees which have negligible effects on future stand development. The difference between the present and desired number of trees per acre is marked for removal in the thinning, with tree selection based on spacing, size, condition, vigor and general appearance. In this respect, the method is similar to thinning from below.

Average residual tree spacings corresponding to 16, 18, 20, 22 and 24 percent of the average dominant stand height were applied to each periodic thinning. These treatments represent a wide range in stand density. The five thinning treatments and an unthinned control were randomized in four blocks.

Initial measurements and thinning treatments began in 1953 when the plantation was 26 years old. The next five remeasurements and thinnings were made at three-year intervals in 1956, 1959, 1962, 1965, 1968 and 1971. The thinning interval was then increased to five years, with thinnings made in 1976 and 1981. The 1981 data for the plantation at 55 years of age are analyzed in this report. Views of plots thinned to 16 and 24 percent of height are shown in Figs. 1 and 2. A view of a control plot is shown in Fig. 3.

Kellogg Plantation

This plantation is located in the Kellogg Research Forest near Battle Creek, owned and operated by Michigan State University. It was established in 1936 on rolling abandoned farm land where considerable erosion had occurred. The soil is Oshtemo loamy sand. The spacing was approximately 7x8 feet. The site index for red pine is about 65.

Fig. 1. A plot in the Dunbar Forest plantation thinned nine times since 1953 to 16 percent of height.

Fig. 2. A plot in the Dunbar Forest plantation thinned nine times since 1953 to 24 percent of height.

Fig. 3. An unthinned control plot in the Dunbar Forest plantation. The average spacing was 12 percent of height and the basal area per acre was 313 sq. ft. in 1981 at age 55.

Four row thinning treatments and thinnings to four levels of residual basal area were initially applied in this study. Two row thinning treatments removed every other row and every third row. The second two treatments removed every fourth row, with the second treatment removing the center row of the remaining three rows in one set of plots. Residual basal area thinnings were made to 70, 90, 110 and 130 square feet per acre. The eight thinning treatments and an unthinned control were randomized on one-tenth-acre plots in four blocks.

Initial measurements and thinning treatments began in 1960 when the stand was 24 years old. Periodic stand measurements indicated that some treatment areas did not need to be thinned at the same time as others. Thus, subsequent thinning regimes were modified as indicated in Table 1. Data from the 1980 measurement and thinning, when the plantation was 45 years old, are analyzed in this report. Views of a plot thinned to 130 sq. ft. of basal area per acre, and of a control plot are shown in Figs. 4 and 5.

Table 1. Thinning schedules and treatments for the Kellogg Forest red pine plantation

Initial thinning treatment, 1960	Subsequent thinning treatments			
	1967	1970	1974	1980
70 sq. ft. B.A.	none	70 sq. ft. B.A.	none	95 sq. ft. B.A.
90 sq. ft. B.A.	90 sq. ft. B.A.	none	95 sq. ft. B.A.	105 sq. ft. B.A.
110 sq. ft. B.A.	110 sq. ft. B.A.	none	115 sq. ft. B.A.	120 sq. ft. B.A.
130 sq. ft. B.A.	130 sq. ft. B.A.	none	135 sq. ft. B.A.	140 sq. ft. B.A.
Alt. row cut	none	85 sq. ft. B.A.	none	100 sq. ft. B.A.
3rd row cut	100 sq. ft. B.A.	none	105 sq. ft. B.A.	105 sq. ft. B.A.
4th row cut; sel. 2nd cut	115 sq. ft. B.A.	none	120 sq. ft. B.A.	125 sq. ft. B.A.
4th row cut; center row 2nd cut	Center row cut	none	110 sq. ft. B.A.	125 sq. ft. B.A.
Control	none	none	none	none

Table 2. Thinning schedules and treatments for the Hiawatha National Forest red pine plantation.

Initial thinning treatment, 1962	Subsequent thinning treatments		
	1969	1976	1982
30 sq. ft. B.A.	30 sq. ft. B.A.	30 sq. ft. B.A.	none
45 sq. ft. B.A.	45 sq. ft. B.A.	45 sq. ft. B.A.	none
60 sq. ft. B.A.	60 sq. ft. B.A.	60 sq. ft. B.A.	none
80 sq. ft. B.A.	80 sq. ft. B.A.	80 sq. ft. B.A.	85 sq. ft. B.A.
100 sq. ft. B.A.	100 sq. ft. B.A.	100 sq. ft. B.A.	105 sq. ft. B.A.
130 sq. ft. B.A.	130 sq. ft. B.A.	130 sq. ft. B.A.	135 sq. ft. B.A.
160 sq. ft. B.A.	160 sq. ft. B.A.	160 sq. ft. B.A.	165 sq. ft. B.A.
Alt. row cut	90 sq. ft. B.A.	95 sq. ft. B.A.	100 sq. ft. B.A.
3rd row cut	120 sq. ft. B.A.	120 sq. ft. B.A.	125 sq. ft. B.A.
4th row cut; center row 2nd cut	Center row cut	110 sq. ft. B.A.	115 sq. ft. B.A.
4th row cut; 22% height 2nd cut	22% height	22% height	22% height
17% height	17% height	17% height	17% height
20% height	20% height	20% height	20% height
24% height	24% height	24% height	24% height
30% height	30% height	30% height	30% height
Control	none	none	none

Hiawatha National Forest Plantation

This plantation is located in the Sault Ste. Marie District of the Hiawatha National Forest near Trout Lake. It was established by the Civilian Conservation Corps in April 1938 on a level area in deep furrows at a spacing somewhat closer than 6x6. Soils on the area are mostly East Lake fine sand or sand, but Rubicon and Rousseau fine sands and sands are also present. The site index for red pine is approximately 65.

Initial measurements and thinnings began in 1962 when the stand was 25 years old. The 16 randomized treatments on one-tenth-acre plots in four blocks included:

— Residual basal areas of 30, 45, 60, 80, 100, 130 and 160 sq. ft. per acre;

— Row thinnings removing every other row, every third row, and two treatments removing every fourth row, with the second of these treatments removing the center row of the three remaining rows in one set of plots;

— Percent of height thinnings corresponding to 17, 20, 24, and 30 percent of average dominant stand height; and

— An unthinned control.

Plots were measured in 1965, 1969, 1976 and 1982. In 1969, it became obvious that some treatment areas, such as the very low basal area plots, did not need rethinning at the same time as others, and that other kinds of thinning would have to follow initial row thinning. Therefore, treatments listed in Table 2 were applied in 1969, 1976 and 1982.

Data from the 1982 measurement and thinning, when the plantation was 45 years old, are analyzed in this report. Views of plots thinned to 100 sq. ft. of basal area per acre, with every third row removed, with 20 percent of height, and a control, are shown in Figs. 6, 7, 8 and 9.

Results and Discussion

For each of the three areas, a brief summary of earlier published reports is included. Results are summarized for the thinning treatment used in each plantation study area on the number of trees, basal area, cubic-foot and board-foot volumes. Results are shown for both the thinning removals and the residual stand after the most recent thinning. The

Fig. 4. A plot in the Kellogg Forest plantation thinned five times since 1960 to 130 sq. ft. of basal area per acre.

Fig. 6. A plot in the Hiawatha National Forest plantation thinned four times since 1962 to 100 sq. ft. of basal area per acre.

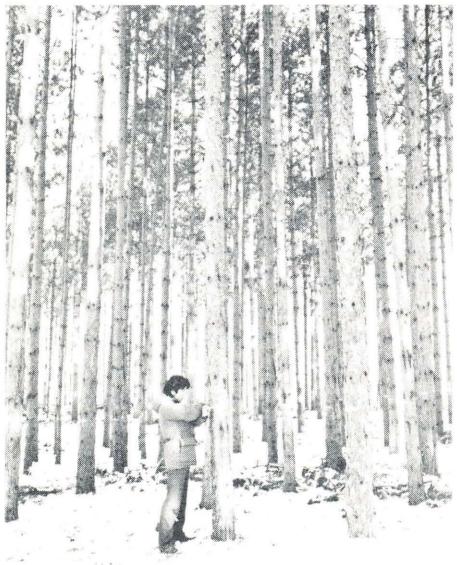

Fig. 5. An unthinned control plot in the Kellogg Forest plantation. The basal area was 234 sq. ft. per acre in 1980 at age 45.

Fig. 7. A plot in the Hiawatha National Forest plantation thinned in 1962 by removing every third row. Subsequent thinnings in 1969, 1976, and 1982 were made to 120, 120, and 125 sq. ft. of basal area per acre.

average tree diameters in the residual stands are also listed.

Data on the total production in cubic feet and board feet are analyzed for significant differences by Duncan's (9) multiple range and multiple F test procedures. The total values of the volumes produced are also analyzed for an economic comparison of the thinning treatments.

Dunbar Plantation

Two earlier reports were published for this plantation. Results in 1959 (5), six years after initial thinning, did not show any significant differences between treatments. At 32 years of age, the plantation's total production ranged from 3,908 cubic feet per acre for the 18 percent of height treatment, to 3,333 cubic feet per acre for the 24 percent treatment. The mean annual increment for these two treatments ranged from 126 cubic feet per acre to 107 cubic feet per acre, respectively.

Results in 1968 (7), after 15 years of thinning, showed that total production in basal area, cubic feet and board feet was greater for the lighter thinnings and the control

Fig. 8. A plot in the Hiawatha National Forest plantation thinned four times since 1962 to 20 percent of height.

Fig. 9. An unthinned control plot in the Hiawatha National Forest plantation. The basal area per acre was 259 sq. ft., and the spacing was 12 percent of height in 1982 at age 45.

than for the heavier thinnings. Total volume production ranged from 7,930 cubic feet per acre for the control plots, to 6,798 cubic feet per acre for the 24 percent treatment. The mean annual increment was the highest for the control plots, 193 cu. ft. per acre, and lowest for the 24 percent treatment, 166 cu. ft. per acre.

Average tree diameter varied inversely with stand density, ranging from 10.4 to 8.6 inches dbh. A financial evaluation showed that the lighter thinnings had greater total value production than the heavier thinnings, ranging from $503 per acre for the 24 percent thinning, to $613 for the 18 percent treatment, but these differences were not significant. The internal rate of return did not differ significantly by treatment and ranged from 8.7 to 9.1 percent.

Data as of 1981 for the five levels of the percent of height thinning treatments and the unthinned control are summarized in Tables 3 through 9. These data span 28 years of thinning treatment and also list total volume production for the 55-year-old plantation. For comparison with basal area thinning methods, the basal areas per acre after the beginning of the most recent growth period in 1976 are also listed in the tables.

The number of trees per acre varied widely, from 148 in the 24 percent of height treatment to 276 for the 16 percent treatment (Table 3). With an average dominant stand height of approximately 72 feet, the residual spacings after thinning in 1981 ranged from 12.6 x 12.6 feet for the 16 percent treatment, to 17.2 x 17.2 feet for the 24 percent treatment. The control plots reached a 12 percent of height spacing, equal to an actual average spacing of 8.4 x 8.4 feet. Mortality from competition in the control plots was light.

Average tree diameters vary inversely with stand density (Table 4). The increases in the average tree diameters due to the removal of trees smaller than the stand average were fairly uniform in all treatments. Increases through growth were larger for the heavier thinning treatments.

Basal area growth for the 28-year study period did not differ appreciably among treatments (Table 5). In several treatments, more basal area has been cut in thinning than has grown in the 28-year period. Residual basal area per acre in 1981 for the percent of height treatments ranged from 127 sq. ft. for the 24 percent treatment to 198 sq. ft. for the 16 percent treatment. With 313 sq. ft. per acre, the control plots were still increasing in basal area, with very little natural thinning taking place.

In Table 6, the treatments are ranked and analyzed for significant differences in the total cubic-foot volume production at age 55. The F-value for treatments was 7.9, significant at the 1% level.

Total cubic-foot volume production was the highest on the control plots, but it did not differ significantly from the 16 to 18 percent treatments. Production on the 16, 18 and 20 percent treatment areas was not significantly different. However, the 22 and 24 percent treatments were significantly lower than the control, 16 and 18 percent treatments. Thus, considering strictly total cubic-foot volume production by this plantation to age 55, thinning has been of questionable value. However, thinning to 18 percent of height could be applied without a significant decrease in the total cubic-foot volume production.

Competition in the denser stands has not retarded stand cubic-foot volume growth appreciably. Planted red pine can carry fairly high stand densities without reducing total stand growth. However, the influence of tree size on value and the timing of periodic thinning yields and incomes may be much more important than total volume produced over time. Value and periodic income may determine whether thinning planted red pine is appropriate and which thinning method and level are best economically.

Table 7 shows the ranking of the treatments for board-foot volume production. The lighter thinning treatments and the control show higher board-foot production than the heavier thinnings. However, these differences were not statistically significant. As in cubic-foot volume production, sawtimber values related to tree size, and the value of periodic thinning volumes, need to be considered for their effects on ranking the performance of the various thinning treatments and board-foot volume production.

Table 8 lists the local stumpage values per cord of pulpwood and per MBF (thousand bd. ft.) of sawtimber used to compute total value production by thinning treatments shown in Table 9.

The unthinned control areas produced the most value to age 55, with the two lightest thinnings, 16 and 18 percent, having only slightly lower production. Beginning with the 20 percent thinning, the total value produced drops steadily as thinning intensity increases. The heaviest thinning is significantly different from the control and the two lightest thinnings, but not from the 20 and 22 percent treatments.

As with cubic-foot and board-foot volume production, the total value production points toward the maintenance of fairly high stand densities and light thinnings. However, these indications are based on a uniform sawtimber stumpage rate regardless of the difference in tree diameter associated with different thinning treatments. The average tree

Table 3. Stand data for red pine thinning study to age 55 - Dunbar Forest

Treatment	Removed in nine thinnings 1953-81	Mortality 1953-81	Residual stand 1981[a]	Basal area after thinning 1976
	------ No. of trees/acre ------			Sq. ft./acre
Control	—	62	622	296
16% height	341	47	276	198
18% height	421	20	275	190
20% height	421	—	230	161
22% height	371	5	175	143
24% height	521	1	148	127

[a] The average number of trees per acre in the plantation in 1953 before thinning was 674.

Table 4. Tree diameter data for red pine thinning study to age 55 - Dunbar Forest

Treatment	Average diameter after thinning 1981[a]	Diameter change 1953-81			Basal area after thinning 1976
		Due to growth	Due to cutting	Total	
	---------- Inches ----------				Sq. ft./acre
24% height	12.6	4.4	1.5	5.9	127
22% height	12.4	3.6	2.2	5.8	143
20% height	11.6	2.9	1.6	4.5	161
18% height	11.2	2.7	1.5	4.2	190
16% height	11.2	3.0	1.3	4.3	198
Control	9.5	2.4	—	2.4	296

[a] The average tree diameter in the plantation in 1953 before thinning was 6.9 inches.

Table 5. Basal area data for red pine thinning study to age 55 - Dunbar Forest

Treatment	Removed in nine thinnings 1953-81	Mortality 1953-81	Residual stand 1981[a]	28-year growth 1953-81	Basal area after thinning 1976
	---------- Sq. ft./acre ----------				
16% height	116	4	192	137	198
22% height	149	—	143	136	143
18% height	136	2	187	134	190
20% height	145	—	165	132	161
24% height	166	2	127	131	127
Control	—	5	313	127	296

[a] The average basal area per acre in the plantation in 1953 before thinning was 174 sq. ft.

Table 6. Merchantable cubic-foot volume data for red pine thinning study to age 55 - Dunbar Forest[a]

Treatment	Removed in nine thinnings 1953-81	Mortality 1953-81	Residual stand 1981[b]	28-year growth 1953-81	Total production to age 55[c]	Mean annual increment to age 55	Basal area after thinning 1976
	Cu. ft./acre						Sq. ft./acre
Control	—	65	11,382	8,658	11,382	207	296
18% height	3,948	—	6,934	7,812	10,882	198	190
16% height	3,617	64	7,139	7,994	10,756	196	198
20% height	4,100	—	6,135	7,331	10,235	186	161
22% height	4,110	70	5,307	6,946	9,417	171	143
24% height	4,482	—	4,720	6,586	9,202	167	127

[a] Merchantable cubic-foot volume is to a 4-inch top, inside bark.
[b] The average volume per acre in the plantation in 1953 before thinning was 2,757 cu. ft.
[c] Volumes not enclosed within the same bracket are significantly different at the 5% level.

Table 7. Board-foot volume data for red pine thinning study to age 55 - Dunbar Forest[a]

Treatment	Removed in nine thinnings 1953-81	Mortality 1953-81	Residual stand 1981[b]	28-year growth 1953-81	Total production to age 55[c]	Mean annual increment to age 55	Basal area after thinning 1976
	Bd. ft./acre						Sq. ft./acre
16% height	9,599	241	32,131	39,590	41,730	759	198
Control	—	—	41,665	39,560	41,665	756	296
18% height	10,631	—	30,969	39,350	41,600	756	190
20% height	11,159	—	28,064	36,768	39,223	713	161
22% height	12,665	320	25,266	35,660	37,931	690	143
24% height	12,443	—	22,786	33,745	35,229	641	127

[a] Board-foot volumes are by the ¼-Inch International Rule, to a 6-inch top.
[b] The average volume per acre in the plantation in 1953 before thinning was 2,117 bd. ft.
[c] Total production was not significantly different at the 5% level.

diameter in 1981 for the heaviest thinning, 24 percent, was 12.6 inches, while the control plots had an average tree diameter of 9.5 inches. The application of a variable sawtimber stumpage rate somewhat related to tree diameter would alter the rankings of the total value produced by the various thinning treatments. The heavier and moderate thinnings would rank higher because tree diameters in these treatments are larger than in the lighter thinnings and in the controls. For example, a reduction in the average stumpage rate for the control plots from $40 to $38 per MBF would alter the value rankings to 16 percent, 18 percent, 20 percent, control, 22 percent, and 24 percent, in that order. At this time, however, trees 9.5 to 12.6 inches in diameter are all considered to be small sawtimber by timber buyers. Thus, a higher stumpage rate for the larger trees is not realistic, but may be so in the future. Differences in tree diameters between the higher and lower stand densities are increasing.

Table 8. Local stumpage values used for computing thinning incomes, 1953-81, and stand value in 1981 - Dunbar Forest

Date of thinning	Value per cord of pulpwood[a]	Value per MBF of sawtimber[b]
1953	$1.00	$ —
1956	2.00	6.00
1959	2.50	8.00
1962	2.50	10.00
1965	3.50	14.00
1968	4.00	20.00
1971	5.00	28.00
1976	6.00	34.00
1981	8.00	40.00

[a] 1 cord = 80 cu. ft.
[b] International ¼-inch Rule; trees 8.5 inches and larger.

Kellogg Forest Plantation

After the first thinning in 1960 at age 24, a report (10) showed that row thinning by removing every third row was the most economical by a significant margin over all applied treatments. In all row thinnings, even when every other row was removed, there were adequate numbers of potential final crop trees in the residual stands.

The 1980 data for the four residual basal areas, four row thinning treatments and the unthinned control in this plantation are summarized in Tables 10 through 16. These data cover 20 years of thinning treatment and also show total production of this 45-year-old plantation.

The number of trees per acre in 1980 varied from 148 for the 70 sq. ft. basal area treatment, to 260 for the 130 sq. ft. basal area thinning Table 10). These densities are approximately equivalent to

Table 9. Total value production for red pine thinning study to age 55 - Dunbar Forest - per acre basis

Treatment	Residual 1981 sawtimber stand volume	Residual 1981 sawtimber stand value @ $40 per M bd. ft.	Residual 1981 pulpwood stand volume,[a] and tops of sawtimber trees,[b]	Residual 1981 pulpwood stand value @ $8 per cord	Value of all thinnings 1953-81, with 5% interest compounded through 1981	Total value produced through 1981[c]	Basal area after thinning 1976
	Bd. ft.		Cds.				Sq. ft.
Control	41,665	$1,666.60	29.2	$233.32	$ —	$1,899.92	296
16% height	32,131	1,285.24	7.4	59.14	544.14	1,888.50	198
18% height	30,969	1,238.76	7.2	57.88	576.18	1,872.81	190
20% height	28,064	1,122.56	6.2	49.38	587.02	1,758.97	161
22% height	25,266	1,010.64	6.0	47.54	622.71	1,680.88	143
24% height	22,786	911.44	5.0	40.12	623.75	1,575.30	127

[a] Pulpwood stand: trees 5-8-inch dbh classes.
[b] Pulpwood volume in tops of sawtimber trees averages .22 cords per M bd. ft.
[c] Values not enclosed within the same bracket are significantly different at the 5% level.

Table 10. Stand data for red pine thinning study to age 45 - Kellogg Forest

Treatment	Removed in five thinnings 1960-80	Mortality 1960-80	Residual stand 1980[a]	Stand density after thinning 1974	
				Basal area	Percent of height
	---------- No. of trees/acre ----------			Sq. ft./acre	Percent
Control	—	58	680	213	14
130 sq. ft. B.A.	492	72	260	135	20
4th row cut, center row 2nd cut	575	78	222	110	22
4th row cut, selection 2nd cut	548	5	215	120	22
110 sq. ft. B.A.	586	52	190	115	24
3rd row cut	518	68	178	106	24
Alt. row cut	572	48	170	98	24
90 sq. ft. B.A.	558	52	160	96	27
70 sq. ft. B.A.	658	40	148	84	28

[a] The average number of trees per acre in the plantation in 1960 before thinning was 799.

average spacings of 17 x 17 feet for the 70 sq. ft. basal area treatment, and 13 x 13 feet for the 130 sq. ft. treatment. The spacing in the control plots is approximately 8 x 8 feet. Equivalent percents of height at age 45 range from 28 percent for the 70 basal area treatment to 21 percent for the 130 basal area treatment. The control plots reached a 13 percent of height average spacing.

Average tree diameters varied somewhat with stand density, but the range was only a little over an inch from the lightest to the heaviest thinning (Table 11). The increases in diameter due to cutting the smaller trees in the thinnings was about the same in all treatments, but increases in diameter due to growth were larger for the heavier thinnings.

Basal area growth for the 20-year study period was higher for the lighter thinnings and the control than for the heavier thinnings (Table 12). Considerably more basal area was removed in all the thinnings than grew in the 20-year study period. Basal area on the control plots reached 234 sq. ft. per acre in fairly steady increases, without appreciable mortality.

Table 13 ranks and compares the treatments for significant differences in total cubic-foot volume production at age 45. The F-value for treatments was 5.46, significant at the 1% level. Total cubic-foot volume production was highest by the control plots, but did not differ significantly from the 130 basal area, every fourth row, every third row and the 110 basal area thinning treatments. Production did not differ significantly with treatments by every fourth row cut with the center row taken in the second cut, the 110 basal area, every third row cut, or the 90 basal area treatment. Finally, the third row cut, 90 basal area, alternate row cut, and the 70 basal area treatments did not differ significantly in total cubic-foot volume production. Thus, considering strictly total cubic-foot volume production in this plantation to age 45, thinnings may have been of questionable value. Light thinnings to a residual basal area of approximately 106 sq. ft. per acre could be applied without significantly decreasing the total cubic-foot volume production. The denser stands have produced greater cubic-foot volumes without significant retardation from competition. The relationships of tree size to tree value and thinning yields to incomes need to be examined to evaluate the economics of the thinning treatments.

Table 14 shows the rankings and comparisons of the treatments for board-foot volume production. Differences between treatments were highly significant, F = 10.47. The lighter thinnings and the control plots show significantly

Table 11. Tree diameter data for red pine thinning study to age 45 - Kellogg Forest

Treatment	Average diameter after thinning 1980[a]	Diameter change 1960-80			Stand density after thinning 1974	
		Due to growth	Due to cutting	Total change	Basal area	Percent of height
	---------- Inches ----------				Sq.ft/acre	Percent
90 sq. ft. B.A.	11.1	3.9	1.3	5.2	96	27
70 sq. ft. B.A.	11.0	4.1	1.4	5.5	84	28
110 sq. ft. B.A.	10.8	3.6	1.3	4.9	115	24
3rd row cut	10.6	3.6	1.0	4.6	106	24
Alt. row cut	10.5	3.8	1.0	4.8	98	24
4th row cut, selection 2nd cut	10.3	3.1	1.4	4.5	120	22
4th row cut, center row 2nd cut	10.1	3.5	.9	4.4	110	22
130 sq. ft. B.A.	10.0	3.0	1.0	4.0	135	20
Control	7.8	1.8	—	1.8	213	14

[a] The average tree diameter in the plantation in 1960 before thinning was 5.8 inches.

Table 12. Basal area data for red pine thinning study to age 45 - Kellogg Forest

Treatment	Removed in five thinnings 1960-80	Mortality 1960-80	Residual stand 1980[a]	20-year growth 1960-80	Stand density after thinning 1974	
					Basal area	Percent of height
	---------- Sq. ft./acre ----------					Percent
4th row cut, selection 2nd cut	130	1	125	106	120	22
Control	—	7	234	97	213	14
4th row cut, center row 2nd cut	129	11	125	97	110	22
110 sq. ft. B.A.	132	13	121	93	115	24
130 sq. ft. B.A.	117	19	139	90	135	20
Alt. row cut	125	10	103	84	98	24
3rd row cut	126	17	109	81	106	24
70 sq. ft. B.A.	130	6	96	81	84	28
90 sq. ft. B.A.	126	11	107	81	96	27

[a] The average basal area per acre in the plantation in 1960 before thinning was 153 sq. ft.

higher total board-foot volume production than the heavier thinnings. The heaviest thinning, 70 sq. ft. of residual basal area, has produced less than two-thirds of the bd. ft. volume produced by the 130 sq. ft. basal area treatment. Some consideration of value differences due to tree diameter differences may modify the economic rankings of the range of thinning treatments.

Table 15 lists the local stumpage values per cord of pulpwood and per MBF of sawtimber. These were used to compute the total value production by thinning treatments shown in Table 16.

The unthinned controls have produced the most value to age 45, with the lighter thinnings producing only slightly less. Beginning with the fourth row cut and the center row removed in the second thinning (basal area 110 sq. ft. in 1974), the total value produced drops significantly, with the heaviest thinning, 70 sq. ft. of basal area, producing the lowest total value.

These results are based on applying a uniform sawtimber stumpage rate to all treatments, regardless of tree diameter. Average tree diameters ranged from 7.8 inches for the control plots to 11.1 inches for the 90 sq. ft. basal area treatment. If the stumpage rate for the control plots were reduced by just $2 per M because of smaller tree diameter, the control plots would then rank third in total value produced. Regardless, these results indicate that the lighter thinnings and higher stand densities have produced higher total values than the heavier thinnings and lower stand densities.

Hiawatha National Forest Plantation

Three years after the initial thinning in 1962, measurement of all treatments showed two results: stand growth varied directly with stand density; and trees on the south side of the two or three remaining rows in row thinnings grew significantly more than trees on the north side; and trees in the center of the three remaining rows grew only slightly more than trees in control plots (6).

After a second thinning in 1969, measurement showed that thinnings that left 90 to 100 sq. ft. of residual basal area, regardless of method, had significantly higher growth than other densities. Average tree diameters were inversely related to stand density. A financial evaluation showed that treatments in the 90 to 120 sq. ft. basal area range had the highest value production (8).

Data for the 1982 measurement and thinning covering the 20-year study period are summarized in Tables 17 through 23. Also listed are total volume production data for the 45-year-old plantation.

The number of trees per acre in 1982 ranged from 52 for the 30 sq. ft. basal area treatment to 485 for the 160 sq. ft. basal area treatment (Table 17). The close initial spacing in this plantation was still evident in the control plots, with 1,060 trees per acre, equivalent to a spacing of 6.4 x 6.4 feet, even after about 10% mortality.

Average tree diameter was closely correlated with thinning intensity (Table 18). The d.b.h. range between the heaviest thinning and the control was more than six inches. Diameter increases due to growth were largest for the heavier thinnings, and were fairly uniform for all treatments due to cutting trees smaller than the stand averages.

Table 13. Merchantable cubic-foot volume data for red pine thinning study to age 45 - Kellogg Forest[a]

Treatment	Removed in five thinnings 1960-80	Mortality 1960-80	Residual stand 1980[b]	20-year growth 1960-80	Total production to age 45[c]	Mean annual increment to age 45	Stand density after thinning in 1974	
							Basal area	Percent of height
	Cu. ft./acre						Sq. ft./acre	Percent
Control	—	110	7,701	5,328	7,701	171	213	14
130 sq. ft. B.A.	2,860	500	4,822	5,039	7,682	171	135	20
4th row cut, selection 2nd cut	3,253	—	4,384	5,293	7,637	170	120	22
4th row cut, center row 2nd cut	3,026	211	4,353	5,004	7,379	164	110	22
110 sq. ft. B.A.	3,068	327	4,276	4,817	7,344	163	115	24
3rd row cut	2,985	396	3,821	4,334	6,806	151	106	24
90 sq. ft. B.A.	2,756	241	3,783	4,088	6,539	145	96	27
Alt. row cut	2,639	158	3,610	4,059	6,249	139	98	24
70 sq. ft. B.A.	2,537	121	3,397	3,780	5,934	132	84	28

[a] Merchantable cubic-foot volume is to a 4-inch top, inside bark.
[b] The average volume per acre in the plantation in 1960 before thinning was 2,392 cu. ft.
[c] Volumes not enclosed within the same bracket are significantly different at the 5% level.

Table 14. Board-foot volume data for red pine thinning study to age 45 - Kellogg Forest[a]

Treatment	Removed in two thinnings 1974-80	Mortality 1974-80	Residual stand 1980	6-year growth 1974-80	Total production to age 45[b]	Mean annual increment to age 45	Stand density after thinning in 1974	
							Basal area	Percent of height
	Bd. ft./acre						Sq. ft./acre	Percent
130 sq. ft. B.A.	4,742	814	19,884	6,104	24,626	547	135	20
Control	—	200	24,404	8,260	24,404	542	213	14
4th row cut, selection 2nd cut	5,223	—	18,471	7,048	23,694	527	120	22
110 sq. ft. B.A.	4,949	856	18,225	4,746	23,174	515	115	24
4th row cut, center row 2nd cut	3,198	110	18,207	6,658	21,405	476	110	22
3rd row cut	4,939	480	16,136	5,042	21,075	468	106	24
90 sq. ft. B.A.	3,703	155	16,231	4,738	19,934	443	96	27
Alt. row cut	2,615	88	15,242	6,089	17,857	397	98	24
70 sq. ft. B.A.	1,420	—	14,544	4,750	15,964	355	84	28

[a] Board-foot volumes are by the ¼-Inch International Rule, to a 6-inch top.
[b] Volumes not enclosed within the same bracket are significantly different at the 5% level.

Basal area growth for the 20-year period did not differ widely among most treatments, but it was substantially lower in the two heaviest thinnings and the control plots (Table 19). Increasing mortality in the control plots has slowed the basal area increases, but the basal area had reached 259 sq. ft. per acre in 1982 at 45 years.

In Table 20, the treatments are ranked and compared for differences in total cubic-foot volume production by the 45-year-old plantation. Statistical analysis showed treatment differences to be highly significant, with an F-value of 32.61. The lighter thinnings and the control show significantly higher total cubic-foot volume production than the heavier thinnings. Of the percent of height treatments, only the 30% thinning was not in the top production group. Treatments leaving residual basal areas above 120 sq. ft. per acre were also in the upper production group. With increasing thinning intensity and decreasing residual stand density, production decreased significantly.

Stands with residual areas below 100 sq. ft. per acre do not appear to make full use of the available

Table 15. Local stumpage values used for computing thinning incomes, 1960-80, and stand values in 1980 - Kellogg Forest

Date of thinning	Value per cord of pulpwood[a]	Value per MBF of sawtimber[b]
1960	$2.50	$25.00
1967	3.50	35.00
1970	4.00	40.00
1974	4.50	45.00
1980	5.00	50.00

[a] 1 cord = 80 cu. ft.
[b] International ¼-inch Rule; trees 8.5 inches and larger.

Table 16. Total value production for red pine thinning study to age 45 - Kellogg Forest - per acre basis

Treatment	Residual 1980 sawtimber stand volume	Residual 1980 sawtimber stand value @ $50 per M bd. ft.	Residual 1980 pulpwood stand volume[a] and tops of sawtimber trees[b]	Residual 1980 pulpwood stand value @ $5 per cord	Value of all thinnings 1960-80, with 5% interest compounded through 1980	Total value produced through 1980[c]	Stand density after thinning 1974	
							Basal area	Percent of height
	Bd. ft.		Cds.				Sq. ft.	Percent
Control	24,404	$1,220.20	50.5	$252.38	$ —	$1,472.58	213	14
130 sq. ft. B.A.	19,884	994.20	5.2	26.24	422.34	1,442.78	135	20
4th row cut, sel. 2nd cut	18,471	923.55	6.8	33.80	484.83	1,442.18	120	22
110 sq. ft. B.A.	18,225	911.25	4.4	21.98	461.41	1,394.64	115	24
4th row cut, center row 2nd cut	18,207	910.35	5.6	28.10	388.46	1,326.91	110	22
3rd row cut	16,131	806.55	4.5	22.71	441.42	1,270.68	106	24
90 sq. ft. B.A.	16,231	811.55	3.6	17.86	370.22	1,199.63	96	27
Alt. row cut	15,242	762.10	4.8	23.79	303.20	1,089.09	98	24
70 sq. ft. B.A.	14,544	727.20	3.6	17.94	252.78	997.92	84	28

[a] Pulpwood stand: trees in the 5-8-inch dbh classes.
[b] Pulpwood volume in tops of sawtimber trees averages .22 cords per M bd. ft.
[c] Values not enclosed within the same bracket are significantly different at the 5% level.

growing space on this site. Understory herbs and shrubs were noticeably denser in the heavier thinnings.

Board-foot volumes were computed for the first time in the 1982 measurement. Previously, the average tree diameters were too small to show appreciable sawtimber volumes. The board-foot volume data for 1982 are ranked in Table 21. Differences between treatments were highly significant $F = 31.25$.

The total board-foot volume production to age 45 was related to both stand density and tree diameter. The treatments with stand densities in the 24 to 30 percent of height, or 80 to 120 sq. ft. basal area range, showed significantly higher production than higher or lower densities. The treatments that still have large numbers of trees below the minimum sawtimber diameter are bound to show considerable board-foot volume ingrowth before the next periodic thinning. But the lowest stand densities where all trees are already of sawtimber size will not show such ingrowth. Thus, the present ranking may shift somewhat in favor of the lighter thinning treatments in the future.

Table 22 lists the local stumpage values per cord of pulpwood and per MBF of sawtimber used to compute total value production by the thinning treatments listed in Table 23.

Thinnings in the 80 to 130 sq. ft. residual basal area range or in the 30 to 20 percent of height range produced the highest total values to age 45. Rather small differences were shown throughout these ranges of stand densities. Higher and lower stand densities showed significantly lower total value

Table 17. Stand data for red pine thinning study to age 45 - Hiawatha National Forest

Treatment	Removed in five thinnings 1962-82	Mortality 1962-82	Residual stand 1982[a]	Stand density after thinning 1974	
				Basal area	Percent of height
	--------- No. of trees/acre ---------			Sq. ft./acre	Percent
Control	—	114	1,060	245	12
160 sq. ft. B.A.	676	21	485	161	17
17% height	747	43	460	149	17
20% height	795	10	320	125	20
130 sq. ft. B.A.	908	4	315	132	21
3rd row cut	883	22	300	122	21
4th row cut, center row 2nd cut	811	47	272	107	22
4th row cut, 22% ht. 2nd cut	938	24	270	120	22
24% height	896	4	220	108	24
100 sq. ft. B.A.	921	4	205	101	25
Alt. row cut	951	4	190	93	26
30% height	970		145	86	30
80 sq. ft. B.A.	997		145	80	30
60 sq. ft. B.A.	1,060		115	63	38
45 sq. ft. B.A.	1,103	2	72	47	47
30 sq. ft. B.A.	1,240		52	35	58

[a] The average number of trees per acre in the plantation in 1953 before thinning was 1,176.

Table 18. Tree diameter data for red pine thinning study to age 45 - Hiawatha National Forest

Treatment	Average diameter after thinning 1982[a]	Diameter change 1962-82			Stand density after thinning in 1976	
		Due to growth	Due to cutting	Total change	Basal area	Percent of height
	Inches				Sq.ft/acre	Percent
30 sq. ft. B.A.	12.9	6.5	1.3	7.8	35	58
45 sq. ft. B.A.	12.7	6.1	1.4	7.5	47	47
60 sq. ft. B.A.	11.7	5.3	1.2	6.5	63	38
30% height	10.9	4.3	1.2	5.5	86	30
80 sq. ft. B.A.	10.6	4.2	1.1	5.3	80	30
Alt. row cut	9.8	3.6	.9	4.5	93	26
100 sq. ft. B.A.	9.7	3.4	1.0	4.4	101	25
24% height	9.7	3.2	1.1	4.3	108	24
130 sq. ft. B.A.	8.8	2.6	1.0	3.6	132	21
4th row cut, 22% ht. 2nd cut	8.8	2.5	1.2	3.7	120	22
4th row cut, center row 2nd cut	8.8	2.8	.5	3.3	107	22
3rd row cut	8.7	2.6	1.0	3.6	122	21
20% height	8.6	2.3	1.0	3.3	125	20
160 sq. ft. B.A.	7.8	1.9	.7	2.6	161	17
17% height	7.7	1.7	1.0	2.7	149	17
Control	6.6	1.3	.0	1.3	245	12

[a] The average tree diameter in the plantation in 1962 before thinning was 5.2 inches.

Table 19. Basal area data for red pine thinning study to age 45 - Hiawatha National Forest

Treatment	Removed in four thinnings 1962-82	Mortality 1962-82	Residual stand 1982[a]	20-year growth 1962-82	Stand density after thinning 1976	
					Basal area	Percent of height
	Sq. ft./acre					Percent
24% height	179	2	114	110	108	24
130 sq. ft. B.A.	160	1	134	110	131	21
30% height	196	—	94	110	86	30
80 sq. ft. B.A.	189	—	90	108	80	30
4th row cut, 22% height 2nd cut	171	2	116	104	120	22
100 sq. ft. B.A.	173	1	106	104	101	25
20% height	149	1	131	104	125	20
Alt. row cut	181	1	101	104	93	26
3rd row cut	160	4	124	103	122	21
4th row cut, center row 2nd cut	157	5	115	100	107	22
160 sq. ft. B.A.	111	4	164	97	161	17
60 sq. ft. B.A.	189	—	86	94	63	38
17% height	122	4	149	93	149	17
45 sq. ft. B.A.	192	1	64	79	47	47
Control	—	14	259	78	245	12
30 sq. ft. B.A.	204	—	48	59	35	58

[a] The average basal area per acre in the plantation in 1962 before thinning was 180 sq. ft.

production. The control, 17 percent, and 160 basal area treatments have shown low board foot volume growth because of overstocking. These three treatments have the smallest average tree diameters and the highest numbers of trees. If a somewhat lower sawtimber stumpage rate was applied to the sawtimber volumes in these treatments because of the smaller tree diameters, their rankings in total value produced would be even lower.

Comparison of Results with Other Studies

In reporting preliminary results three years after initial thinning in an 18-year-old red pine plantation near Houghton in Michigan's upper peninsula, with an estimated site index of 81, Coffman (3) recommended thinning to 90 sq. ft. of basal area per acre. For both natural and planted red pine stands in northern Minnesota on areas with the site index ranging from 45 to 60, Lundgren (11) also found that 90 sq. ft. of basal area was projected to produce the highest financial returns on rotations ranging from 55 to 85 years. Interest rate for costs and returns was set at 8 percent.

In two later reports, Lundgren (12, 13) simulated growth and yield of red pine plantations using REDPINE, an unpublished growth and yield model. For all sites, his projected cubic-foot volumes were considerably higher than those listed by Buckman (2) and earlier authors. Lundgren found that merchantable cubic-foot volume production drops rapidly on all sites with fewer than 200 established trees per acre. For initial densities above 200 trees per acre, production rose gradually, peaking at about 800 trees per acre and 120 sq. ft. of basal area for site index 50, and at 1,000 trees and 140 sq. ft. on site index 70. Board-foot volume production peaked at 200 trees per acre on all sites. He also compared his predicted cubic-foot volumes with 12 published reports of red pine yields, primarily from research studies in the Lake States and Ontario, Canada. For similar stand ages and sites, no significant differences were found.

From results in thinning six red pine plantations in lower Michigan, Cooley (4) recommended that initial thinnings should be row thinnings, and that stand density could be reduced to about 60 sq. ft. of basal area per acre without reducing total yield. Our results show that stand densities below 110 sq. ft. of basal area per acre reduced total yields significantly. For thinning pole timber size red pine stands, Benzie (1) recommends

Table 20. Merchantable cubic-foot volume data for red pine thinning study to age 45 - Hiawatha National Forest[a]

Treatment	Removed in four thinnings 1962-82	Mortality 1962-82	Residual stand 1982[b]	20-year growth 1962-82	Total production to age 45[c]	Mean annual increment to age 45	Stand density after thinning in 1976	
							Basal area	Percent of height
	Cu. ft./acre						Sq. ft./acre	Percent
20% height	3,158	9	3,823	4,624	6,980	155	125	20
160 sq. ft. B.A.	2,194	38	4,760	4,682	6,954	155	161	17
130 sq. ft. B.A.	3,023	15	3,922	4,624	6,945	154	132	21
Control	—	216	6,941	4,563	6,941	154	245	12
24% height	3,514	42	3,276	4,335	6,789	151	108	24
17% height	2,454	45	4,332	4,585	6,785	151	149	17
4th row cut, 22% height 2nd cut	3,413	21	3,364	4,451	6,777	151	120	22
3rd row cut	3,040	102	3,625	4,392	6,664	148	122	21
4th row cut, center row, 2nd cut	3,079	57	3,348	4,198	6,428	143	107	22
100 sq. ft. B.A.	3,241	27	3,056	4,029	6,297	140	101	25
30% height	3,652	—	2,618	3,821	6,269	139	86	30
Alt. row cut	3,362	15	2,883	3,874	6,245	139	93	26
80 sq. ft. B.A.	3,390	—	2,512	3,702	5,901	131	80	30
60 sq. ft. B.A.	3,066	—	2,330	3,037	5,396	120	63	38
45 sq. ft. B.A.	3,016	32	1,662	2,412	4,678	104	47	47
30 sq. ft. B.A.	2,992	—	1,232	1,782	4,224	94	35	58

[a] Merchantable cubic-foot volume is to a 4-inch top, inside bark.
[b] The average volume per acre in the plantation in 1962 before thinning was 2,323 cu. ft.
[c] Volumes not enclosed within the same bracket are significantly different at the 5% level.

Table 21. Board-foot volume data for red pine thinning study to age 45 - Hiawatha National Forest[a]

Treatment	Removed in thinning 1982	Residual stand 1982	Total production to age 45[b]	Mean annual increment to age 45	Stand density after thinning 1976	
					Basal area	Percent of height
	Bd. ft./acre				Sq. ft./acre	Percent
24% height	2,344	12,710	15,054	335	108	24
30% height	2,629	11,252	13,882	308	86	30
100 sq. ft. B.A.	1,680	12,028	13,708	305	101	25
80 sq. ft. B.A.	2,304	10,636	12,940	288	80	30
Alt. row cut	1,624	11,313	12,937	287	93	26
130 sq. ft. B.A.	1,185	11,314	12,499	278	132	21
4th row cut, center row 2nd cut	1,534	10,021	11,555	257	107	22
4th row cut, 22% height 2nd cut	1,359	10,126	11,485	255	120	22
60 sq. ft. B.A.	—	10,612	10,612	236	63	38
20% height	1,103	9,464	10,567	235	125	20
3rd row cut	937	9,575	10,512	234	122	21
45 sq. ft. B.A.	—	8,136	8,136	181	47	47
30 sq. ft. B.A.	—	6,074	6,074	135	35	58
160 sq. ft. B.A.	124	5,846	5,970	133	161	17
17% height	—	3,872	3,872	86	149	17
Control	—	3,443	3,443	76	245	12

[a] Board-foot volumes are by the ¼-Inch International Rule, to a 6-inch top.
[b] Volumes not enclosed within the same bracket are significantly different at the 5% level.

residual densities of 90 sq. ft. of basal area per acre and somewhat higher residual basal areas for thinning sawtimber stands.

Total yields in both cubic feet and board feet at age 45 for the Kellogg Forest and Hiawatha National Forest plantations and at age 55 for the Dunbar Forest plantation are much higher than those listed by Buckman (2) in yield tables for both 90 and 120 sq. ft. of basal area stand densities for site index 60 in northern Minnesota.

Rose, Leary and Chen (14) have presented an optimum thinning schedule for maximum cubic-foot volume production for red pine based on plantation data from Michigan, Minnesota and

Wisconsin. In their example, a 20-year-old plantation with an initial basal area of 165 sq. ft. per acre is thinned every 10 years. The residual basal area is increased gradually to 182 sq. ft. at age 40, and then maintained at approximately that level to the culmination of the mean annual increment at age 70. In our studies, cubic-foot volume yields for high density and control plots in general agree with their production yields.

Table 22. Local stumpage values used for computing thinning incomes, 1962-82, and stand values in 1982 - Hiawatha National Forest

Date of thinning	Value per cord of pulpwood[a]	Value per MBF of sawtimber[b]
1962	$4.00	$ —
1969	4.00	—
1976	6.00	—
1982	9.00	60.00

[a] 1 cord = 80 cu. ft.
[b] International ¼-inch Rule; trees 8.5 inches and larger.

Summary and Conclusions

In the Dunbar Forest in Michigan's upper peninsula, 16, 18, 20, 22 and 24 percent of height thinnings were made nine times starting in 1953 when the red pine plantation was 26 years old. At age 55 years in 1981, when the most recent thinning was made, the number of trees per acre ranged from 148 for the 24 percent thinning, to 276 for the 16 percent thinning. The control plots averaged 622 trees per acre. Average tree diameters ranged from 9.5 inches for the control areas, to 12.6 for the 24 percent thinning. Basal area growth has varied little among thinning treatments. The 24 percent thinning shows a basal area of 127 sq. ft. per acre, while the control plots have reached 313 sq. ft. per acre.

Control plots show the highest cubic-foot volume production, but not significantly higher than the 16 and 18 percent thinnings. Heavier thinnings show significantly lower cubic-foot volume production. Thus, based strictly on cubic feet produced, thinning may be of questionable value in this plantation to date.

In board-foot volume production, there were no significant differences among the various treatments, but the lighter thinnings and the control showed higher production.

Total value produced to age 55 was significantly higher for the controls and the lighter thinnings and decreased significantly with the heavier thinnings. Even though average tree diameters ranged from 9.5 inches for the controls to 12.6 inches for the 24 percent thinning, a uniform sawtimber stumpage value was applied because timber buyers consider these sizes to be small sawtimber. A variable stumpage rate related to tree diameter would alter the treatment rankings for total value production.

Based on cubic-foot, board-foot and total value production to date for this 55-year-old red pine plantation, the maintenance of fairly high stand densities by the application of light thinnings

Table 23. Total value production for red pine thinning study to age 45 - Hiawatha National Forest - per acre basis

Treatment	Residual 1982 sawtimber stand volume	Residual 1982 sawtimber stand value @ $60 per M bd. ft.	Residual 1982 pulpwood stand volume[a] and tops of sawtimber trees[b]	Residual 1982 pulpwood stand value @ $9 per cord	Value of all thinnings 1962-82, with 5% interest compounded through 1982	Total value produced through 1982[c]	Stand density after thinning 1976	
							Basal area	Percent of height
	Bd. ft.		Cds.				Sq. ft.	Percent
24% height	12,710	$762.60	4.2	$ 37.76	$453.38	$1,253.74	108	24
30% height	11,252	675.12	2.5	22.27	495.96	1,193.35	86	30
130 sq. ft. B.A.	11,314	678.84	15.1	135.58	361.97	1,176.39	132	21
100 sq. ft. B.A.	12,028	721.68	3.2	29.21	408.10	1,158.99	101	25
Alt. row cut	11,313	678.78	3.5	31.39	431.76	1,141.93	93	26
4th row cut, 22% height 2nd cut	10,126	607.56	12.0	107.56	414.63	1,129.75	120	22
80 sq. ft. B.A.	10,636	638.16	2.3	21.05	452.14	1,111.35	80	30
20% height	9,464	567.84	19.3	173.98	359.82	1,101.64	125	20
3rd row cut	9,575	574.50	16.6	149.67	366.04	1,090.21	122	21
4th row cut, center row 2nd cut	10,021	601.26	12.0	107.82	378.60	1,087.68	107	22
160 sq. ft. B.A.	5,846	350.76	48.1	432.55	233.64	1,016.95	161	17
60 sq. ft. B.A.	10,612	636.72	2.3	21.01	348.72	1,006.45	63	38
Control	3,443	206.58	76.2	685.87	—	892.45	245	12
17% height	3,872	232.32	42.2	379.81	253.35	865.48	149	17
45 sq. ft. B.A.	8,136	488.16	1.8	16.10	348.11	852.37	47	47
30 sq. ft. B.A.	6,074	364.44	1.3	12.02	359.03	735.49	35	58

[a] Pulpwood stand: trees in the 5-8-inch dbh classes.
[b] Pulpwood volume in tops of sawtimber trees averages .22 cords per M bd. ft.
[c] Values not enclosed within the same bracket are significantly different at the 5% level.

appears to be preferable to lower stand densities resulting from heavier thinnings.

In the Kellogg Forest plantation near Battle Creek, Michigan, row and basal area thinnings have been applied since 1960 to red pine that was then 24 years old. Row thinnings included removing every other row, every third row, and two treatments removing every fourth row, with the center row of the three remaining rows removed in the second thinning in one of these treatments. Basal area thinnings were made to 70, 90, 110, and 130 sq. ft. of basal area per acre. Unthinned controls were also left. Subsequent thinnings on the plots initially given row thinnings were made on a basal area basis.

In the initial thinning in 1960, removing every third row proved to be the most economical method by a significant margin. Also, there were adequate numbers of potential final crop trees in all plots given row thinnings.

In 1980, when the most recent thinning was made, the number of trees per acre varied from 148 for the 70 basal area thinning to 260 for the 130 basal area treatment. The control plots had 680 trees per acre. Tree diameters ranged from 7.8 inches for the control plots to 11.1 inches for the 90 basal area thinning. Basal area growth was higher for the lighter thinnings and the controls than for the heavier thinnings. The control plots reached 234 sq. ft. of basal area per acre in 1980.

Cubic-foot volume production was highest on the control plots, followed closely by the higher basal area treatments. Basal areas below approximately 110 sq. ft. per acre showed significantly lower cubic-foot volume production.

In board-foot volume production, the higher basal area treatments and the control plots ranked significantly higher than the heavier thinnings. At age 45, the 70 basal area thinning produced only two-thirds of the volume produced by the 130 basal area thinning.

Total value produced to age 45 was highest by the control plots, with the lighter thinnings only slightly lower. Below 110 sq. ft. of basal area, total value produced dropped significantly. As in the case of the Dunbar Forest thinning study, the application of a variable sawtimber stumpage value related to tree size would change the rankings for total value production.

The Kellogg Forest plantation data is for a stand that is 10 years younger than the Dunbar Forest plantation and the site index is about 10 feet lower. However, results to date utilizing different thinning approaches in the two plantations are remarkably consistent in numbers of trees, tree diameters, cubic-foot and board-foot volumes and total value produced. Although the volumes and values reflect age and site differences for the two plantations, the higher stand densities and the lighter thinnings ranked higher than the lower stand densities and heavier thinnings in both plantations.

Thinning in the Hiawatha National Forest started in 1962 when the plantation was 25 years old. Residual basal area treatments included 30, 45, 60, 80, 100, 130, and 160 sq. ft. per acre. Row thinning treatments included removing every other row, every third row, and two treatments removing every fourth row with the center row of the three remaining rows removed in the second thinning in one of these treatments. Percent of height thinnings included 17, 20, 24 and 30 percent. Unthinned control plots were also left. Subsequent thinnings in the initial row thinning treatments were either basal area or percent of height thinnings.

At age 45 in 1982, when the most recent thinning was made, the number of trees per acre varied from 52 for the 30 basal area treatment, to 485 for the 160 basal area plots. The close initial spacing in this plantation was still evident in the control plots, which had 1,060 trees per acre, equivalent to a 6.4 by 6.4 spacing, even after about 10 percent of the original trees had died. Tree diameters ranged from 6.6 inches for the controls, to 12.9 inches for the 30 basal area treatment. The average tree diameter in the controls had increased only 1.4 inches in the 20-year thinning study period.

Basal area growth varied little among most treatments, except for the 30 and 45 basal area treatments, where it was markedly lower. The basal area on the control plots reached 259 sq. ft. per acre in 1982 at age 45.

In cubic feet, the lighter thinnings and the control showed significantly higher volume production than the heavier thinnings. Among the percent of height treatments, only the heaviest thinning, 30 percent, was not in the top cubic-foot volume production group. The heavier thinnings showed decreasing production. Stands with residual basal areas below 100 sq. ft. per acre did not appear to make full use of the site. Understory herbs and shrubs were noticeably more abundant in the heavier thinnings.

Because of the retarding effect of the close initial spacing in the plantation on tree diameter growth, board-foot volumes were computed for the first time in 1982. They showed that treatments with stand densities in the 30 to 24 percent of height or 80 to 120 basal area ranges have produced more board feet than higher or lower densities. However, these board-foot volume data are preliminary. They are bound to show large changes during the next thinning interval because of ingrowth. Several treatments, especially the lighter thinnings, had large numbers of trees just below the minimum sawtimber diameter.

Highest total values have been produced by thinning treatments in the 30 to 20 percent of height and the 80 to 130 basal area ranges. Differences throughout these ranges were small. Lower and higher stand densities showed lower total value production. Since board-foot volume is the most important component of stand value, the higher stand densities should increase in value more rapidly in the next decade or so than the lower stand densities because their board-foot volumes

will increase rapidly through ingrowth. Application of sawtimber values related to tree size would reduce the present value in the higher stand densities which have the smaller trees.

The Hiawatha National Forest plantation has about the same age and site index as the Kellogg Forest plantation. Thus, the Hiawatha National Forest plantation thinning results differ from the Dunbar Forest results because of lower age and site index. However, the volumes and values are also lower for the Hiawatha National Forest plantation than for the Kellogg Forest plantation. It appears that the major reason for these differences at this point in the plantations' growth and development is the large difference in the number of trees per acre when the thinnings were started. The Dunbar Forest plantation had 674 trees per acre, the Kellogg Forest plantation had 799 and the Hiawatha National Forest plantation had 1,176. Accompanying average tree diameters were 6.9, 5.8 and 5.2 inches, respectively. Obviously, the initial spacing in the Hiawatha National Forest plantation was too close, and its effects on retarding early stand growth have not been eliminated.

In general, the results of these three thinning studies point toward the maintenance of fairly high stand densities in red pine plantations on comparable sites. Where row thinnings can be applied, they are an appropriate initial thinning approach. Removing every third row is the most economical method. Subsequent periodic thinnings should maintain stand densities in the range of 110 to 130 sq. ft. of basal area per acre. A small increase in residual stand density with each periodic thinning appears feasible. In the percent of height approach, periodic thinnings to 20 to 30 percent of height appear to result in desirable stand densities. The residual stand density level appears to be more important than the means by which it is attained.

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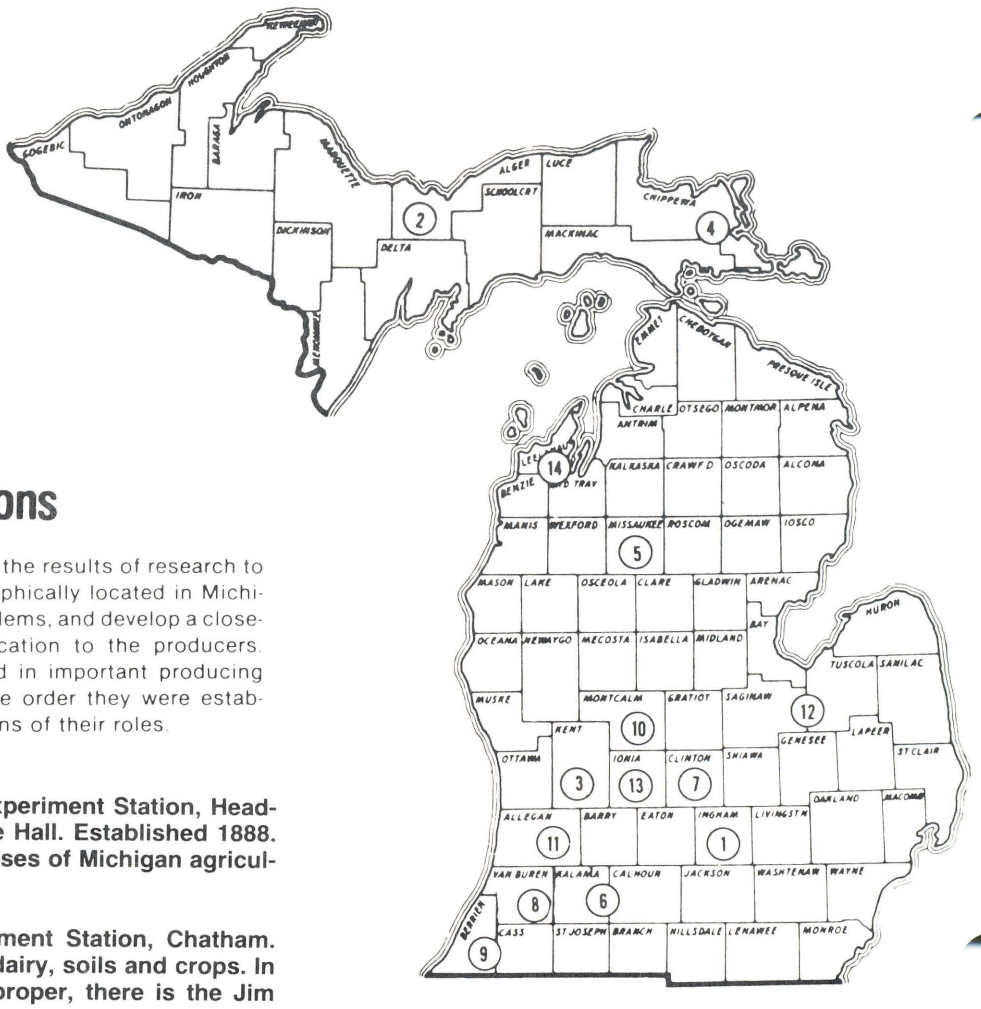

Outlying Field Research Stations

These research units bring the results of research to the users. They are geographically located in Michigan to help solve local problems, and develop a closeness of science and education to the producers. These 14 units are located in important producing areas, and are listed in the order they were established with brief descriptions of their roles.

1. **Michigan Agricultural Experiment Station, Headquarters, 109 Agriculture Hall. Established 1888. Research work in all phases of Michigan agriculture and related fields.**

2. **Upper Peninsula Experiment Station, Chatham. Established 1907. Beef, dairy, soils and crops. In addition to the station proper, there is the Jim Wells Forest.**

3. **Graham Horticultural Experiment Station, Grand Rapids. Established 1919. Varieties, orchard soil management, spray methods.**

4. **Dunbar Forest Experiment Station, Sault Ste. Marie. Established 1925. Forest, fisheries and wildlife management.**

5. **Lake City Experiment Station, Lake City. Established 1928. Breeding, feeding and management of beef cattle and fish pond production studies.**

6. **W. K. Kellogg Biological Station Complex, Hickory Corners. Established 1928. Natural and managed systems: agricultural production, forestry and wildlife resources. Research, academic and public service programs.**

7. **Muck Soils Research Farm, Laingsburg. Plots established 1941. Crop production practices on organic soils.**

8. **Fred Russ Forest Experiment Station, Decatur. Established 1942. Hardwood forest management.**

9. **Sodus Horticultural Experiment Station, Sodus. Established 1954. Production of small fruit and vegetable crops. (land leased)**

10. **Montcalm Experimental Farm, Entrican. Established 1966. Research on crops for processing with special emphasis on potatoes.**

11. **Trevor Nichols Experimental Farm, Fennville. Established 1967. Studies related to fruit crop production with emphasis on pesticides research.**

12. **Saginaw Valley Beet and Bean Research Farm, Saginaw. Established 1971, the farm is owned by the beet and bean industries and leased to MSU. Studies related to production of sugar beets and dry edible beans in rotation programs.**

13. **Clarksville Horticultural Experiment Station, Clarksville. Purchased 1974. First plots established 1978. Research on all types of tree fruits, small fruits, vegetable crops and ornamental plants.**

14. **Northwest Michigan Horticultural Experiment Station, Traverse City. Established 1979. Research and education for cherry and other horticultural crops in northwest Michigan.**

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