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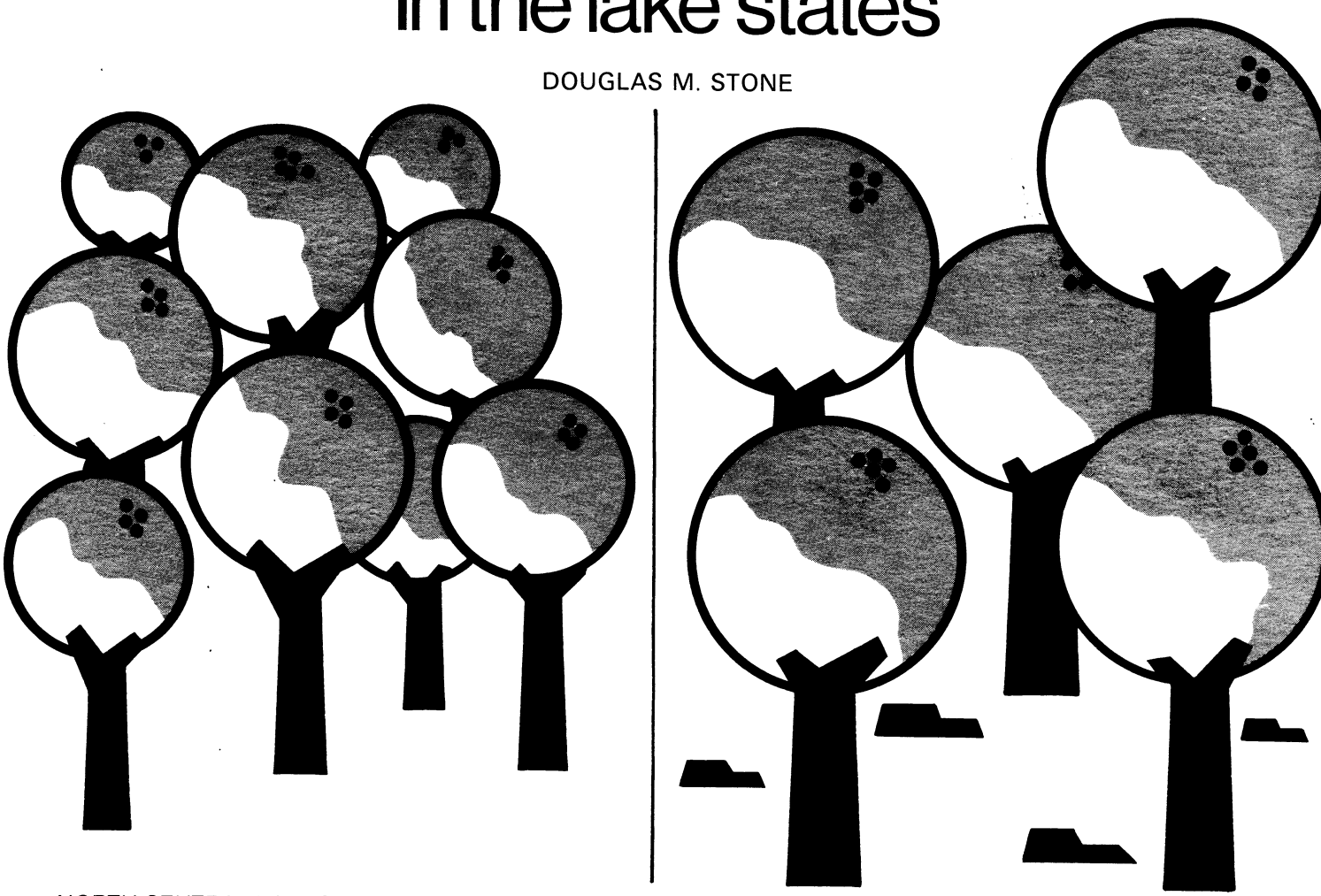
DOUGLAS M. STONE



NORTH CENTRAL FOREST EXPERIMENT STATION
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THE AUTHOR

Douglas M. Stone, Associate Silviculturist, earned a Bachelors degree in Forest Management at Michigan Technological University, and Masters and Ph.D. degrees in Physiological Ecology at the University of Michigan. Since joining the North Central Forest Experiment Station in 1970 he has carried on timber management research at the Northern Hardwoods Laboratory at Marquette, Michigan. His current studies involve various aspects of silviculture and ecology of northern hardwoods in the Lake States.

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service - U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55108

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FERTILIZING AND THINNING NORTHERN HARDWOODS IN THE LAKE STATES

Douglas M. Stone

The northern hardwood forest type occupies 32 million acres (13 million ha) in the northeastern United States and more than 70 million acres (28.4 million ha) in Canada (Quigley and Babcock 1969). In the Lake States, northern hardwoods occupy about 10 million acres (4 million ha), comprised predominantly of second growth stands. They are dominated by such high value species as sugar maple and yellow birch, which have good potential for intensive management. High stumpage prices for quality hardwoods and shortages of the better grades of saw logs and veneer have stimulated interest in more intensive management. So we initiated studies to explore cultural practices designed to increase growth rates and hasten the production of veneer and saw logs from second growth northern hardwood stands.

METHODS

Four studies were established in six fully stocked northern hardwood stands in the Upper Peninsula of Michigan and northeastern Wisconsin. All six stands developed after heavy cutting 50 to 60 years ago and are predominantly even-age with a scattering of larger residual stems. Five of the stands are growing on medium to good sites (site indexes 60 to 70 (18.3 to 21.3 m)) and contain many potential crop trees. In these stands we selected and fertilized individual trees. The sixth stand is on a relatively poor site (site index 54 (16.5 m)) and includes very few potential crop trees. On this site, 0.1-acre plots were fertilized and all trees 3.0 inches (7.6 cm) d.b.h. and larger were measured. Results for each site were evaluated by analysis of variance.

All of the stands were fertilized in the spring before leaf-out; each stand was treated only once. In the five stands using individual crop trees, fertilizers were surface broadcast on a 0.01 acre (0.004 ha) plot surrounding each study tree. In the other stand (near Hurley, Wisconsin), fertilizers were broadcast on 0.1 acre (0.04 ha) plots and on 19-foot (5.8 m) isolation strips around each plot. The location and important characteristics of each study follows:

Well-Drained Sites

Sugar Maple

A combined thinning and fertilization study was installed in two pole-size sugar maple (*Acer saccharum* Marsh.) stands, each with an abundance of potential crop trees. One stand (Dukes) is located on the Upper Peninsula Experimental Forest near Marquette, Michigan. The soil is a well-drained sandy loam; site index for maple is about 65 (19.8 m). The other stand (Melstrand) is on the Grand Sable State Forest near Munising, Michigan. The soil is a well-drained loamy sand with finer-textured bands in the subsoil; site index is 62 feet (18.9 m). More detailed stand and site conditions have been reported (Stone and Christenson 1974).

Half the study trees were released by cutting all competing trees with crowns within 5 to 10 feet (1.5 to 3.0 m) of the crop tree crowns. One of the following treatments was then applied to six thinned and six nonthinned trees:

(1) Control--no treatment.
(2) N--100 lb/acre (112 kg/ha) elemental nitrogen.
(3) NP--N plus phosphorus at 100 lb/acre (112 kg/ha) P_2O_5.
(4) NK--N plus potassium at 100 lb/acre (112 kg/ha) K_2O.
(5) NPK--N plus P plus K as above.
(6) 3N+PK--N at 300 lb/acre (336 kg/ha) plus P and K as above.

The nutrient sources were ammonium nitrate, treble superphosphate, and muriate of potash. The treatments were replicated 6 times on each site for a total of 144 study trees. Diameters were measured to the nearest 0.01 inch (0.25 mm) at breast height each fall. Results were evaluated by analysis of variance to separate the effects of thinning from those of fertilization.

Yellow Birch

This study was installed to determine if growth of previously released pole-size yellow birch (*Betula alleghaniensis* Britton) could be increased by fertilization and to see if soil drainage would affect the response to fertilization.

One stand (AuTrain) is growing on the Hiawatha National Forest near Munising, Michigan. The soil is a well-drained complex of loamy, fine sands; site index for birch is about 65 (19.8 m). The stand is predominantly pole-size birch and maple with an occasional hemlock (*Tsuga canadensis* (L.) Carr.); it had been commercially thinned 8 years before treatment.

Moderately Well-Drained Sites

Yellow Birch

This stand is on the Ottawa National Forest near Kenton, Michigan. It is primarily a hemlock-hardwood stand with a scattering of red maple (*Acer rubrum* L.). This is a moderately well-drained site with a heavier (silt loam) soil texture; site index is 70 (21.3 m) for birch. This stand was commercially thinned 4 years before treatment. Both stands were fertilized in mid-May, 1972, using the same procedures and application rates used in the previous study. The 6 treatments are replicated 9 times on each site for a total of 108 study trees.

Sugar Maple

This study was installed to see if the more favorable competitive status of previously released sugar maple crop trees would enable them to more effectively utilize the added nutrients. In addition, we wanted to compare the results of our individual crop tree release with a commercial thinning, and to evaluate ammonium nitrate and urea as nitrogen sources.

The stand is on the Munising District, Hiawatha National Forest, near Chatham, Michigan. It is predominantly maple with a few yellow birch, and an occasional beech (*Fagus grandifolia* Ehrh.). Half of the stand had been commercially thinned 5 years before, and the other half had been marked for a thinning to be made a couple years after fertilization. The soil is similar to that at Dukes, but has a slightly heavier texture, very fine sandy loam, particularly in the upper horizons where root density is greatest. Internal drainage is more restricted than at Dukes due to a dense fragipan at about 16 inches (40 cm). It is classed as moderately well drained. Site index for maple is a little more than 60 feet (18.3 m).

Groups of six trees, well matched for crown size and initial d.b.h., were selected in both the thinned and nonthinned parts of the stand. In early May, 1972, one of the following treatments was applied to each tree in each group.

(1) Control--no treatment.
(2) AN--N at 100 kg/ha (89 lb/acre) as ammonium nitrate.
(3) AN+PK--N as above plus P and K each at 50 kg/ha (44.5 lb/acre).
(4) UN--N at 100 kg/ha (89 lb/acre) as urea.
(5) UN+PK--N as above plus P and K each at 50 kg/ha (44.5 lb/acre).
(6) 3UN--N at 300 kg/ha (267 lb/acre) as urea.

Treble superphosphate and muriate of potash were the other nutrient sources. Treatments were replicated 10 times in each portion of the stand for a total of 120 sample trees.

Sugar and Red Maple

This study was established in 1966 near Hurley, Wisconsin. Species composition was variable but averaged 72 percent sugar maple and 18 percent red maple; miscellaneous hardwood species made up the other 10 percent. The soils on these plots are a heterogeneous mixture; about two-thirds of the area is moderately well drained, and one-third is somewhat poorly drained. Soil texture ranges from sandy loam to silt loam with very fine sandy loam predominant. Site index for sugar maple and red maple averages 54 feet (16.5 m), somewhat below average for the area (Carmean and Watt 1975). Tree quality is distinctly below average due to generally poor form and a high incidence of stem defects throughout most of the stand.

Eighteen 0.1-acre (0.04 ha) plots were laid out and all trees 3.0 inch (7.6 cm) d.b.h. and larger were measured and marked.

Due to wide variation in stand and site conditions two plots were rejected initially and a third was deleted later. This left three replications of the following five treatments:

(1) Control--no treatment.
(2) N--N at 150 lb/acre (168 kg/ha).
(3) P--phosphorus at 150 lb/acre (168 kg/ha).
(4) NP--N and P each at 150 lb/acre (168 kg/ha).
(5) NPK--N, P, and K each at 150 lb/acre (168 kg/ha).

The nutrient sources were ammonium nitrate, treble superphosphate, and muriate of potash; all application rates were on an elemental basis.

RESULTS

Well-Drained Sites

Sugar Maple

After three growing seasons there has been no significant difference in d.b.h. growth due to fertilization. In fact, most of the fertilized trees have grown less than the controls (table 1). This occurred with both thinned and nonthinned trees on both sites. Of the nonthinned trees at Dukes, for example, d.b.h. growth in all fertilizer treatments has averaged less than that of those not fertilized. At Melstrand, nonthinned trees that received NPK grew 5 percent more than the controls, but those in all other treatments grew less. Of the released trees, two treatments averaged slightly more than the controls, but all others grew less. At Dukes, released trees fertilized with 3N+PK were the same as the controls, those that received NP grew 2 percent more, and all others grew less.

Thinning was far more effective than fertilization in stimulating diameter growth. There was a statistically significant increase due to thinning on both sites every year. For the 3-year period, the thinning response of nonfertilized trees was about 80 percent on the sandy loam at Dukes and 72 percent on the sand at Melstrand. Fertilized trees also responded well to release. Although actual growth averaged somewhat less than that of nonfertilized trees, the response to release was slightly greater, 82 percent at Melstrand and 90 percent at Dukes.

Yellow Birch

The birch poles on the well-drained sand at AuTrain have shown no significant response to fertilization. Trees in the NP treatment grew 14 percent more than the controls, and those that received the triple N combination averaged 9 percent more, but those in the other three treatments all have grown less (table 2).

Moderately Well-Drained Sites

Yellow Birch

Fertilized trees growing on the moderately well-drained silt loam at Kenton

Table 1.--*Mean annual d.b.h. growth of maple poles on two sites (treatments applied in early spring 1971)*

Treatment	Nonthinned 1971	Nonthinned 1972	Nonthinned 1973	Nonthinned 3-year average	Nonthinned Response[1]	Thinned 1971	Thinned 1972	Thinned 1973	Thinned 3-year average	Thinned Response
	Inches				*Percent*	*Inches*				*Percent*
DUKES										
Control	0.140	0.125	0.158	0.141	--	0.188	0.265	0.307	0.253	--
N	.107	.102	.123	.111	-22	.163	.210	.197	.190	-25
NP	.113	.120	.117	.117	-17	.240	.245	.292	.259	2
NK	.115	.118	.110	.114	-19	.182	.223	.238	.214	-15
NPK	.127	.127	.128	.127	-10	.165	.228	.263	.219	-14
3N+PK	.123	.130	.133	.129	-9	.188	.262	.310	.253	0
MELSTRAND										
Control	0.110	0.105	0.147	0.121	--	0.173	0.187	0.263	0.208	--
N	.080	.092	.108	.093	-23	.133	.193	.252	.193	-7
NP	.110	.105	.120	.112	-7	.153	.212	.297	.221	6
NK	.117	.103	.122	.114	-6	.185	.210	.308	.234	13
NPK	.112	.115	.153	.127	5	.157	.160	.237	.184	-11
3N+PK	.090	.112	.135	.112	-7	.123	.173	.247	.181	-13

[1]To minimize errors due to rounding the figures in this column (all tables) are based on total cumulative growth rather than the 3-year average.

Table 2.--*Mean annual d.b.h. growth of previously released yellow birch poles on two sites (fertilizers applied in May 1972*

Treatment	1972	1973	1974	3-year average	Response
	- - - - - *Inches* - - - - -				*Percent*
AUTRAIN					
Control	0.212	0.240	0.219	0.224	--
N	.216	.234	.196	.215	-4
NP	.239	.273	.252	.255	14
NK	.239	.221	.187	.216	-4
NPK	.199	.210	.176	.195	-13
3N+PK	.244	.268	.220	.244	9
KENTON					
Control	0.152	0.184	0.161	0.166	--
N	.199	.247	.213	.220	32
NP	.197	.210	.177	.194	17
NK	.183	.236	.192	.204	23
NPK	.181	.226	.186	.197	19
3N+PK	.167	.231	.173	.190	14

Table 3.--*Mean annual d.b.h. growth*[1] *of fertilized sugar maple poles on a moderately well-drained site (South Superior)*

Treatment	1972	1973	1974	3-year average	Response
	- - - - - *Inches* - - - - -				*Percent*
NONTHINNED					
Control	0.106	0.134	0.095	0.112	--
AN	.118	.150	.102	.123	11
AN+PK	.114	.142	.075	.110	-1
UN	.118	.134	.087	.113	1
UN+PK	.126	.134	.118	.126	13
3 UN	.110	.154	.098	.121	8
PREVIOUSLY THINNED					
Control	0.138	0.193	0.138	0.156	--
AN	.189	.201	.146	.178	14
AN+PK	.154	.205	.138	.165	6
UN	.158	.189	.142	.163	4
UN+PK	.162	.189	.114	.155	-1
3 UN	.150	.209	.142	.164	7

[1]Original measurements made in metric units; converted to inches to facilitate comparison with other studies in this report.

have tended to respond to fertilization. Although the results are not significant statistically, several trends are evident:

(1) 100 lb/acre (112 kg/ha) of N as ammonium nitrate was the most effective treatment. The addition of P and/or K decreased the response to N (table 2).

(2) The most expensive 3N+PK combination gave the least response. By the third year, growth was only slightly greater than the controls; that of trees that received N alone was still about 30 percent greater. The 32 percent response to N alone has resulted in growth about equal to that of the nonfertilized trees on the well-drained site at AuTrain.

Sugar Maple

Fertilization has not significantly changed the growth rate of either the thinned or nonthinned maples on the South Superior site. However, like the yellow birch on the moderately well-drained site at Kenton, fertilization has produced some slight trends (table 3). Nitrogen at 100 kg/ha (89 lb/acre) applied as ammonium nitrate increased d.b.h. growth of nonthinned trees by 11 percent and that of thinned trees by 14 percent. However, the addition of P and K decreased the N response of the thinned trees and nullified it in the nonthinned trees. The same amount of N applied as urea showed little response by either thinned or nonthinned poles. Urea plus P and K gave a 13 percent increase in the nonthinned part of the stand, but nothing in the thinned portion. The triple rate of N (300 kg/ha) as urea produced a slight increase over the lower rate, but less than that of N at 100 kg/ha applied as ammonium nitrate. The overall increase for all fertilization treatments averaged about 6 percent.

In contrast to the lack of a significant response to fertilization, there has been a highly significant increase in growth following thinning. The thinning responses varied from 23 percent in the UN+PK treatment to 51 percent in the AN+PK treatment; the average was about 40 percent for all treatments combined. The growth response following commercial thinning on this site was substantially less than that observed in the individual crop tree release at Dukes (table 1). Nevertheless, the nonfertilized trees in the thinned portion of the stand have grown nearly 25 percent more than the best fertilizer treatment in the nonthinned part of the stand, and 32 percent more than the average for all fertilized but nonthinned trees (table 3).

Sugar and Red Maple

Growth has been extremely poor on the site at Hurley, and there has been no significant increase due to fertilization. On a percentage basis, growth on the N and NP plots appears much greater than that on the control plots, but the actual differences are small (table 4). If growth continues at these same rates, for example, it will take nearly 30 years for the poles on the N plots to gain an inch (2.54 cm) in d.b.h. over those on the control plots. Phosphorus fertilizer was of no apparent

Table 4.--*Eight-year d.b.h. growth of sugar and red maple poles (4.6 to 8.5 in.) fertilized in May, 1966, Hurley, Wisconsin*

Treatment	Block I	Block II	Block III	Plot average	Mean annual	Response
	Inches					*Percent*
Control	0.56	0.60	0.55	0.57	0.072	--
N	.75	.90	.97	.86	.107	49
P	.59	.43	.68	.53	.066	-8
NP	.78	1.09	.56	.75	.093	29
NPK	.87	.68	.58	.69	.086	19

benefit on this site; after 8 years, growth has averaged 8 percent less than on the control plots. The complete NPK treatment was less effective than the NP combination and substantially less than N alone.

The smaller size classes, i.e., 3.0 to 4.5 in. (7.6 to 11.4 cm) d.b.h. have grown less than the poles (Carmean and Watt 1975). Including these trees in the analysis gives a mean annual growth of 0.053 in. (0.135 cm) for the control trees, and 0.071 in. (0.180 cm) on the nitrogen plots. Although this represents a 34 percent response at these growth rates, it would require about 56 years for the fertilized trees to average 1.0 in. (2.54 cm) more than the controls.

No thinning treatments were included in this study. This is unfortunate because diameter growth of maple poles is strongly influenced by stand density. In fact, well over half of the variation in 8-year diameter growth of maples on these plots is explained by the variation in initial stand density. The "response" to N and NP for example, occurred on plots averaging 78 and 82 ft^2 of basal area per acre (17.9 and 18.8 m^2/ha) while the control and P plots averaged 94 and and 100 ft^2 (21.6 and 23.0 m^2/ha). This alone accounts for much of the variation in the growth rates indicated in table 4.

DISCUSSION

None of the fertilization treatments on these six sites has shown a statistically significant increase in d.b.h. growth over the first 3 years following fertilizer application. In general, released trees on the well-drained sites (Dukes, Melstrand, and AuTrain) have grown at greater than 0.2 in. (0.51 cm) per year and fertilization has tended to decrease these rates, at least at breast height (tables 1 and 2). Corresponding trees on the more moist (moderately well-drained) sites (Kenton and South Superior) have grown at less than 0.2 in. (0.51 cm) per year and have tended to respond to fertilization (tables 2 and 3). However, the initial trends are relatively small and unless they increase substantially, will require several years to gain an inch (2.54 cm) in diameter over the nonfertilized controls (table 5), particularly the slow-growing stand at Hurley (table 4).

In contrast to the small and variable fertilization responses, those due to thinning have been large and consistent. Moreover, they are statistically significant on both well-drained and moderately well-drained sites. The thinning responses range from 39 percent in the commercially thinned stand on the South Superior site to 80 percent from the individual crop tree release at Dukes (table 5). This amounts to a little over 6 rings per inch (2.54 cm) at South Superior, and about 4 per inch at Dukes--growth rates that are substantially greater than any of the fertilizer treatments have produced without thinning.

Although these results are not final, they do have management implications. Pole-size birch and maple growing on well-drained soils of medium and better site quality respond well to release, both on an individual crop tree basis and by commercial thinning. The maple poles in these studies have grown at 4 to 5 rings per inch following crop tree release; previously thinned (commercially) yellow birch poles have averaged 4.5 rings per inch. Adding fertilizers to these sites has resulted in decreased d.b.h. growth more often than it has increased it. Thus, competition for other factors appears to limit growth more than availability of mineral nutrients on well-drained soils with a site index of 60 and greater. In condsidering silvicultural investments on these sites, these data indicate that regulation of stand density should have first priority.

Table 5.--*Soil characteristics, most responsive treatments, mean annual increment, and growth responses of young northern hardwoods on six sites in Upper Michigan and northern Wisconsin*

Study area	Species	Site index	Soil texture	Drainage classification	Treatments	M.A.I.	Growth response	
						(in.)	*Percent*	yr/in.
Dukes	SM[1]	65	SL[2]	WD[3]	Thinning	0.253	80[4]	9
					Thin+NP	.259	84[4]	8
Melstrand	SM	62	LS	WD	Thinning	.208	72[4]	11
					Thin+NK	.234	93[4]	9
AuTrain	YB	65	LS	WD	NP	.255[5]	14	32
Kenton	YB	70	SiL	MW	N	.220[5]	32	19
South Superior	SM	60	SL	MW	NPK	.126[6]	13	71
					N	.178[7]	14	45
					Thinning	.156[8]	39	23
Hurley	SM,RM	54	VFSL[9]	MW[9]	N	.071[10]	34	56
						.107[11]	49	29

[1]SM= sugar maple, YB= yellow birch, RM= red maple.
[2]SL= sandy loam, LS= loamy sand, SiL= silt loam, VFSL= very fine sandy loam.
[3]WD= Well-drained, MW= moderately well-drained.
[4]Compared to nonthinned and nonfertilized trees.
[5]Commercially thinned stands.
[6]Nonthinned portion of the stand.
[7]Previously thinned portion of the stand.
[8]Nonfertilized trees in thinned vs. nonthinned portion of the stand.
[9]Variable; the predominant condition on the site.
[10]All trees 3.0 in. d.b.h. and greater.
[11]Poles 4.6 to 8.5 in. d.b.h.

The fertilization trends observed on the more moist (moderately well-drained) soils are promising but have not been consistent enough to significantly increase growth of fertilized trees over the nonfertilized ones on those sites. Because of the differences in species, stocking, and site quality, exact comparisons cannot be made between stands. In general, however, diameter growth on the moderately well-drained soils was better related to site quality than to added nutrients. In these three stands, site indices ranged from 70 (21.3 m) at Kenton, to about 60 (18.3 m) at South Superior, down to 54 (16.5 m) at Hurley; mean annual d.b.h. growth of nonfertilized trees was in the same order: 0.17 (0.42 cm) at Kenton, 0.11 (0.28 cm) on the South Superior, and 0.07 (0.18 cm) at Hurley. Returns on investments in timber management can be expected to follow the same order. Considering the most responsive treatment on each site, for example (table 5), the poles at Kenton have averaged 4.5 rings per inch, those on the South Superior about 5.5, and those at Hurley 9.5 rings per inch.

On a percentage basis, this order is reversed: i.e., the least response occurs on the best site, and the greatest on the poor site. This anomaly occurs frequently when comparisons are made between studies where initial conditions are not comparable. Because growth tends to be relatively low on poor sites, a small actual response may appear large when expressed as a percent of the control. As reiterated by Leonard *et al.* (1972), a 100 percent increase of near-nothing is still near-nothing. A more realistic comparison is given by either (1) the mean annual increment, or (2) the time required for the response to gain an inch (2.54 cm) in d.b.h. over the controls at the measured growth rate (table 5). For example, thinning on the South Superior site and fertilization at Hurley each produced a similar response on a percentage basis (table 5). The actual response, however, was much greater at South Superior, where thinned trees will average an inch more than nonthinned trees in 23 years. In contrast, the 34 percent response at Hurley would require 56 years for the fertilized trees to average an inch more than the controls, if it would last that long.

Expressing growth responses as years per inch rather than as percentage also illustrates the relation between the magnitude of fertilizer responses and site quality. At these growth rates, the poles in the most responsive treatments on the moderately well-drained sites will average an inch more than the corresponding control trees in 19 years on the best site at Kenton, in 23 years on the medium site at South Superior, and in 29 years on the poor site at Hurley.

CONCLUSIONS

Fertilizing birch and maple poles on well-drained soils with site indices of 60 (18.3 m) and over generally decreased d.b.h. growth the first 3 years. On three moderately well-drained soils, fertilization has stimulated growth slightly, but the increases were relatively small and were not statistically significant. On these more moist sites the magnitude of the fertilization response was related to site quality as reflected by the site index. The largest actual growth response occurred on the best site and the smallest on the poor site; on a percentage basis this order was reversed.

Thinning significantly increased growth each year on all sites where it has been evaluated. The growth responses following thinning have been much larger and far more consistent than those due to fertilization.

These results indicate that: (1) on well-drained soils with site indices of 60 (18.3 m) and greater, diameter growth of pole-size birch and maple growing in even-age stands is limited more by competition than by availability of N, P, or K. In considering silvicultural investments on these sites, regulation of stand density should have first priority. (2) The chances of stimulating growth by fertilization are greatest on moist (moderately well-drained) sites where available soil water is sufficient and apparently enables the crop trees to utilize the additional nutrients more effectively. The size of the growth responses is related to stand conditions and site quality as indicated by the site index. The most promising trends have occurred on the better sites.

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1977. Fertilizing and thinning northern hardwoods in the Lake States. USDA For. Serv. Res. Pap. NC-141, 7 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Reports results of fertilizing and thinning pole-size sugar maple and yellow birch crop trees on six different sites. Thinning significantly increased diameter growth, but fertilization did not. Crop trees on moist (moderately well-drained) soils have tended to respond to fertilization. Discusses silvicultural implications.

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