Effects of residual stand density on growth and volume production in even-aged red maple stands

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Abstract: The effects of five residual stand densities (9.2, 13.8, 16.1, 18.4 m^2/ha, and an unthinned control (27.2 m^2/ha)) on10-year stand and crop tree growth and bole quality were studied in an even-aged red maple stand in Michigan. A secondary treatment of removing the understory trees (5–10 cm DBH) was applied on half the plots. Diameter growth was significantly greater in all cutting treatments than in the control. Ten-year diameter growth in the heaviest cut treatment was nearly three times that of the control. The interaction between understory removal treatments and density treatments was significant for net basal area growth. Ingrowth in the heavier cut treatments accounted for a significant portion of net basal area growth in the plots without understory removal. Mortality was highest in the control and lowest in the heavier cut treatments. Epicormic branching significantly reduced clear bole length of crop trees in the heavier cut treatments, especially when the understory was removed. For these reasons, a more conservative first entry thinning level of about 17–18 m²/ha without controlling the understory is recommended for even-aged red maple stands.

Résumé : Les auteurs ont étudié les effets de cinq densités résiduelles (9,2, 13,8, 16,1 et 18,4 m^2/ha et un témoin non éclairci avec 27,2 m^2/ha) sur la croissance et la qualité du fût des arbres du peuplement final dans un peuplement équienne d'érable rouge âgé de 10 ans et situé au Michigan. Un traitement secondaire qui consistait à éliminer les arbres en sous-étage (5–10 cm de diamètre à hauteur de poitrine) a été appliqué dans la moitié des parcelles. La croissance en diamètre était significativement meilleure dans toutes les parcelles éclaircies que dans les parcelles témoins. Dans l'éclaircie la plus forte, la croissance en diamètre sur 10 ans atteignait près de trois fois la croissance dans les parcelles témoins. Il y avait une interaction significative entre l'élimination du sous-étage et la densité résiduelle dans le cas de l'accroissement net en surface terrière. Dans les éclaircies les plus fortes, le recrutement expliquait une partie importante de l'accroissement net en surface terrière dans les parcelles où le sous-étage n'avait pas été éliminé. La mortalité était la plus élevée dans les parcelles témoins et la plus faible dans les éclaircies les plus fortes. La formation de branches adventives a significativement réduit la longueur du fût sans défaut des arbres du peuplement final dans les éclaircies les plus fortes, surtout lorsque le sous-étage avait été éliminé. Pour ces raisons, les auteurs recommandent un niveau d'éclaircie plus conservateur laissant environ 17–18 m^2/ha lors d'une première intervention sans éliminer les arbres en sous-étage dans les peuplements équiennes d'érable rouge.

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Introduction

Red maple (*Acer rubrum* L.) is an important timber producing species in the Lake States. Red maple volumes in the region have recently shown striking increases. For example, net annual growth of red maple growing stock between the last two forest surveys for Michigan, Wisconsin, and Minnesota averaged 3.1×10^6, 1.8×10^6, and 0.4×10^6 m^3, respectively (Leatherberry and Spencer 1996; Miles and Chen 1992; Schmidt 1997). Average net annual growth of red maple ranked first in Wisconsin, second in Michigan, and seventh in Minnesota among all tree species.

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In the Lake States, red maple grows on a wide range of sites. It is usually found in even-aged, pole- and small sawlog-size, pure and mixed-species stands. On poorer sites, red maple products are usually limited to pulpwood or firewood. However, on better sites, high-quality sawlogs can be grown. Red maple responds well to thinning (Burns and Honkala 1990). Erdmann et al. (1985) found that crown-released, pole-size red maple trees in Michigan had as much as 70% more diameter growth than unreleased trees after 7 years. Other studies in West Virginia (Trimble 1974) and in New Hampshire (Marquis 1969) found that younger red maples nearly doubled their growth rate after being released.

However, little is known about how growth and volume production of red maple respond to different levels of residual basal area. Controlling the density of the overstory has led to significant growth increases in crop trees of other species (Burns and Honkala 1990). However, cutting too heavily can degrade log quality because of the sprouting and growth of epicormic branches (Smith 1986). Nearly all hardwood species are capable of forming epicormic branches, some more readily than others. Red maple has a low susceptibility to epicormic branching so heavier cutting to promote growth on crop trees is a possibility (Jemison and Schumacher 1948; Smith 1965; Trimble and Seegrist 1973).

Thinning overstory trees improves growth on the residuals by reducing competition, primarily for light. However, these trees and the understory trees and shrubs are also competing for water and nutrients. Further increases in growth and volume production may be attained by removing the understory competition for water and nutrients.

In 1978, a study was established to examine red maple crop tree and stand responses to various levels of residual basal area. A secondary objective was to determine if removing the understory improved growth and volume production of the residual trees.

Study area

The study was established in a nearly pure 8.6-ha stand of even-aged red maple about 35 km north of Marquette, Mich. Stem analysis of five red maple trees indicated that the stand age was about 50 years old and that the site index for red maple averaged 18.7 m at 50 years. The stand became established after logging of white pine (*Pinus strobus* L.) and hardwood. A fire in 1923 or 1924 probably destroyed the advanced sugar maple (*Acer saccharum* Marsh.) reproduction and allowed the red maples to dominate. The soil is a Finch loamy sand (Aeric Haplaquod) that developed on an outwash plain. The soil is somewhat poorly drained, with numerous mottles beginning at 60 cm below the surface.

Before treatment, the stand averaged 17.2 cm in diameter at breast height (DBH; 1.4 m) and had 26.1 m^2/ha of basal area. Species composition obtained from 20 rectangular 0.2-ha plots showed that red maple, sugar maple, and yellow birch (*Betula alleghaniensis* Britton) dominated the stand with 65, 26, and 4% of the basal area, respectively. Other species of minor importance included eastern hemlock (*Tsuga canadensis* (L.) Carr), paper birch (*Betula papyrifera* Marsh.), balsam fir (*Abies balsamea* (L.) Mill.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), largetooth aspen (*Populus grandidentata* Michx.), trembling aspen (*Populus tremuloides* Michx.), juneberry (*Amelanchier* spp.), and white spruce (*Picea glauca* (Moench) Voss).

Methods

Twenty 0.2-ha rectangular plots each surrounded by a 10-m isolation strip were established in the fall and winter of 1978. The plots were grouped into four blocks based on uniform soil, site, stocking conditions, and species composition (five plots per block).

Stand density

Five residual basal area levels were randomly assigned to the five plots within each block. The five stand density levels are 9.2, 13.8, 16.1, 18.4, and about 27.2 (unthinned control) m^2/ha basal area. Stand density was reduced to these levels primarily by cutting from below. Cull and defective trees were also cut. Thinning favored the most healthy, vigorous, straight-stemmed, defect-free dominant and codominant red maple trees. Other species were retained to satisfy initial stocking level requirements and to maintain uniform spacing.

Understory sapling control

Saplings (trees 5–10 cm DBH) were cut on half of each stand density treatment plot to determine their effect on overstory growth. An understory removal treatment was randomly assigned to half of each stand density plot including the unthinned control plot.

Measurements

Plot data

Diameter at breast height of all stems 10 cm and larger was recorded before cutting and annually for 10 years after cutting. Plot basal areas and volumes were calculated from these data. Ten-year survivor growth, mortality, and ingrowth were calculated. Survivor growth is growth of trees left after cutting. Net growth was calculated as survivor growth – mortality + ingrowth.

Volume equations were developed from a sample of felled and sectioned tree boles. Plot volumes were determined from Spurr's (1954) volume line method and the cut tree data.

Crop tree data

Eight dominant and codominant red maple crop trees above the average stand diameter were selected from each understory treatment plot and treatment combination (320 crop trees in the study). The following data were collected initially and 5 and 10 years after cutting for each crop tree: crown class; total and merchantable heights (top diameter inside bark of 20 cm for sawlogs); height to live crown; and clear bole length. In addition, stem diameters were recorded at 0.3, 2.8, 5.3, 7.8, and 10.3 m above the groundline. Bark thickness was calculated from the cut tree data. Tree volume was calculated for each crop tree using Smalian's formula for all measurement periods.

Data analysis

The study is a split-plot experiment in a randomized block design. Analysis of variance was used to test differences between means according to the model:

$$Y_{ijk} = \mu + B_i + D_j + \varepsilon_{ij} + U_k + DU_{jk} + S_{ijk}$$

where Y_{ijk} is the sample plot average of variable measured in replication i, density j, and understory k; μ is the overall mean; B_i is the effect of the ith block; D_j is the effect of the jth residual basal area treatment; ε_{ij} is the main plot error; U_k is the effect of kth understory treatment; DU_{jk} is the interaction between the jth residual basal area treatment and kth understory treatment; and S_{ijk} is the subplot error. All effects were considered random. Comparisons between individual treatment means were made only when analysis of variance indicated significant differences among treatments ($p < 0.05$). Individual comparisons were then tested using the least significant difference method with a common estimate of experimental error.

Results

Plot data

Diameter growth of survivor trees

Analysis of variance indicated that the interaction between the understory removal treatments and the residual basal area treatments was not significant for initial and 10-year diameters and 10-year diameter growth.

There were no significant diameter differences among understory removal treatments in 1978 or 1988. However, removing the understory trees did significantly increase 10-year diameter growth by 0.2 cm.

Initial diameters (1978) of survivor trees (trees after cutting that were alive after 10 years) were not significantly different among residual basal area treatments. Initial diameters ranged from 16.6 to 19.3 cm in the 18.4- and 16.1-m^2/ha treatments, respectively (Table 1).

Fig. 1. Cumulative diameter growth (cm) for 10 years after cutting by residual basal area treatment (m^2/ha).

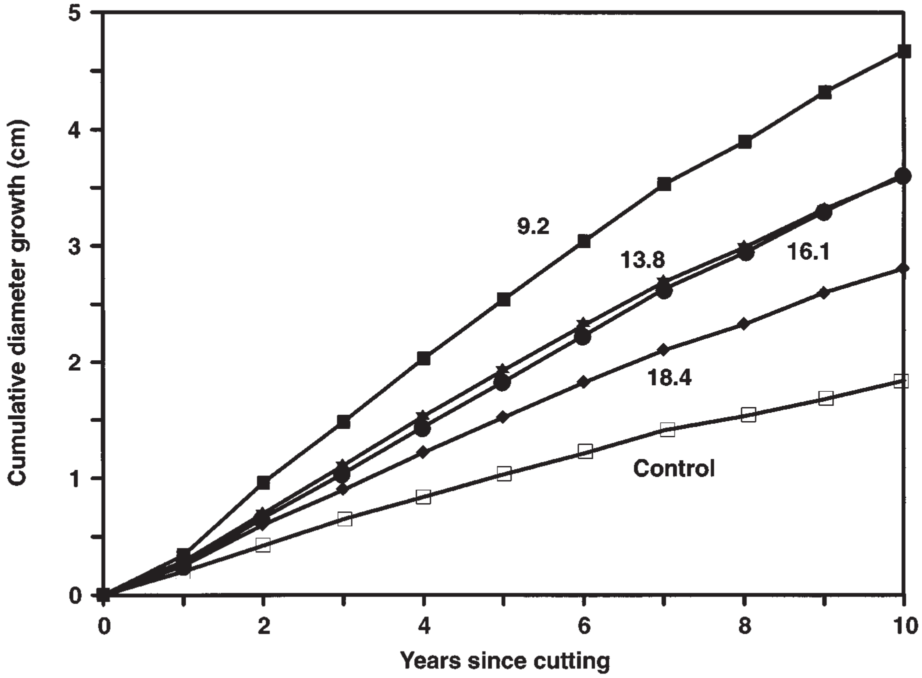


Table 1. Mean plot initial (1978) DBH, 10-year (1988) DBH, and 10-year diameter growth (cm) by residual basal area treatment (m^2/ha) with the understory treatments combined.

Residual basal area treatment*	1978	1988	Growth
9.2	18.0	22.7*a*	4.7*a*
16.1	19.3	22.9*a*	3.6*b*
13.8	16.7	20.3*b*	3.6*b*
18.4	16.6	19.4*b*	2.8*c*
Control	17.0	18.9*b*	1.9*d*

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).

*Treatment means are ranked by 10-year diameter growth.

Table 2. Mean plot ingrowth and mortality basal area over 10 years, and 10-year net basal area growth (m^2/ha) by residual basal area treatment (m^2/ha).

Residual basal area treatment*	Ingrowth†	Mortality	Ten-year net growth
13.8	1.6*b*	0.0*b*	7.4
18.4	0.8*c*	0.1*b*	7.2
9.2	3.0*a*	0.0*b*	6.8
16.1	1.0*bc*	0.2*b*	6.8
Control	0.3*c*	0.7*a*	5.6

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).

*Treatment means are ranked by 10-year net basal area growth.

†Mean ingrowth basal area is from the plots with no understory control only. Because all the trees from 5 to 10 cm DBH were cut in the understory removal treatments, no ingrowth occurred in these plots during the period. Using all plots in the analysis caused a significant understory removal and residual basal area treatment interaction.

Diameters after 10 years differed by treatment (Table 1). Diameters in both the 9.2- and 16.1-m^2/ha treatments were significantly greater than those in the other treatments. Diameter growth over the period was significantly different among treatments. Among the treatments, diameter growth in the 9.2-m^2/ha treatment was greatest (4.7 cm). Diameter growth in the next two lighter cuts (13.8 and 16.1 m^2/ha) was the same (3.6 cm) but greater than in the 18.4-m^2/ha treatment (2.8 cm) and the control (1.9 cm).

The spread among treatments increased throughout the measurement period (Fig. 1). Analysis of coefficients described by Meredith and Stehman (1991) indicates that the slopes of the cumulative growth lines over time are linear and significantly different among treatments. The slope of the 9.2-m^2/ha residual basal area treatment is significantly greater than all other treatments. The slopes of the other cut treatments are not significantly different among themselves, but they are significantly greater than the control. This indicates that growth responses due to cutting treatments will occur beyond 10 years. The original intent of the study was to follow these treatments through to sawlog-size trees. However, the treatments were compromised by severe winds in 1989, and the study was closed.

Basal area growth

Ingrowth occurred only in the plots where the understory was not cut. Trees smaller than 5 cm DBH in the understory removal plots did not reach 10 cm during the study period. For this reason, the understory removal and residual basal area treatment interaction was significant for ingrowth basal area and net basal area growth. In the plots where ingrowth did occur, basal area ingrowth was significantly different among residual basal area treatments (Table 2). Basal area ingrowth increased from the densest overstory treatment

Fig. 2. Ten-year ingrowth basal area (m^2/ha) by initial residual basal treatment (m^2/ha).

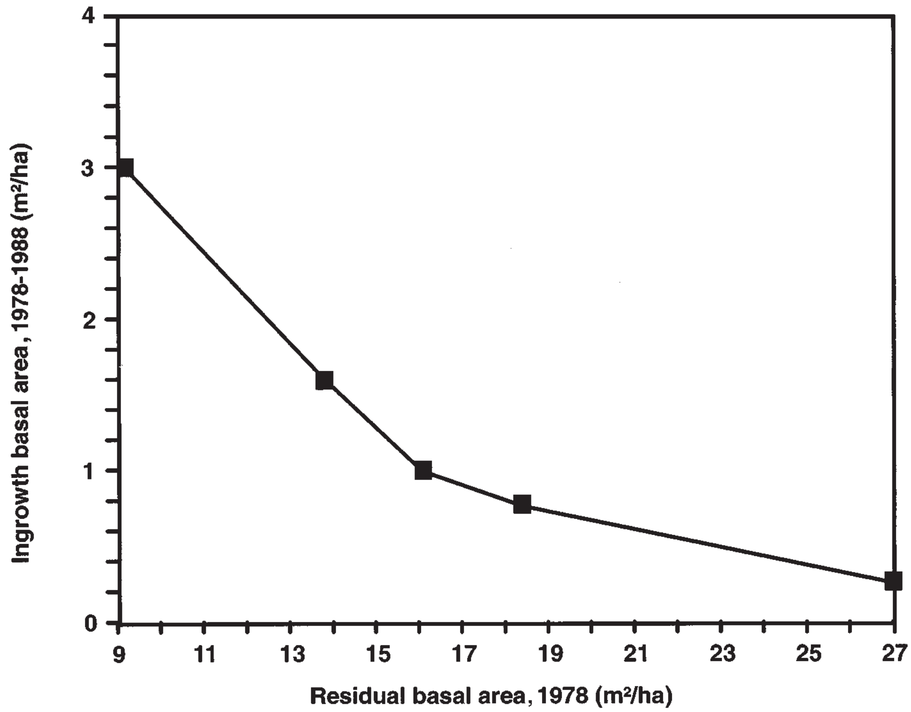
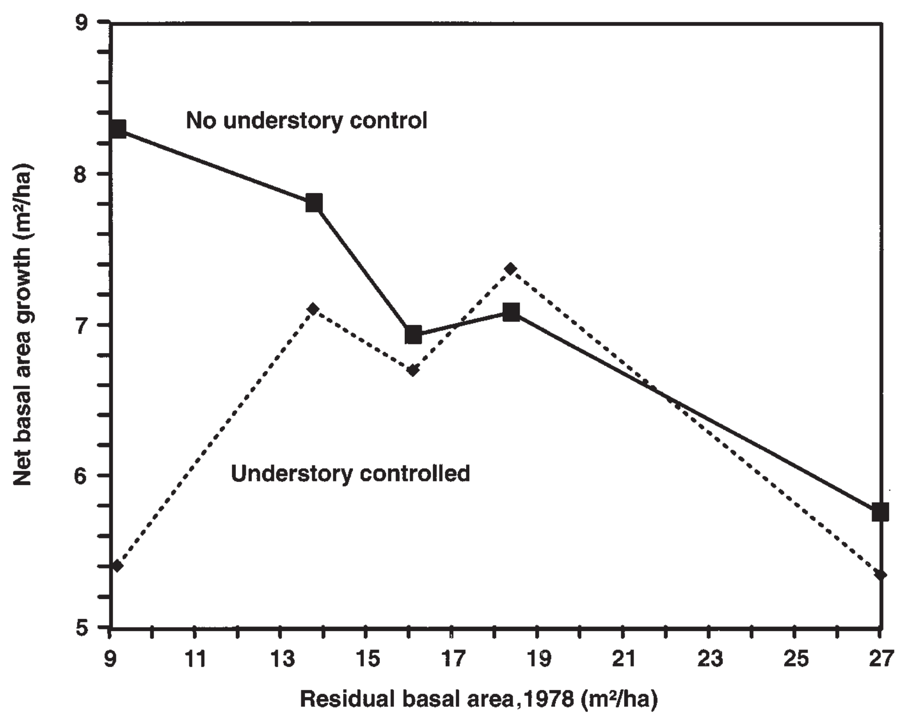


Fig. 3. Ten-year net basal area growth (m^2/ha) by understory removal treatment and residual basal area treatment (m^2/ha).



(0.3 m^2/ha) to the least dense overstory treatment (3.0 m^2/ha), (control and 9.2-m^2/ha treatment, respectively). This increase was curvilinear, with larger ingrowth increases in the less dense treatments (Fig. 2).

Basal area of trees that died in the study period was significantly greater in the control than in all residual basal area treatments. No trees died in either the 9.2- and 13.8-m^2/ha residual basal area treatments. Basal area of trees that died in the study period was not different among cutting treatments.

Analysis of variance indicated that the interaction between the understory removal treatments and the residual basal area treatments was significant for net basal area growth over the 10-year period. The interaction was caused by the large difference in net basal area growth between plots where the understory was cut and plots where the

Table 3. Mean plot ingrowth and mortality volume over 10 years and 10-year net volume growth (m^3/ha) by residual basal area treatment (m^2/ha).

Residual basal area treatment*	Ingrowth†	Mortality	Ten-year net growth
13.8	8.6*b*†	0.3*b*	55.1
18.4	4.1*c*	0.6*b*	54.6
16.1	5.4*bc*	1.3*b*	51.2
9.2	16.4*a*	0.0*b*	49.3
Control	1.5*c*	4.5*a*	43.6

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).

*Treatment means are ranked by 10-year net volume growth.

†Mean ingrowth volume is from the plots with no understory control only. Because all the trees from 5 to 10 cm DBH were cut in the understory control treatments, no ingrowth occurred in these plots during the period. Using all plots in the analysis caused a significant understory control and residual basal area treatment interaction.

Table 4. Mean plot net volume growth (m^3/ha) by understory removal treatment and residual basal area treatment (m^2/ha).

Residual basal area treatment*	Understory removal treatment	
	None	Controlled
9.2	57.4*a*	41.1*b*
13.8	55.9*a*	54.4*a*
18.4	52.8*ab*	56.5*a*
16.1	50.7*ab*	51.7*a*
Control	45.0*b*	41.1*b*

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).

*Treatment means are ranked by net volume growth without understory control.

understory was not cut in the 9.2-m^2/ha treatment (Fig. 3). Ingrowth accounted for 44% of the net basal area growth in these plots. Ingrowth occurred only in those plots where the understory was not cut.

In the plots with the understory removed, net basal area growth in both the control and 9.2-m^2/ha treatment was less than the more intermediate levels of cutting (Fig. 3). Net basal area growth among the intermediate levels of the residual basal area treatments were not significantly different. In the plots without the understory removed, net basal area growth was greater in the heavier cutting treatments (9.2- and 13.8-m^2/ha residual basal area densities) than in the control. Generally, in the plots without the understory cut, the net basal area growth increased with increased intensity of cutting.

Volume growth

Tree volumes (30-cm stump to 10.2-cm diameter inside bark) were calculated from the following local volume-line equation developed from cut trees on the site:

$$\text{Volume} = 0.000602\,(\text{DBH}^2) - 0.022, \qquad R^2 = 0.97$$

where volume is expressed in cubic metres per hectare and DBH is expressed in centimetres. Volume and basal area results were similar, which is to be expected because both values are calculated with DBH^2. The interaction between the understory removal treatment and residual basal area treatment for volume ingrowth and net volume growth was significant. Volume ingrowth when the understory was removed was greatest in the 9.2-m^2/ha residual basal area treatment (16.4 m^3/ha) and accounted for about 30% of the net volume growth for the period (Table 3). Volume ingrowth increased with increased intensity of cutting. Volume mortality was greatest in the control (4.5 m^3/ha) over the period (about 10% of the total net volume growth). Mortality volume was minor in the cut treatments.

As in the basal area results, ingrowth in the plots where the understory was not removed significantly added to the net volume growth in the 9.2-m^2/ha residual basal area treatment (Table 4). Net volume growth between the two understory treatments was similar among the other residual basal area treatments.

Table 5. Mean crop tree diameter growth (cm) by location on stem (height in metres above the ground) and residual basal area treatment (m^2/ha).

Residual basal area treatment*	Location on stem†					
	0.3	1.4	2.8	5.3	7.8	10.3
9.2	5.7*a*	5.1*a*	4.5*a*	4.3*a*	4.1*a*	4.1
13.8	4.8*ab*	4.4*b*	4.0*ab*	3.8*ab*	3.9*ab*	3.8
16.1	4.6*b*	4.3*b*	3.9*ab*	3.7*ab*	3.6*ab*	3.7
18.4	4.2*b*	3.9*b*	3.5*b*	3.3*b*	3.3*b*	3.4
Control	3.2*c*	3.0*c*	2.6*c*	2.6*c*	2.6*c*	2.8

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).

*Treatment means are ranked by intensity of basal area removal (greatest to least).

†Location is in metres above the ground.

Crop tree data

The interaction between understory removal treatment and residual basal area treatment was not significant for crop tree stem diameter growth, volume growth, or change in height to minimum sawlog diameter.

Stem diameter growth

Stem diameter growth was significantly different among basal area treatments at all stem heights above the ground except at 10.3 m (Table 5). Diameter growth at all stem heights decreased with decreased intensity of cutting.

Diameter growth was greater at 0.3-m and 1.4-m stem heights than at the other stem heights for all residual basal area treatments. Diameter growth, while significantly greater among residual basal area treatments, was not significantly different at 2.8, 5.3, 7.8, and 10.3 m for any particular treatment (Table 5). Stem taper appears to be changing in the heavier cut treatments. Diameter growth differences between the 9.2-m^2/ha residual basal area treatment and the control are greater at the lower stem heights than diameter growth differences at the upper stem heights.

Volume growth

Average crop tree volume in 1988 and average crop tree volume growth were significantly different among treatments (Table 6). Average volume growth was greatest in the

Fig. 4. Ten-year increase in height to minimum sawlog diameter (m) by residual basal area treatment (m^2/ha) with the understory removal treatments combined.

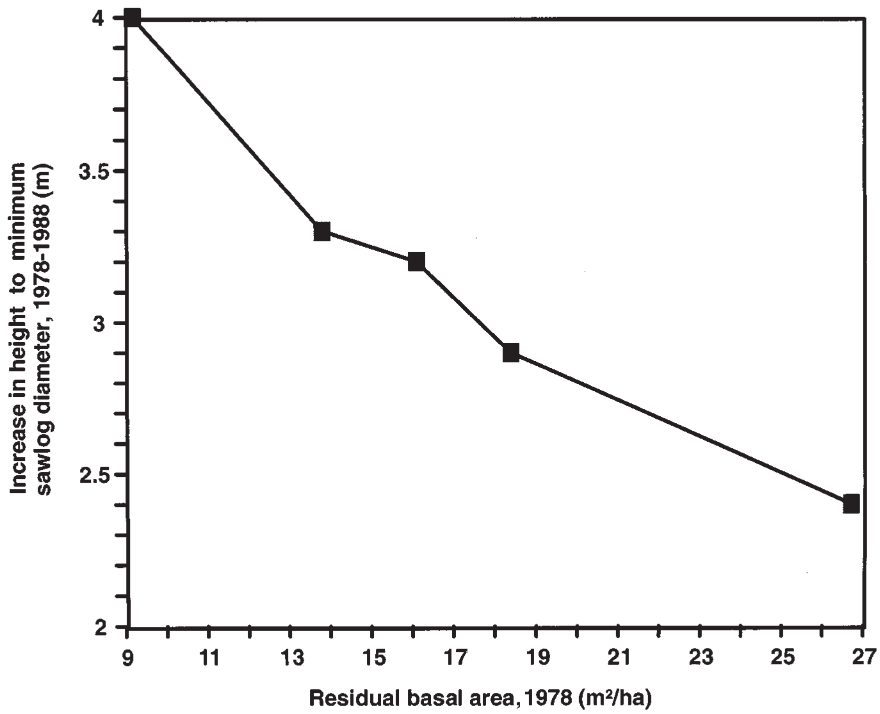


Table 6. Average initial (1978) crop tree volume, 10-year (1988) crop tree volume, and 10-year crop tree volume growth (m^3/tree) by residual basal area treatment (m^2/ha) with the understory treatments combined.

Residual basal area treatment*	1978	1988	Growth
9.2	0.22	0.34*a*	0.12*a*
16.1	0.22	0.33*ab*	0.11*ab*
13.8	0.20	0.31*bc*	0.11*ab*
18.4	0.21	0.30*bc*	0.09*b*
Control	0.22	0.29*c*	0.07*c*

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).
*Treatment means are ranked by 10-year average crop tree volume growth.

Table 7. Average change in clear bole length (m) from 1978 to 1988 by residual basal area treatment (m^2/ha) and understory treatment.

	Understory		
Residual basal area treatment*	Not controlled	Controlled	Difference
Control	0.44*a*	0.50*a*	0.06
18.4	0.06*ab*	–0.22*ab*	–0.28
13.8	–1.12*c*	–1.09*b*	0.03
9.2	–0.57*bc*	–2.78*c*	–2.21
16.1	–1.04*c*	–3.60*c*	–2.56

Note: Means followed by the same letter in a column are not significantly different ($p < 0.05$).
*Treatment means are ranked by change in clear bole length with the understory controlled.

9.2-m^2/ha residual basal area treatment (0.12 m^3/tree) but was not significantly greater than in the 13.8- and 16.1-m^2/ha residual basal area treatments. Average crop tree volume growth in the control was significantly less than all of the residual basal area treatments (0.07 m^3/tree).

Controlling the understory significantly increased volume growth by about 0.02 m^3/tree. Considering 150 crop trees/ha, this would convert to about 3 m^3/ha volume growth over a 10-year period or a 0.3 m^3/ha per year growth difference by eliminating the understory.

Change in height to minimum sawlog diameter

Height to a minimum sawlog diameter increased from 1978 to 1988 with increased intensity of cutting (Fig. 4). Minimum sawlog heights in the 9.2- and 13.8-m^2/ha residual basal area treatments increased significantly more than in the 18.4-m^2/ha residual basal area treatment and the control (4.0 and 3.3 m; 2.9 and 2.4 m, respectively). Minimum sawlog height increase in the 16.1-m^2/ha residual basal area treatment was intermediate to the other treatments.

Clear bole (limb-free) length

The interaction between residual basal area treatment and understory removal treatment was significant for change in clear bole length resulting from the formation of epicormic branches. The decrease in height to the first live branch was generally less when the understory trees were retained (Table 7). This trend was more evident for the heavier cut treatments (9.2 and 13.8 m^2/ha). Ten-year changes in clear bole length were similar and are related to epicormic branches (greater than 2.5 cm in diameter) that developed over the period. Generally, the heavier the cutting, the greater the decrease in height to the first live branch and reduction in clear bole length.

Discussion and conclusions

Red maple trees in this study responded well to thinning: the lower the residual basal area, the greater the growth. This has been documented for red maple in other studies (Erdmann et al. 1985; Marquis 1969; Trimble 1974). The diameter growth in the lowest residual basal area treatment was nearly 2.5 times the diameter growth in the control, and it appears the difference will continue to increase for at least several more years. Net basal area growth and volume growth followed patterns similar to diameter growth.

Stem diameter growth up to 7.8 m above the ground on crop trees was significantly more in all levels of thinning than in the control. Average 10-year volume growth of crop trees in the 9.2-m^2/ha basal area treatment was 1.7 times the average 10-year volume growth in the control. The other treatments were intermediate but also had significantly more volume growth than the control. All this suggests that cutting heavily in even-aged red maple stands maximizes growth. Erdmann et al. (1985) suggested leaving 13.8-m^2/ha residual basal area in small, 10- to 15-cm diameter stands.

Controlling the understory (removing trees less than 10 cm DBH) had little effect on plot or crop tree growth. Although statistically significant, the difference was so slight that removal probably cannot be justified economically.

What is discouraging in our study is the amount of epicormic branching that occurred, especially in the heavier cutting treatments. Reduction of clear bole was as much as 3.6 m because of the development of epicormic sprouts into large branches in the 9.2-m^2/ha residual basal area treatment and with the understory removed. Red maple in the past has been considered one of the least susceptible hardwoods to form epicormic branches (Jemison and Schumacher 1948; Smith 1965; Trimble and Seegrist 1973). In a study located nearby, Erdmann et al. (1985) found little epicormic branching on red maple crop trees crown released from competitors up to 4.6 m. After revisiting this site in 1997, we observed few additional epicormic branches (unpublished data). In fact, most of the epicormic branches reported in that study have since died.

Most of the literature suggests that released dominant and codominant hardwood crop trees should remain free of epicormic branches. In this study, all of the crop trees were dominant or codominant, and yet, many of them produced epicormic branches that lowered the clear bole length. Why is there an inconsistency between studies of similar ages? Perhaps stress, site quality, genetics, or a combination of these factors leads to more prominent epicormic branching. Whatever the reason, landowners can't accept faster growth with great reductions in clear bole length if they want to grow high-quality sawlogs.

Erdmann et al.'s (1985) suggestion of residual basal areas as low as 13.8 m^2/ha in pole- and small sawlog-size stands was based on the average stocking levels recommended for northern hardwoods in the *Manager's handbook for northern hardwoods in the north central States* (Tubbs 1977). These stocking level curves were developed from the average growing space requirements of sugar maple, yellow birch, and white ash in even-aged stands. However, more recent research in developing even-aged stocking tables and charts for high-quality forest grown trees of different species indicates that dominant and codominant red maple trees have significantly narrower crown diameters in relation to stem diameters of sugar maple, yellow birch, and white ash trees (unpublished data). Therefore, a more conservative first thinning of 17- to 18.5-m^2/ha residual basal area in pole- and small sawlog-size red maple stands is recommended as the best compromise between crop tree growth and stem quality improvement.

Removing the understory tended to reduce clear bole length even further. Apparently, the understory trees help shade epicormic branches so they eventually die. Because removing the understory resulted in reduced clear bole length and gained only minimal growth, it is not recommended.

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