TULIP-POPLAR HARDINESS TRIALS IN SOUTHERN ONTARIO

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ABSTRACT. Three strains of tulip-poplar (*Liriodendron tulipifera* L) were planted in 13 plots in the spring of 1973 and in one plot in the spring of 1975 in four of the climatic zones of southern Ontario. This study was designed to evaluate their hardiness with the ultimate objective of planting this valuable species north of its natural range in this Province. Initial results after five growing seasons indicate that this species can be safely planted north of its natural range in climatic zone D providing it is planted in woodlot openings where there is protection from early fall frosts.

INTRODUCTION

Tulip-poplar or yellow-poplar (*Liriodendron tulipifera* L) is native to eastern half of the United States from Vermont and Michigan south to Louisiana and Florida (10) and also extending northward into southern Ontario where it occurs naturally along a narrow 16 to 32 km (10 to 20 mile) band on the north shore of Lake Erie (2) in climatic zones A, B and the southern half of C west of the Niagara River (Fig. 2).

The tree reaches its greatest development on the deep, moist, rich, well-drained, loose textured, alluvial soils where it often attains a height of 369 m (120 ft) and a diameter of 45.7 cm to 61 cm (18 to 24 inches) in 50 to 60 years (6). In the United States, this species is of great commercial importance being used for veneer, lumber and as core stock for furniture and fixtures (6). Tulip-poplar is also valuable to the honey industry producing great quantities of nectar. For instance, McCarthy (6) estimated that a 20 year-old tree is capable of producing 3.5 kg (8 lbs) of nectar a year.

Tulip-poplar were planted over 50 years ago outside their natural range in the vicinity of Guelph and Owen Sound. Some of the trees are now merchantable. These observations stimulated the establishment of tulip-poplar by planting trees from Indiana in 1956 and from Maryland in 1959 in openings in a second growth hard maple stand near Cambridge, Ontario. Most of the trees grew exceptionally well and one phenotype from Maryland attained a height of 13.2 m (43 ft) and a dbh of 15.2 m (6.1 in) in 18 years. These initial trials and a statment made by Dr. C. Heimburger in 1967 that tulip-poplar growing in the mountains of West Virginia were hardier than the strains growing in Ohio and southern Ontario initiated the experiment. He based his theory on ecological studies of that state which indicated that during the last ice age, the advancing ice flowed down the valleys destroying all plant growth in its path but leaving those tulip-poplar growing in the upper elevations unharmed. They and their descendents survived during and after this harsh geological period whereas the tulip-poplar now growing naturally in Ohio and in southern Ontario are descendents of southern strains which followed the retreating ice northward up the valleys into Ohio and southern Ontario. Heimburger and Holst (5) describe in detail the genetic consequences of glaciation effects on tree populations in mountainous areas with particular reference to pine and spruce.

It was decided to test Dr. Heimburger's theory by planting three strains from the mountains of West Virginia, from the Ohio valley and from Ontario north of its natural range (Fig. 2) to determine if the mountain strain from West Virginia is sufficiently hardy to be successfully planted as far north as the pre-cambrian shield. The Ohio and Ontario strains would serve as controls. This experiment would also determine if and where the range of tulip-poplar could be expanded north of its natural range in Ontario. Such information could then be delineated on a map where this species could be successfully planted in this province. To accomplish these objectives, the hardiness of the three strains of tulip-poplar had to be assessed in relation to the climatic zones prepared by the Ontario Ministry of Agriculture and Food (Fig. 1 and Table 1). Simultaneously plus trees which appeared to be climatically programmed for a particular zone in southwestern Ontario could also be selected from the outplanted stock.

MATERIALS AND METHODS

Seed and seedlings

Professor F. C. Cech, University of West Virginia was

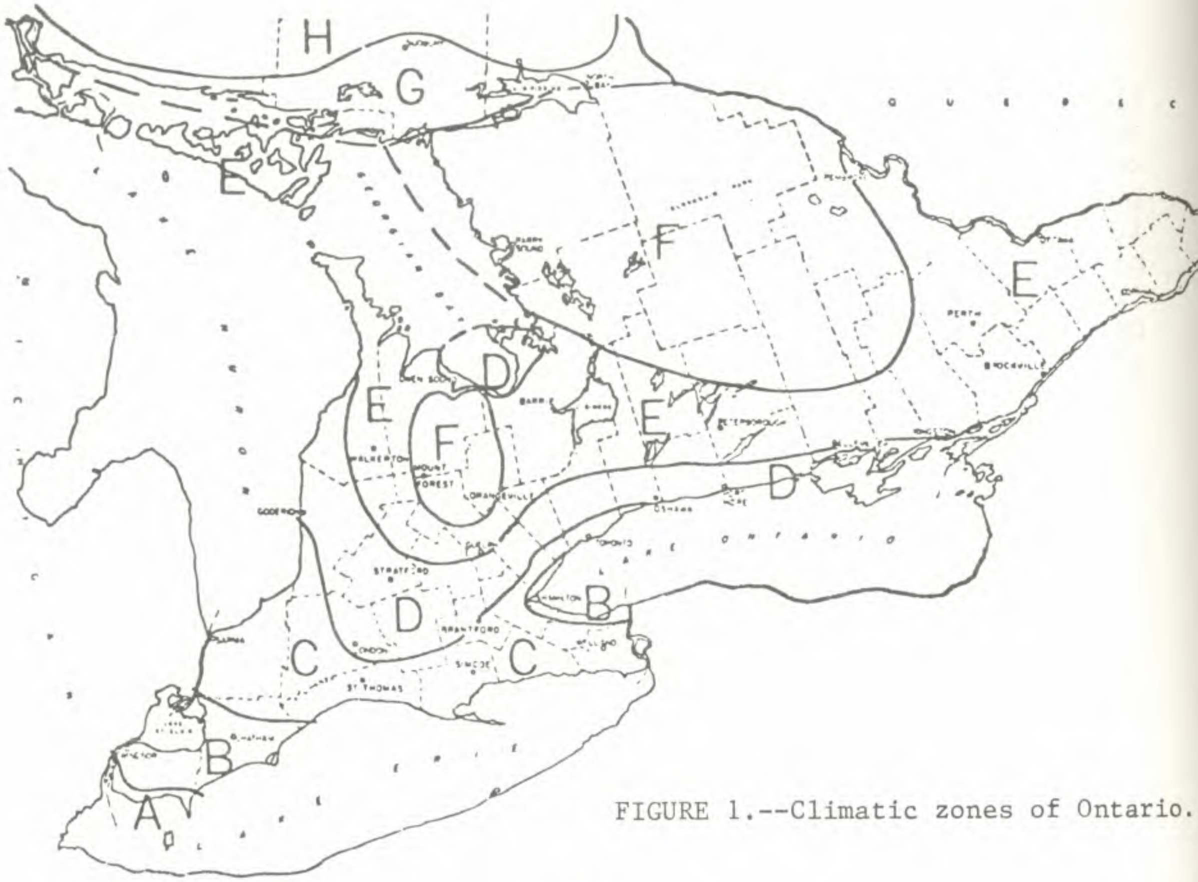

FIGURE 1.--Climatic zones of Ontario.

TABLE 1
Average Frost-free Period in Climatic Zones of Ontario

Zone	Average frost-free period (days)	Average date of last spring frost	Average date of first fall frost
A	165 or more	May 1	Oct 13
B	155-165	May 8	Oct 10
C	150-155	May 11	Oct 7
D	140-150	May 15	Oct 2
E	120-140	May 22	Sept 25
F	110-120	June 1	Sept 17
G	95-110	June 8	Sept 12
H	95 or less	After May 31	Before Sept 10

Ontario Ministry of Agriculture and Food contacted in 1968 regarding the availability of tulip-poplar seed from stands in the mountains and from the valleys of West Virginia for this experiment. In late 1969, Professor Cech sent seed from Parsons, Tucker County which had been collected in the mountains at an elevation of 920 m (3000 ft) and from the Ohio Valley in Jackson County at an elevation of 215 m (700 ft). Both locations were close to latitude 39°, and longitude 82° in West Virginia. The third source of seed was collected along the north shore of Lake Erie in southern Ontario at an elevation of 208 m (675 ft), in the vicinity of latitude 42°45' and longitude 80°30' within 8 km (5 miles) of Lake Erie. The two seedlots were stratified in the snow during the winter and sown in the nursery at Maple the following spring. A total of 38 trees from both seed lots germinated in 1970, 332 in 1971, 24 in 1972 and 3 in 1973. The seed from Ontario was collected in late September, 1969 and was sown in the last week of October, 1969 in the nursery at St. Williams. Each year the one-year-old seedlings were transplanted to the nursery where they remained for two years before being outplanted in the experiment at the beginning of the fourth growing season. All seedlings from the two West Virginia seed lots grew well in the Maple nursery but unfortunately nitrates were applied too late in the 1972 growing season which resulted in severe dieback of the succulent stems during the ensuing fall and winter. The Ontario tulip-poplar were not fertilized so late in the 1972 season which permitted most of the stems to harden by early fall of that year.

Planting sites

Planting sites were generally located on well drained, deep, loose textured soils in openings in hard maple (*Acer saccharum* Marsh) stands. This decision was based on observations in natural woodlots in southern Ontario where it was noted that this speies appears to reproduce in openings following logging or some other disturbance and never in open fields except in those open areas adjoining the edge of a woodlot. The chosen locations were then inspected in the late summer and early fall of 1972 and in one instance in the spring of 1973 for their suitability. For the experiment thirteen stands were chosen in 1972 and one in 1974 between Cambridge in the south and North Bay in the north and between Clinton in the west and Havelock in the east. However data on hardiness were only collected from 12 of the 14 plots as almost all of the trees in plot 2 were destroyed by rabbits and in the case of the other plot, plot 4, it had not only been planted two years later than the rest of the plots but it also had been decimated by rabbits.

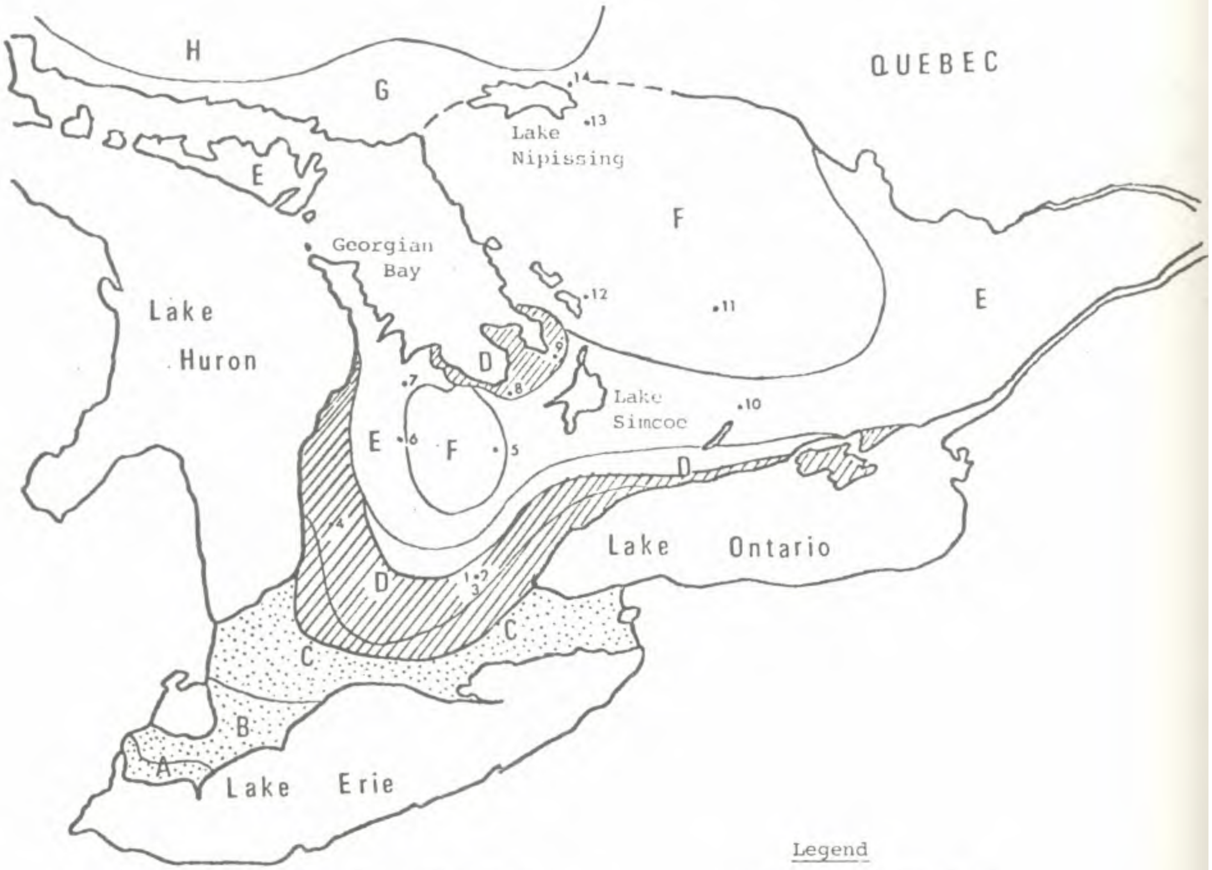

Fig.2 - Location of the tulip poplar
(1) Plots in the climatic zones of southern Ontario

(2) Natural and potential range of Tulip Poplar in Ontario.

Legend

Natural Range

Potential Range

Legend

Plots	Location
1	Cambridge
2	Cambridge
3	Cambridge
4	Clinton
5	Primrose
6	Durham
7	Chatsworth
8	Sunnidale
9	Coldwater
10	Havelock
11	Gooderham
12	Bracebridge
13	Powassan
14	North Bay

Courtesy of the Ministry of Agriculture and Food

There was considerable variation in the physiographic and geographic features of the 14 locations (Table 2). For instance, the elevation varied from 191 m (620 ft) to 415 m (1350 ft); the pH ranged from 3.4 to 7.1. The geological materials consisted of lacustrine, kame, moraine and spillway deposits. The soils ranged from sandy loams to silt and clay loams (Table 2) and the climatic zones from D to G (Fig. 2). There was also considerable variation in the forest cover types among the 14 stands even though all locations were on hard maple sites. In all instances, hard maple occurred either as scattered trees or as the dominant species in the stand. In one instance, one of the replications was planted in an opening in a second growth white cedar (*Thuja occidentalis* L) stand which had been converted by logging from a hard maple mixture to permanent pasture over 60 years ago and was now being reforested naturally with white cedar. In a second instance, all three replications were established in openings in a partially logged Scotch pine (*Pinus sylvestris* L) stand which had been planted 30 years earlier in openings in a partially logged hard maple-white pine (*Pinus strobus* L) mixture. In a third instance all replications were established in an open scrub aspen (*Populus tremuloides* Michx) stand surrounded on three sides by 20-year-old red pine (*Pinus resinosa* Ait) plantation and the fourth side of the plot lying along the edge of a dense hard maple woodlot.

Table 2 - Physiographic and geographic features of the 14 locations in southern Ontario where tulip poplar was planted in 1973.

Plot No.	Elevation M	Elevation ft	Lat.	Long.	Geological material	Soil	pH	CZ*
#1	305	1000	43°19'	80°20'	Spillway	Sandy loam	5.1	D
#2	305	1000	43°16'	80°21'	Till moraine	Clay loan	7.1	D
#3	290	950	43°22'	80°13'	Limestone plain	Silty clay	6.7	D
#4	306	1000	43°16'	81°30'	Till moraine	Silty loam	7.0	D
#5	366	1500	44°05'	79°52'	Kame Moraine	Sand	6.2	F
#6	328	1075	44°11'	80°52'	Spillway	Clay loam	6.5	E
#7	335	1100	44°25'	80°55'	Moraine	Clay loam	6.0	E
#8	189	620	44°24'	80°06'	Sand plain	Silty sand	7.0	D
#9	198	650'	44°40'	79°53'	Kame moraine	Sand loam	6.8	D
#10	198	650	44°27'	77°45'	Shallow till	Clay loam	4.6	E
#11	381	1250	44°50'	78°13'	Till moraine	Clay loam	5.4	F
#12	305	1000	45°06'	79°18'	Sand plain	Silty sand	4.3	F
#13	335	1100	46°05'	79°00'	Clay plain	Clay loam	3.6	F
#14	411	1350	46°20'	79°24'	Till moraine	Silty clay	3.4	G

*CZ - Climatic zone.

Experimental design

The tulip-poplar hardiness experiment was designed to test the relative hardiness of the three clones in relation to latitude in southern Ontario and to evaluate some of the critical site factors in each plot which were considered to effect the growth and survival of the planted trees. By 1977, the results indicated it would be more desirable to evaluate growth and survival in relation to the climatic zones of southern Ontario than to latitude only. (Fig. 1).

The hardiness of the three clones of tulip-poplar was evaluated by establishing a series of transect plots at 40 km to 80 km (25 to 50 mile) intervals running for a distance of 333 km (208 miles) from Cambridge in the south to North Bay in the north between 43°16' and 46°20' latitude and from Havelock in the east to Clinton in the west, a distance of 307 km (192 miles) between 77°45' and 81°30' longitude.

To minimize differences in site factors, the three strains of tulip-poplar were planted in a randomized and replicated design (Table 3).

Data were collected on height, type of growth, type of injury, cause of injury and survival each fall for five years following the completion of height growth of that year. Compilation of the data consisted of evaluating growth and survival in relation to the climatic zones, early fall frosts, late spring frosts, minimum winter temperature, rate of growth and type of growth for each of the three strains of tulip-poplar. Browsing by rabbits and severe shading were also recorded as such factors indirectly effected the frost hardiness of the afflicted trees.

Method of evaluating tree hardiness

The degree of hardiness of a tree can be identified each year by the origin of the leader. For instance a tree is hardy in a particular year if that year's leader is of terminal origin; moderately or slightly hardy if the leader originates from a lateral bud and not at all hardy if the new growth is of coppice origin or if a tree is dead after being killed below the root collar. A tree therefore can be considered completely hardy for a particular zone if it always produces leaders from terminal buds; partly hardy if it produces leaders from lateral buds and lateral shoots of the current seasons wood and not at all hardy if the leaders are always of coppice origin.

Table 3 - Randomized and replicated planting design for the three tulip-poplar strains.

Rep 1	Rep 2	Rep 3
V1	0	V2
V2	V2	0
0	V1	V1

V1 - mountains of West Virginia
V2 - Ohio valley of West Virginia
0 - Lake Erie, Southern Ontario

RESULTS AND DISCUSSION

Measurements and observations taken each year for the past five growing seasons indicated that freezing and or browsing were the two main factors which adversely affected growth and survival of the planted tulip-poplar in the 14 plots lying within the boundaries of climatic zones D, E, F and G of southern Ontario (Fig. 2).

Effects of early fall frosts on growth

Early fall frosts appeared to be the type of frost which was almost totally responsible for dieback in the planted tulip-poplar trees. Observations of terminal leaders indicated that tulip-poplar are generally programmed for a longer growing season than are our native hardwoods by remaining green and succulent into September and consequently are vulnerable to any killing frosts at that time.

The results for five growing seasons indicated that there were more trees with terminal leaders in Zone D than in Zones E, F and G (Table 4). This would be expected as early fall frosts occur later and the frost-free period is longer by at least three weeks in Zone D than in the other zones (Tables 7 and 8). Table 4 shows clearly that most of the leaders in Zones E, F and G originate each year from lateral buds or coppice following an early fall frost of the previous year.

Although there is supposedly a gradual transition in temperature from one zone to another (9), nevertheless there was an abrupt decrease in mean height of the tulip-poplar in Zone E as compared to the height of the same strains in Zone D. For instance, the mean height growth for five growing

Table 4 - Effects of early fall frosts on the type of shoots produced for five growing seasons in four climatic zones in southwestern Ontario.

Type of shoots

		Fall 1973 %				Fall 1974 %				Fall 1975 %				Fall 1976 %				Fall 1977 %			
C.Z.	T.P.	T	L	C	D	T	L	C	D	T	L	C	D	T	L	C	D	T	L	C	D
Mountain strain																					
D	30	7	53	37	3	62	28	7	3	43	54		3	59	33	8		37	48	15	
E	24	4	75	17	4		26	70	4	32	59	9		23	50	27		9	54	28	9
F	32	4	71	25			25	75			63	25	12	5	62	33		28	33	24	15
G	8		62	38			25	38	37			40	60				100				
Ohio Valley strain																					
D	48	2	35	60	3	56	33	3	8	42	58			58	39	3		33	44	23	
E	36	3	53	41	3	3	28	57	12	16	71	10	3	40	30	30		20	47	27	6
F	48	3	36	61		6	16	56	22		28	54	18	9	52	35	4	18	41	23	18
G	12		83	17				83	17			40	60			100				25	75
Ontario strain																					
D	48	32	58	8	2	36	41	10	13	41	56	3		62	35	3		41	41	18	
E	36	28	53	17	2	11	31	42	16	37	43	20		17	31	40	12	7	46	32	15
F	48	42	50	8		3	42	33	22		46	36	18		52	43	5	14	32	18	36
G	12	42	41	7		17	58		25		56	11	33		50	50				17	83

Legend:

T - terminal shoots
L - lateral shoots
C - coppice
D - dead tree
C.Z. - climatic zone
T.P. - trees planted

seasons in Zone D varied from 1.9 m to 2.3 m (6.6 to 7.5 ft) as compared to only 0.6 m and 0.8 m (2.1 ft and 2.6 ft) in Zone E for the three strains (Table 5). The pronounced differences in growth between the two zones may be attributed to the first fall frosts which generally occurred in the last two weeks of September in Zone D (Table 7) and earlier in Zone E resulting in a shorter growing season as compared to Zone D (Table 8). The longer growing season in Zone D is also indicated by a total of from 33% to 62% of the trees with terminal leaders as compared to only from 3% to 40% with terminal leaders in Zone E (Table 4). The percentages for 1973 were not included for discussion as the trees had been fertilized in the nursery too late in the growing season making them vulnerable to early fall frosts. Dieback from the early fall frosts became even more critical in Zone F where the average fall frost occurred generally between the 2 September and the 17 September (Table 7). The type of leaders produced each year revealed that from 86% to 100% of the trees were either partially or completely frozen back over the past five years in Zones E, F and G (Table 4). As would be expected, the trees in plot 14 in Climatic Zone G suffered the most from the early fall frosts which occurred between September 6 and 16 (Table 7). Undoubtedly the temperature was lower in this plot than at the North Bay weather station where the influence of Lake Nipissing has a moderating effect.

Effects of late spring frosts on growth

Annual measurements made each fall on this year's and last year's leaders indicated that none of the trees were frozen back by late spring frosts. It would appear that since the tulip-poplar were planted in stand openings, they were protected from the late spring frosts by the surrounding canopy. These results were different from those experienced by Funk (4) in Ohio who reported considerable dieback from late spring frosts in tulip-poplar planted in an open field. Undoubtedly the exposed trees were not protected and consequently were frozen back by the late spring frosts.

Effects of minimal winter temperature on growth

No direct evidence of injury could be related to the minimal winter temperatures between 1973 and 1977 (Table 8). The coldest temperatures occurred in January of 1975, 76 and 77 and only once in February in 1974 for the four zones. The lows ranged from -22°C to -41°C in that time. No record was kept of the lows in January and February of 1973 as the trees were still in the nursery or in January and February of 1978

Table 5 - Effects of early fall frost on the growth and survival of three strains of tulip poplar for five growing seasons in four climatic zones in southern Ontario.

Climatic Zone	No. of Plots	Spring 1973 No. of trees	Spring 1973 Ht m	Spring 1973 Ht ft	Fall 1977 No. of trees	Fall 1977 Ht m	Fall 1977 Ht ft	Ht of tallest tree m	Ht of tallest tree ft	Survival %
					Mountain strain					
D	4	30	0.18	0.6	27	2.30	7.5	4.41	14.5	90
E	3	24	0.21	0.7	22	0.79	2.6	2.56	8.4	92
F	4	32	0.21	0.7	18	0.76	2.5	1.21	4.0	75
G	1	8	0.15	0.5	0	-	-	-	-	0
					Ohio strain					
D	4	48	0.91	0.3	36	1.78	5.8	3.71	12.2	81
E	3	36	0.12	0.4	28	0.79	2.6	1.37	4.5	77
F	4	48	0.12	0.4	18	0.61	2.0	1.58	5.2	48
G	1	12	0.18	0.6	1	0.21	0.7	0.21	0.7	8
					Ontario strain					
D	4	48	0.55	1.8	34	1.87	6.1	4.87	16.0	77
E	3	36	0.55	1.8	27	0.58	1.9	1.79	5.9	75
F	4	48	0.55	1.8	14	0.52	1.7	1.15	3.8	38
G	1	12	0.52	1.7	1	0.21	0.7	0.21	0.7	8

Table 6 - Effects of severe rabbit browsing on three strains of tulip poplar in two plots in climatic zone D

Plot	No.	Fall 1973 No of trees	Fall 1973 Ht m	Fall 1973 Ht ft	Fall 1977 No of trees	Fall 1977 Ht m	Fall 1977 Ht ft	Ht of tallest tree m	Ht of tallest tree ft	% survival
Cambridge	#2	32	0.24	0.8	19	0.58	2.5	2.29	7.5	59
Clinton*	#4	34	0.82	0.6	2	2.08	6.8	2.50	8.2	6

* Planted in spring 1975

Table 7 - Last spring frosts and first fall frosts recorded at the weather stations nearest the tulip-poplar plots between 1973 and 1977

Experimental Plot	#	1973 Last spring frost	1973 First fall frost	1974 Last spring frost	1974 First fall frost	1975 Last spring frost	1975 First fall frost	1976 Last spring frost	1976 First fall frost	1977 Last spring frost	1977 First fall frost
Climatic Zone D											
Cambridge	1	May 19	Sep 17	May 8	Sep 23	Apr 26	Oct 3	Apr 27	Oct 11	May 7	Oct 15
Cambridge	2	May 19	Sep 17	May 8	Sep 23	Apr 26	Oct 3	Apr 27	Oct 11	May 7	Oct 15
Cambridge	3	May 19	Sep 17	May 8	Sep 23	Apr 26	Oct 3	Apr 27	Oct 11	May 7	Oct 15
Clinton	4	May 18	Sep 21	May 8	Sep 23	May 2	Oct 3	May 12	Oct 19	May 14	Oct 14
Sunnidale	8	May 19	Oct 18	May 11	Oct 4	Apr 28	Oct 17	Apr 12	Oct 17	May 15	Oct 14
Coldwater	9	May 18	Oct 21	May 8	Sep 23	May 28	Oct 7	May 4	Oct 11	May 9	Oct 7
Climatic Zone E											
Durham	6	May 19	Sep 17	May 28	Sep 4	May 14	Sep 10	May 23	Sep 24	June 9	Oct 7
Chatsworth	7	May 19	Sep 17	May 28	Sep 23	May 14	Oct 3	May 24	Oct 11	June 9	Oct 7
Havelock	10	May 17	Sep 10	May 11	Sep 19	May 7	Sep 10	Apr 30	Sep 25	June 9	Oct 7
Climatic Zone F											
Primrose	5	May 19	Sep 17	May 28	Sep 23	May 7	Sep 10	May 7	Oct 11	June 9	Oct 13
Gooderham	11	May 23	Sep 10	May 28	Sep 18	May 14	Sep 10	June 2	Sep 6	June 9	Sep 29
Bracebridge	12	May 17	Sep 10	May 11	Sep 18	Apr 28	Sep 10	May 13	Sep 24	June 3	Sep 29
Powassan	13	June 3	Sep 17	-	-	May 13	Sep 13	May 7	Sep 2	June 3	Sep 29
Climatic Zone G											
Northbay	14	May 17	Sep 16	May 19	Sep 16	Apr 28	Sep 14	May 12	Sep 6	May 9	Oct 6

Table 8 - Frost free periods recorded at the weather stations nearest the tulip-poplar plots between 1973 and 1977. (days)

Plot No.	1973 Frost free period	1974 Frost free period	1975 Frost free period	1976 Frost free period	1977 Frost free period
		Climatic zone D			
#1	120	137	159	166	160
#2	120	137	159	166	160
#3	120	137	159	166	160
#4	125	137	153	159	152
#8	151	145	171	187	151
#9	155	137	161	159	150
		Climatic zone E			
#6	120	98	118	123	119
#7	120	117	141	139	119
#10	115	130	125	147	119
		Climatic zone F			
#5	120	117	125	156	125
#11	109	112	118	95	111
#12	115	129	134	133	117
#13	105	-	122	117	117
		Climatic zone G			
#14	121	119	138	116	149

as the final data on growth were collected in October 1977.

The number of trees which had terminal growth over the past five years (Table 4) indicated that some of the trees had hardened for the winter and were able to withstand lows of -31°C in Zone D, -37°C in Zone E and -41°C in Zone F. It is possible that if the trees had not been planted in stand openings where they were protected from sudden changes in temperature and from exposure, many would have suffered from such extremes. This observation was confirmed in the summer of 1977 in a tulip-poplar stand which had been planted in 1971 in an open field in Zone D. Here many of the exposed trees suffered from frost cracks and dieback following the severe winter of 1976-77.

Table 9 - Lowest winter temperature recorded at weather stations nearest the tulip poplar plots.

Experimental Plot	#	1973			1974			1975			1976			1977		
		Day	Month	Temp °C	Day	Month	Temp °C	Day	Month	Temp °C	Day	Month	Temp °C	Day	Month	Temp °C
Climatic Zone D																
Cambridge	1	24	12	-21	8	2	-23	20	1	-23	23	1	-31	18	1	-31
Cambridge	2	24	12	-21	8	2	-23	20	1	-23	23	1	-31	18	1	-31
Cambridge	3	24	12	-21	8	2	-23	20	1	-23	23	1	-31	18	1	-31
Clinton	4	16	12	-27	8	2	-22	20	1	-22	18	1	-33	18	1	-31
Sunnidale	8	24	12	-20	8	2	-24	9	1	-23	23	1	-30	18	1	-31
Coldwater	9	18	12	-18	8	2	-25	20	1	-28	23	1	-33	18	1	-31
Climatic Zone E																
Durham	6	19	12	-24	8	2	-31	20	1	-27	18	1	-34	18	1	-36
Chatsworth	7	19	12	-24	15	2	-26	20	1	-25	18	1	-32	18	1	-36
Havelock	10	24	12	-31	8	2	-27	20	1	-26	18	1	-36	18	1	-37
Climatic Zone F																
Primrose	5	24	12	-24	8	2	-28	20	1	-29	23	1	-35	18	1	-36
Gooderham	11	24	12	-32	8	1	-34	20	1	-33	23	1	-41	18	1	-40
Bracebridge	12	18	12	-27	8	1	-31	20	1	-34	23	1	-38	18	1	-40
Powassan	13	24	12	-34	8	1	-34	9	2	-38	23	1	-41	18	1	-37
Climatic Zone G																
North Bay	14	18	12	-28	8	1	-30	20	1	-33	23	1	-37	18	1	-32

Effects of browsing on growth and hardiness

Tulip-poplar in two of the six plots in Zone D had been severely browsed by rabbits each year since establishment which not only drastically reduced their mean height growth for five growing seasons to 0.8 m (2.5 ft) as in plot 2, but also severely reduced their survival to only 8% as in plot 4 (Table 6). Furthermore, this type of injury induced the formation of succulent suckers which were vulnerable to early fall frosts. However, in spite of the browsing, two trees in each of the plots were only lightly injured permitting one tree to reach a height of 2.3 m (7.5 ft) in plot 2 after five years and one tree in plot 4 to reach a total height of 2.5 m (8.2 ft) in three growing seasons. These results would indicate that the climatic conditions were excellent being comparable to the four plots in Zone D which had not been browsed (Tables 4, 7 and 8).

Effects of pH on growth

The pH ranged from 3.4 to 7.1 (Table 2) but it did not appear to be a limiting factor on the growth and survival of tulip-poplar. In fact, Phillips (10) found excellent stands of tulip on soils with a pH of from 4.4 to 4.8. For instance, the pH in Powasson plot 13 averaged 3.6 which would be considered critical for such species as black walnut (3) but not for this species. In the second growing season, the coppice leaders in plot 13 attained a maximum height of 1.5 m (5.1 ft) for that year which was somewhat better than the maximum shoot growth of 0.9 (2.8 ft) attained in Sunnidale plot 8 with a pH of 7.0 (Table 2).

Effects of soil on growth

The soils ranged in the 14 plots from well-drained clay loamy to sandy loam (Table 2). The maximum shoot growth on the clay loam in Powasson plot 13 in the 1974 growing season was 1.5 m (5.1 ft) which was somewhat better than the trees growing on the sandy loam soil in Cambridge plot 1 where the maximum shoot growth for the same year was 1.2 m (3.9 ft). It would appear that soil texture does not adversely affect growth providing there is good drainage and adequate moisture. Studies done by Phillips (10) indicate that yellow-poplar grows best on soils with deep, well-drained surface layers overlying loamy or moderately fine-textured subsoils with a good supply of available moisture. Most of the planting sites fulfilled these requirements.

Growth and survival by strains

The tulip-poplar progeny from the mountains of West Virginia attained a mean height of 2.3 m (7.5 ft) in five growing seasons in Zone D as compared to only 1.8 m (5.8 ft) for the Ohio valley and 1.9 m (6.1 ft) for the Ontario strains (Table 5). However the growth rate was almost similar for all three strains in Zones E and F. The mountain strain again appeared to be hardier than the other two strains as there was greater survival for this strain in Zones D, E and F than for either the Ohio or Ontario trees.

Comparison of height growth of tulip-poplar planted in Ontario, Ohio and Alabama

The mean height of each of the three strains of tulip poplar in four plots in Zone D were 1.98 m, 2.01 m and 2.30 m (6.5 ft, 6.6 ft and 7.5 ft) (Table 5) as compared to a maximum mean height of 0.32 m (4.4 ft) for tulip poplar planted five years previously by Merz and Finn (7) in an open field in Ohio. However, the mean height of the three tulip-poplar progenies planted in Zone D were only half the mean height of tulip-poplar planted by Smalley (11) on the best bottomland site in Alabama. It was also noted that the mean height of 2.30 m (7.5 ft) for the mountain strain in Zone D on four sites was approximately 1.25 m (5.4 ft) shorter than the mean height of the average growth on six sites studied by Smalley (11) in Alabama.

Plus tree selections

A total of five trees from the mountain strain, two trees from the Ohio valley strain and four trees from the Ontario strain were selected in Zone D for fast growth, vigour, form and terminal dominance. They ranged in total height from 3.1 m to 4.9 m (10 ft to 16 ft) in five growing seasons. Cuttings will be taken from these trees and planted in several stands in Zone D of southern Ontario. No plus trees were noted in Climatic Zones E, F and G.

CONCLUSIONS

The results of this experiment suggest that selected strains of tulip-poplar can be grown successfully north of its natural range in Ontario providing the trees are planted in deep, moist, well-drained sandy loam to clay loam soils in stand openings. These potential plantable areas are in the north half of climatic zone C and all of climatic zone D lying west of Lake Ontario extending to the southern end of the Bruce Penninsula as well as that portion of Zone D between Lake Simcoe and Georgian Bay (Fig. 2). Although no plots were established along the shoreline of Lake Ontario and the St. Lawrence, there is some indication that tulip-poplar might be grown in those stands on the deep, moist, well-drained soils where shagbark hickory (Carya ovata Mill K. Koch.) occurs naturally.

Early fall frosts and heavy rabbit and deer browsing appear to be the two most limiting factors in the establishment of this species in southern Ontario. Excellent results can be expected for all trees planted on those sites previously described in Zones A, B, C and D providing the trees are not located in areas where there is a high rabbit and deer population (Table 6). If so, the trees will either be dwarfed or killed by the constant browsing and fall frosts.

Although early fall frosts are one of the limiting factors to growth and survival of planted stock in Zones E, F and G, nevertheless moderate growth and excellent survival can be expected on good sites in Zone E.

Soil texture and pH do not appear to be the limiting factors in the establishment of tulip-poplar in southwestern Ontario providing all the other growth factors are satisfactory.

A comparison in the rate of growth among the three strains revealed that the tulip-poplar progeny from the mountains of West Virginia generally grow faster and have better survival than the Ohio Valley and Ontario progenies (Table 5).

Since black walnut occurs throughout most of the natural range of tulip-poplar, we can conclude that it can also be grown successfully on the same sites in Zone D as recommended for tulip-poplar.

RECOMMENDATIONS

It is recommended from the results of this experiment that the Ontario strain of tulip-poplar should continue to be planted in Zones A, B and in the southern half of Zone C, and the West Virginia strain should be planted in the north half of Zone C and all of Zone D west of the Niagara River to Lake Huron as well as in that portion of Zone D lying between Lake Simcoe and Georgian Bay (Fig. 2).

This recommendation, if implemented, will require that the Ministry of Natural Resources procure seed from the mountains of West Virginia and establish seed beds at St. Williams Forest Tree Nursery. Planting of the aforementioned recommended stock must be done in conjunction with the issuing of suitable maps and directives to both forestry personnel and landowners interested in reforesting woodlots in Climatic Zones A, B, C and D of southern Ontario with tulip-poplar.

It is further recommended that since black walnut grows within the same range and on much the same soils as tulip-poplar that black walnut be planted on the deep, well-drained, moist soils in Climatic Zones A, B, C and D. However, to ensure maximum growth and survival in Zone D, plantings there should be confined to stand openings or interplanted with such nurse trees as poplar, white pine and spruce rather than to open fields.

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