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H. Zalasky (1972)

BARK AND WOOD STRUCTURE AND OTHER ASPECTS OF ABIOTIC DIEBACK AND TARGET CANKER IN THE GENUS *POPULUS*.

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Abstract

The symptoms, formation and anatomy of dieback and target canker in poplar affected by freeze-killing in the Canadian Prairie Region are described in detail. Freeze-killing temperatures have been observed to have their greatest impact during the autumn and spring transitions and during the winter when warm spells are followed by cold spells.

Leaves and immature buds were frequently freeze-killed in autumn to signify the first symptom expression of canker and dieback visible in September or October two days after the occurrence of frost. By early April a major portion of the crown of young trees has died back as a result of outright winter-killing of all parenchymata in the bark and wood. Freeze-killing injuries also occurred in April-May and resulted in scabby bark and in canker. Sequences of dieback in shoots and peripheral dieback in target canker are terminated by a band of frayed dead tissues of bark bordering the still living ones. These injuries in poplar are followed rapidly by devitalization of growth pattern, spindly shoots and substantially reduced increment of weak sapwood highly susceptible to subsequent winter injury.

The process of dieback and target canker formation is therefore based upon alternate outgrowth and frost-killing of developing and maturing phloem and xylem occurring respectively during the spring and autumn transitions in temperature. Amount of current rejuvenation of these tissues adjacent to injured ones varied depending upon their vitality and rate of proliferation of parenchyma of the cortex and phloem, phloem ray and xylem ray, in that order. The cambium reestablished later.

In sectional view, crushed and honeycombed necrotic parenchymata saturated with brown gum characterized winter-killed phloem, cambium and rays. Marked alterations were observed in growth pattern of rejuvenated tissues of the sapwood in the frost ring and in the multiple growth layer at margins of the canker. The most frequently observed change in growth pattern was tissue alignment, changes in structure, shape and size of cells and in the presence of callose deposition, attenuations and cell wall perforations not common to normal cells. Both in the phloem and xylem, the ray cells have proliferated to form a lens of parenchymata in advance but not entirely to the exclusion of other vascular tissues that occlude the injured zone. A primitive feature of the damaged zone has been the production of spiral thickenings in tracheids due to loss of energy from killed storage parenchyma and/or due to the effect of low temperature on developing cells. The vessels tended to have scalariform and reticulate perforations. The influence of poor quality soils on the rejuvenation of growth of damaged trees is also discussed as well as the behavior of various clones and native species of poplar and the remedial measures of winter injury.

Bark and wood structure and other aspects of abiotic dieback and target canker in the genus *Populus*

by

Harry Zalasky

Introduction, Past Occurrence and Present Observations

Introduction

Abiotic dieback and target canker in the Prairie Region of Canada has a great impact on the economic value of introduced clones of hybrid poplar and native species of poplar for use as fuel, fiber, wood products and amenity landscaping. The damage results in a short life span of poplar, degrades the quality of fiber and wood that would normally find wide usage, discourages potential users and creates unnecessary risks in estimating the required yearly production level of nursery stock.

The Canadian Forestry Service has undertaken an increasing interest in the problem in the past decade (Cram 1960, Baranyay 1964, Maini and Cayford 1968, Roller and Thibault 1966, Zalasky 1970, Zalasky *et al*. 1968). One of its aims has been progeny testing, detection, reduction and prevention of losses caused by various agencies. The aim was co-ordinated with progeny tests of existing introduced hybrid poplars and with the tree breeding program designed to improve winter hardiness and tree establishment.

In recent years, miscellaneous studies relating to stem disorders such as canker and dieback, late leafing out and progressive loss of vigor due to winter injury have been made in other parts of the world. Frequently these stem disorders have been reported under different titles (Longhammer 1967, Morgeneyer 1960, George 1953, Golfari 1958, Breuel and Bortitz 1965) because of special areas of interest as progeny testing or host-pathogen relationship. A comprehensive review of winter injury in Europe was given by Joachim (1957, 1962, 1964) who has amply illustrated two symptom expressions, "Braunfleckingrind" or scabby bark and frost burls of poplar. Earlier contributions on structure of abiotic scabby bark (Joachim 1957, 1958) and of abiotic frost ring (Harris 1934) and multiple growth layers (Glock *et al*. 1960) of wood have been useful in the present study of canker development. But other citations have also deserved particular mention, such as, Mix 1916, Jacoponi and Loreti 1961, Magnani *et al*. 1965, and Barnard and Ward 1965 because the contributions emphasized other hardwood species with similar stem disorders.

Frost-killing of vital vascular tissues has a great potential in canker and dieback inception during two cycles, the development of phloem beginning in April and of xylem in May, and the maturation of these tissues ceasing in October (Davis and Evert 1968). Its effectiveness in devitalizing rejuvenation of growth becomes an important consideration in the survival of recently planted as well as established trees including natural regeneration of native species in parkland and boreal forest. Recognition of early symptoms can have a bearing on management and cultural practices.

In order to obtain a full picture of host response to winter injury, a study of structure of rejuvenated bark and wood in the injured region seems indispensible. The project was approached with the following objectives:

1. To determine the season and incidence of frost. In some areas frost occurs every month of the year and has varying effects on vegetation. Degree of frost required to cause damage depends on the vegetative parts effected, such as blossoms, leaves or woody parts. For this purpose, monthly weather records were extrapolated by seasons. Frequency of freeze-killing temperature was considered equally important in the cause of damage to woody parts before or after the onset of winter. In either case warm weather is followed by rapid freezing.
2. To elucidate the process of development of abiotic dieback and target canker. Host response in the development of abiotic dieback and target canker is unique and different from necrosis of biotic origin because still living tissues rejuvenate and bridge gaps in the same way as in grafts.
3. To determine the structure of bark and wood in dieback and target canker. The tissues of bark and wood rejuvenated at the point of injury have the same origin and follow the same pattern of development as in grafts. Following the modern concepts of plant anatomy, cell types and arrangement of all tissues were examined from both sections and macerations.

4. To demonstrate influence of soil characteristics on growth response and rejuvenation. Observations of growth response of trees on soils of natural fertility are compared with those maintained by artificial fertilizer. Experience was gained with the behavior of introduced clones and native species.

Review of past occurrence

Winter injury was first reported by Saunders (1904) in poplar clones tested over a period of 5 to 15 years at Brandon, Manitoba and Indian Head, Saskatchewan. It was noted that certain clones were killed outright with the exception of Populus deltoides Marsh, P. laurifolia Lebed., P. nigra L., and the Russian poplar, P. x. berolinensis Dippel, P. certinensis Hort. and P. petrowskyana Shroet. Records of winter damage to trees in subsequent amenity plantings 1901 to 1912 in Alberta, Manitoba and Saskatchewan (Campbell 1908, Ross 1910, 1914) showed that great losses were sustained in some areas as Calgary to Cochrane, Gleichen and Regina to Outlook. Ross illustrated canker of Russian poplar in a Figure published in 1910 and 1939. The origin of canker remained uncertain (Ross 1929-30, 1939; Cram 1960, Baranyay 1964). Killing back of shoots was observed in the autumn and spring. Control measures were considered by mid-thirties to be non-existant. But Cram (1960) reported that some clones were more resistant than others in a progeny test.

From the early days of planting and introduction of farm shelterbelts in the Prairie Provinces, emphasis was placed on low crown and bushy poplar trees. It had a dominating influence on cultural practices, design of shelterbelts and on selection of new introductions of poplar clones. Pruning was discouraged because cankers of unknown origin developed around pruning wounds. Many of the plants, thus, showed strong juvenile branchiness in the first few years after planting. Consequently, such trees have grown into large shrubs surrounding die-back of an original improperly trained shoot. Usually the cause of these failures and mortality has been variously ascribed to neglect such as poor site preparation, poor maintenance after planting, sunscald, etc. Few of these trees persisted beyond 16 years and it was often suggested that drought, site, disease and possibly insects were the cause of the problem.

Even properly maintained trees often succumbed to top dieback, cankering, suckering, height growth retardation and open crown development as a result of continual failure of proliferated secondary leaders. Unfortunately lack of knowledge has led to the use of poplar as a "nurse" crop or temporary early shelter species in mixed shelterbelts for protection of slower growing hardwoods and evergreens. Poplar trees were supposed to be removed when the inner rows of more "permanent" species afforded sufficient shelter. Moreover, the same problems of dieback, loss of leader, forking, cankering and mortality has existed in the permanent species.

Dieback and target canker of winter-injured poplar observed since 1965

The dominant influence of freeze-killing of bark, buds, leaves and stems in the Prairie Provinces is the rapid replacement of warm air by cold Arctic air currents during the autumn onset of winter or during the spring onset of summer. Similarly, a rapid warm-up for several days during the winter months with a sudden drop in temperature effecting freeze-killing of the bark can be equally damaging. Consequently autumn injuries are readily recognizable as tip dieback or cankers particularly in current and 2-year-old wood during September or October. Severe dieback affecting older wood during the winter is recognizable when the tips of affected branches curve inward and down, giving the characteristic appearance, which may be of value in detecting affected trees. There is no color change in the bark and wood injured during the winter comparable to the dark grays of autumn injury and the brown of early spring injury. Because of the reduction in bud compliment and in food storage capacity, the rejuvenation and growth pattern changes markedly in living portions below the killed shoots. These parts flush late in the growing season, and develop spindly shoots with small chlorotic leaves which may show wilt symptoms during mid-July. Early yellowing and browning of the leaves of affected parts stand out in contrast with the rest of the tree. Suckering following perrenial target canker and scabby bark formation is another commonly observed symptom in older established trees. The life span of cankered trees depends largely on the vigor and rejuvenation capacity. Very few of them survive longer than ten years.

The highest incidence of dieback and target canker in planted trees occurs in the agricultural zone of the prairies. Some of the areas of frequent occurrence are: Agricultural amenity plants at Brooks, Calgary, Camrose, Lacombe, Lethbridge, Edmonton, Alberta; Hadashville, Russell, Winnipeg and Woodridge, Manitoba; Estevan, Indian Head, Regina, Rosetowen, Saskatoon and Weyburn, Saskatchewan; Provincial Recreational Parks - Battleford, Echo Lake, Gardiner Dam, Rowan's Ravine and Saskatchewan Landing where poplar was extensively planted in the past 15 years in Saskatchewan. It is also common on current whips in nursery propogation beds and on older commercial stock. A map (Fig. 1) shows the geographical distribution in detail.

On native species it is most evident in the parkland and in burnt- and cut-over areas of the boreal forest and the foothills.

Methods

The report on the role of winter injury in the Prairie Region has been compiled from (1) a detailed study of climatological maps and reports (Anonymous 1965-71, Ashwell 1971, Carder 1961, Crowe et al. 1962, Kendrew and Currie 1955, Thomas 1953, Weir and Mathews 1971); (2) field and histological studies of representative samples demonstrating the effects of frost and the process of dieback and canker formation; (3) analyses of soil and personal observations of the influence of soil characteristics on growth response of clones and species in field progeny tests and plantings observed over a period of several years.

Weather data

All weather data were examined from reports published by Canada Department of Transport (Anomalous 1965-71). Mean averages of maxima and minima were tabulated for the 7-year-period rather than the 10-year-period to assure availability of records for all locations. The method of tabulation was similar to that used by the Department of Transport rather than that of Harris (1934) and Glock *et al.* (1960). In addition freeze-killing temperature of 26°F and below was arrived at from field observations of bark damage. This datum was used in determining the frequency of freeze-killing during the autumn and spring transitions when longer warm spells are followed by sudden drop in night temperature. A separate line was used for frequency data of shorter warm spells with a drop in temperature during the winter months.

Observations and collections in the field

Comprehensive notes on observations of frost injury during the autumn and spring transition were made in the period 1965-1971 at field locations 1 to 4 in Manitoba and in 1970-71 at locations 5 to 7 in Alberta (Fig. 1). Plantings were examined monthly from the date of establishment for canker, dieback, scabby bark and mortality. Data on rejuvenation of trees after dieback, tendency towards occlusion of canker and the date of leafing out of injured trees compared to healthy ones were recorded during the summer in plantings at locations 1, 2, 4 and 7. Current canker material at location 6 and target canker at locations 3, 5 and 6 were used for detailed study in the laboratory. Target canker ranging in age from one to 10 years old were dated by counting the annual growth rings in the healthy wood adjacent to the occlusion wood. Sample materials consisted of autumn, spring and summer collections to obtain a more accurate information on degree of injuries and occlusion responses.

Collections by hosts from each province were as follows: Alberta: P. 'Brooks #1', P. 'Northwest', P. petrowskyana, P. 'Brooks #4 and #10', P. tremuloides Michx. at Edmonton; P. 'berolinensis', P. 'Brooks #10', P. 'Northwest', P. petrowskyana at Lacombe; P. 'Northwest', P. petrowskyana at Lethbridge; P. tremuloides at Clearwater and Hinton: Manitoba: P. balsamifera, P. balsamifera, P. x jackii Sarg. at Delta and Grand Beach; P. 'FNC #44-52', P. 'Northwest', P. 'Saskatchewan', P. 'Tristis #1', P. 'Vernirubens' and P. tremuloides at Birds Hill, Hadashville and Riding Mountain N.P.; P. balsamifera and P. tremuloides at Winnipeg: Saskatchewan: P. 'FNS #44-52', P. 'Northwest', P. 'Wheeler' at Battlefords P.P., Buffalo Pound Lake P.P., Echo Lake P.P., Estevan, Gardener Dam P.P., Pike Lake P.P., Rowan's Ravine P.P., Saskatoon and Saskatchewan Landing P.P., P. tremuloides at Candle Lake and Saskatoon.

Histology

Collections of dieback and target canker were frozen and stored at $-25^{\circ}C$. In dieback, sample material was obtained from the injured portions and of still living stems immediately below the winter-killed parts. In target canker, samples were taken from the central and marginal positions of the canker. Incipient canker was usually sampled by cutting the segment of the injured stem. Each sample was immersed into a solution of 1:1 mucilage, treated under vacuum, frozen in a cryostat and sectioned radially at 16μ thickness. Sections were mounted in lactophenol and aqua-mounting medium on glass slides or stained in lactophenol cotton blue or differentially stained in safranin and fast green. Other samples were treated in kill and fix and a 50:50 solution of alcohol and glycerine before sectioning on a sliding microtome. Microscopic observations of the sections were made at 25X and at higher powers. Maceration of woody tissues was done in glacial acetic and hydrogen peroxide 50:50 solution before mounting on slides. Microphotographs were taken at 100X and 250X magnifications.

Soils data, growth response of progeny material

Soils data on structure and natural fertility at Hadashville and Riding Mountain were obtained from reports by Roller and Thibault (1966) and Zoltai (1968) and from additional sampling and soils analyses. All together, eighteen soil samples were taken from three soil pits, one sample from each of the three upper horizons at the above locations. They were analyzed at the Soils Testing Laboratory, University of Manitoba, Department of Soil Science, Winnipeg, Manitoba. The analyses of the soil at Oliver were obtained from the Agricultural Soil and Feed Testing Laboratory, Edmonton, Alberta by personal contact. Their use was made in determining the kind and rate of application in two demonstration plantings at Birds Hill requiring a complete fertilizer formulation and at Oliver requiring nitrogen and phosphorus at standard rate.

Tree growth response was described largely by growth height and vigor. Notations were made on time of leafing out, time of leaf fall and persistance of leaves into the winter season starting in November.

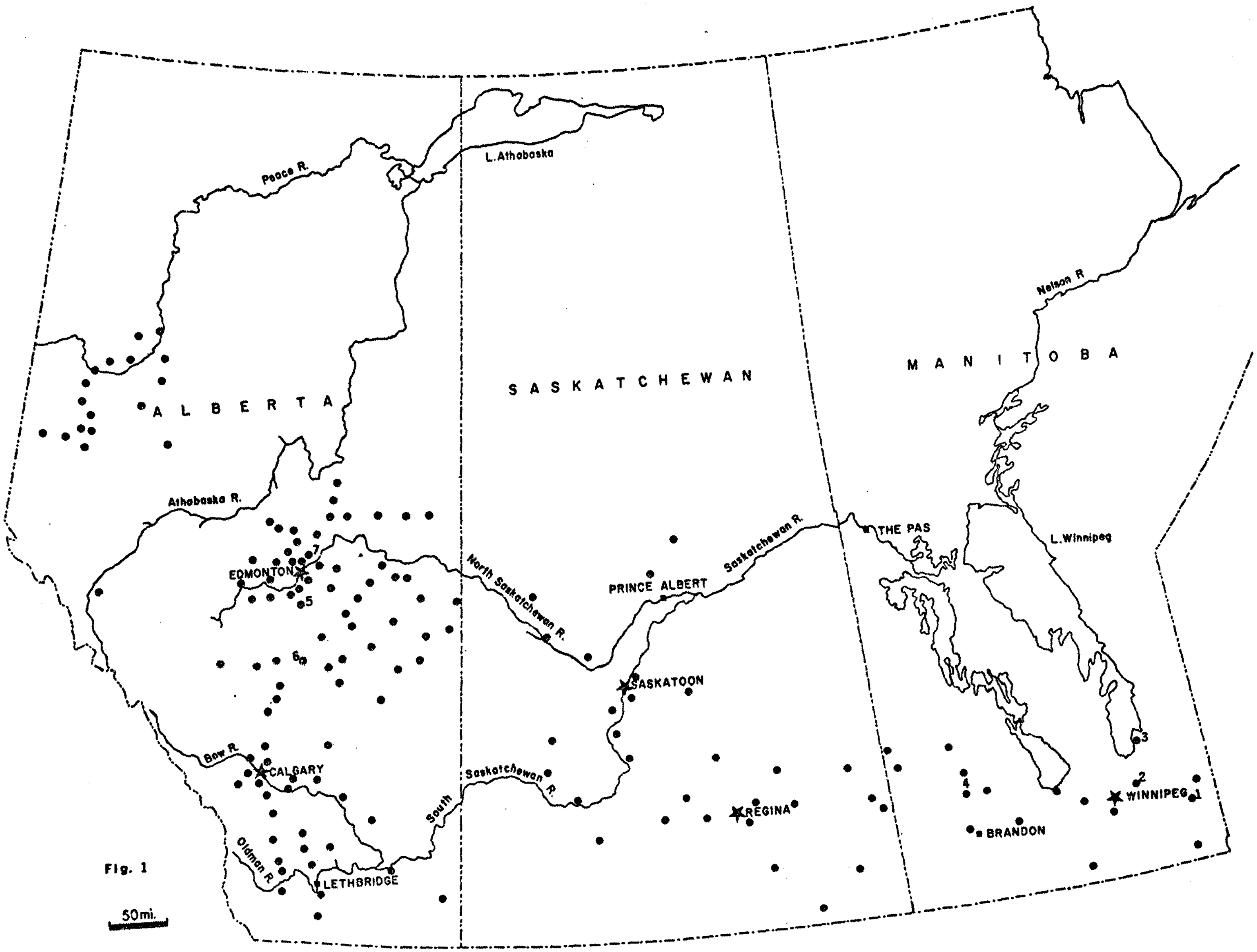
ALBERTA
SASKATCHEWAN
MANITOBA
L. Athabaska
Peace R.
Athabaska R.
EDMONTON
CALGARY
LETHBRIDGE
Bow R.
Oldman R.
South Saskatchewan R.
North Saskatchewan R.
Saskatchewan R.
PRINCE ALBERT
SASKATOON
REGINA
THE PAS
Nelson R.
L. Winnipeg
WINNIPEG
BRANDON
50mi.

Fig. 1

Incidence of Frost

Throughout the prairie, fall frost signifies the approach of winter and occurs during an autumn transition of September and October. In the foothills and the boreal forest, autumn transition begins in the latter part of August in many isolated valleys where air drainage is poor. A winter fast-freeze follows very rapidly with a snow cover and usually lasts from mid-November to mid-March throughout most of the prairie north and east of the foothills. But its duration is rather short in the southwest triangle bordered roughly by Calgary, Brooks and Swift Current. For the most part this area is lacking in snow cover. Throughout the winter months, rapid temperature fluctuation from a 42-60^{o}F range to that of 26^{o} and below-zero-weather is typical of the area. Comparable winters occur in the Hinton and Beaverlodge area. In other parts of the prairie, such extremes of temperature occur more frequently in November and March. During the spring transition in April and May, the frequency of temperature fluctuation increase partly because of chinooks or foehns and partly because of warming trends and onset of summer. Tables 1, 2 and 3 show the mean extreme maximum and minimum temperatures for autumn and spring transitions and the frequency of these extremes during the winter months.

Chinook conditions occur mostly in four areas near Beaverlodge, Hinton, Calgary and Pincher Creek, Alberta and are channelled into major valleys. They produce a rise in temperature, occasionally 30^{o} to 40^{o}F within an hour, persist for hours or days, and terminate by the arrival of strong, cold arctic winds after which cold conditions can be reestablished.

A drop in temperature from 40^{o}F to -30^{o}F is not uncommon. In some winters, Arctic winds push the chinook with sudden rises of 20^{o}F well to the south and east of the normal chinook belt. The northern fringe of the chinook belt reaches slightly north of Beaverlodge and swings in a southeasterly direction towards Edmonton, Saskatoon and Regina. The prevalence and effect of chinook north and northeast of Saskatoon is felt much less than at Swift Current, Saskatchewan. Similar decrease in effect occurs in the southeastern part of the province and in lower Manitoba influenced mainly by warm winds from the southwest and by cold winds from the north and northwest. On a smaller scale in the Riding Mountain area, all conditions required for the production of foehn winds are present.

The longest spring transition occurs at Beaverlodge, Swift Current and Winnipeg; whereas, the longest autumn transitions occur at Prince Albert and The Pas. The longest spring and autumn transitions occur along the foothills and Rocky Mountains from south to north. The average date of last spring frost is May 30 for most of the Prairie Region with variations found in scattered areas where it is one week earlier or up to two weeks later. Freeze-killing temperatures during autumn become evident first week in September in most areas and one week earlier or later in other areas.

Data of freeze-killing during autumn and spring transitions (Table 4) show the incidence of dieback, canker and mortality in various clones of poplar recently planted in the vicinity of Edmonton, Wasagaming and Winnipeg.

TABLE 1

Monthly temperature data for the period 1965-1971 at weather stations nearest to the winter injury study areas in Alberta

	Winter			Spring transition		Summer			Autumn Transition		Winter	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Edmonton Namao A, Latitude N. 53° 40', Longitude W. 113° 28', Elevation 2293 feet												
Mean: (°F)												
Maximum	4.5	22.8	28.8	46.4	62.9	67.0	72.2	71.9	60.9	49.5	30.5	16.8
Minimum	-10.8	3.8	10.8	30.0	39.6	46.9	51.3	50.4	40.2	30.2	14.0	1.8
Daily	3.2	13.4	18.4	37.0	51.3	57.7	61.8	61.2	50.5	38.5	21.7	9.3
Extreme maximum	41	44	49	65	80	84	85	85	79	68	49	44
Extreme minimum	-35	-20	-10	13	26	36	42	39	27	17	-11	-23
No. days $<26^{\circ}$	30	27	27	12	3.2*	0	0	0	1.4*	8	27	30
No. days freeze-thaw**	1	3	3								3	1
Lacombe CDA, Latitude N. 52°28', Longitude W. 113° 45', Elevation 2783 feet												
Mean: (°F)												
Maximum	8.0	25.9	31.8	47.1	63.3	69.8	73.4	73.8	62.8	52.6	31.5	19.8
Minimum	-10.0	3.7	9.5	29.8	37.2	45.0	48.9	47.5	38.1	27.9	14.1	1.3
Daily	- 1.2	14.8	20.7	36.8	50.3	56.7	61.7	60.7	50.5	38.3	22.8	10.6
Extreme maximum	41	46	52	66	81	85	87	88	82	73	53	51
Extreme minimum	-37	-17	-14	11	24	32	38	35	25	13	-14	-26
No. days $<26^{\circ}$	31	27	27	14	4.2*	0	0	0	2.3*	13	26	31
No. days freeze-thaw**	2	4	6								6	2
Brooks Horticultural St., Latitude N. 50°33', Longitude W. 111° 51', Elevation 2487 feet												
Mean: (°F)												
Maximum	12.1	26.7	33.9	51.2	64.7	70.2	79.0	79.5	66.6	54.4	35.1	24.3
Minimum	6.3	3.5	12.6	30.7	38.6	46.9	51.3	49.8	39.9	29.7	15.5	4.4
Daily	2.9	14.7	23.2	39.4	51.9	59.4	65.1	64.7	53.4	40.2	24.7	14.4
Extreme maximum	45	46	55	72	82	89	91	92	87	76	38	59
Extreme minimum	-31	-21	-12	12	26	35	41	39	27	11	-10	-23
No. days $<26^{\circ}$	30	27	25	12	3.2*	0	0	0	4.2*	10	25	29
No. days freeze-thaw**	2	5	8								9	4

*Number after decimal denotes frequency in years during the period 1965-1971. **Fluctuating temperatures $>42^{\circ}$ followed by a rapid freeze temperature of 26° F and lower.

TABLE 2

Monthly temperature data for the period 1965-1971 at weather stations nearest to the winter injury study areas in Manitoba

	Winter			Spring transition		Summer			Autumn transition		Winter	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wasagaming, Latitude N. 50^{o} 39', Longitude W. 99^{o} 58', Elevation 2040 feet												
Mean: (^{o}F)												
Maximum	5.1	16.0	27.4	45.2	59.0	69.2	73.6	70.6	62.1	42.9	27.2	14.4
Minimum	-13.2	-11.7	- 1.0	20.7	32.0	42.3	47.6	38.2	38.1	27.8	12.6	- 3.7
Daily	- 6.1	2.1	13.2	33.0	45.5	55.8	60.6	59.3	51.3	37.0	19.1	4.1
Extreme maximum	32	38	47	65	80	85	87	86	83	66	46	36
Extreme minimum	-42	-40	-29	-13	17	27	35	33	25	12	-18	-33
No. days <26^{o}	31	28	30	20	7	3.1*	0	0	1	12	27	31
No. days freeze-thaw**	0	1	4								2	0
Selkirk, Latitude N. 50^{o} 19', Longitude W. 96^{o} 53', Elevation 739 feet												
Mean: (^{o}F)												
Maximum	3.6	11.8	26.7	45.9	60.4	72.2	76.5	76.5	65.9	49.9	30.6	16.0
Minimum	-15.0	- 9.8	6.2	27.8	38.2	51.2	55.3	53.8	44.8	33.3	17.1	- 0.1
Daily	- 4.0	1.0	16.4	36.9	49.3	61.5	65.9	65.1	55.4	41.7	23.8	7.9
Extreme Maximum	27	37	46	47	84	88	89	91	84	68	51	36
Extreme Minimum	-35	-33	-16	7	22	36	43	41	29	20	- 7	-22
No. days <26^{o}	31	28	28	11	2	0	0	0	2.1*	6	24	30
No. days freeze-thaw**	0	0	2								3	0
Seven Sisters Falls, Latitude W. 50^{o} 07', Longitude W. 96^{o} 02', Elevation 875 feet												
Mean: (^{o}F)												
Maximum	4.9	13.4	28.4	45.7	59.3	70.6	75.3	74.7	56.7	48.9	30.1	16.5
Minimum	-13.3	- 9.5	5.5	27.8	37.8	49.1	57.5	53.0	45.3	34.8	17.7	1.3
Daily	- 4.2	1.9	17.0	36.3	48.6	59.9	65.1	63.9	54.9	41.8	23.9	9.0
Extreme Maximum	28	37	47	66	79	84	88	88	82	67	48	38
Extreme Minimum	-36	-36	-20	- 1	20	34	42	39	20	21	- 6	-23
No. days <26^{o}	31	28	27	11	3	0	0	0	2.2*	4	23	30
No. days freeze-thaw**	0	0	4								1	0

* Number after decimal denotes frequency in years during the period 1965-1971. **Fluctuating temperatures >42^{o} followed by a rapid freeze temperature of 26^{o}F and lower.

TABLE 3

Monthly temperature data for the period 1965-1971 at weather stations nearest to the winter injury study areas in Saskatchewan

	Winter			Spring transition		Summer			Autumn transition		Winter	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Elbow, Latitude N. 51° 07', Longitude W. 106° 36', Elevation 1930 feet												
Mean: ($^{\circ}$F)												
Maximum	4.1	18.3	27.0	47.1	63.8	71.4	77.8	79.3	66.1	50.3	30.6	18.1
Minimum	-12.0	- 2.1	8.8	27.1	41.2	48.4	53.3	51.3	41.8	30.2	15.5	2.0
Daily	- 3.9	8.1	17.7	37.1	51.1	59.9	65.5	65.3	53.4	41.7	23.1	10.0
Extreme maximum	40	35	46	68	81	89	92	92	88	70	53	36
Extreme minimum	-35	-27	-16	18	23	35	43	40	29	15	- 8	-21
No. days <26°	31	28	27	11	3.3*	0	0	0	5.1*	7	23	31
No. days freeze-thaw**	1	1	2								5	1
Swift Current CDA SRL, Latitude N. 50° 17', Longitude W. 107° 45', Elevation 2499 feet												
Mean: ($^{\circ}$F)												
Maximum	10.5	23.2	23.0	48.1	63.3	70.9	78.1	79.7	58.7	51.7	33.4	22.4
Minimum	- 7.2	4.5	10.0	28.0	38.8	47.5	53.3	51.1	41.7	30.7	16.9	6.2
Daily	1.5	13.8	21.6	38.0	51.1	59.2	65.0	65.3	53.8	41.2	24.2	12.3
Extreme maximum	41	43	53	70	82	88	93	96	89	74	55	45
Extreme minimum	-35	-20	- 9	8	24	34	40	38	27	14	- 8	-20
No. days <26°	30	26	25	11	1	2.1*	0	0	1	8	23	24
No. days freeze-thaw**	1	1	3								6	2
Prince, Latitude N. 52° 58', Longitude W. 108° 22', Elevation 1759 feet												
Mean: ($^{\circ}$F)												
Maximum	- 1.9	14.2	24.8	46.1	63.5	70.5	75.5	75.6	70.3	48.8	26.3	13.5
Minimum	-21.0	-10.0	1.6	24.8	34.9	45.5	50.8	50.0	37.9	26.6	10.1	- 2.6
Daily	-11.9	0.4	11.5	33.8	47.9	56.3	61.3	60.5	53.0	35.6	17.0	4.7
Extreme maximum	33	37	42	66	81	87	88	90	84	69	48	36
Extreme minimum	-49	-37	-24	2	23	34	39	35	23	11	-17	-28
No.days <26°	31	28	29	16	3	0	0	0	2	14	28	31
No. days freeze-thaw**	0	1	2								3	0

* Number after decimal denotes frequency in years during the period 1965-1971. **Fluctuating temperatures >42° followed by a rapid freeze temperature of 26°F and lower.

TABLE 4

Freeze-killing injury to clones of hybrid poplar during spring and autumn transition. Data on number of trees dead (-m), with canker (-c), dieback (-d) and foliage damage (F).

Clones	Number of Trees	1965 Autumn	1966 Spring	1966 Autumn	1967 Spring	1965 Autumn	1966 Spring	1966 Autumn	1967 Spring
		MS 510 1965 Hadashville, Man. Cultivated field No fertilizer applied.				MS 510 1965 Riding Mountain N. P., Man. Bulldozed field. No fertilizer applied.			
P.'berolinensis'	5	1-c,4-d	1-c,2-d	2-c	1-d		1-d		
P.'Brooks #1'	5	F	1-c,2-d	1-d	1-d			1-c	
P.'cardeniensis'	5	F1-d	1-d	2-c	1-d		1-d	2-c	
P.'FNS #44-52'	5	F2-d		1-c			2-d		
P.'Gelrica'	5	1-c,5-d	5-c,1-m	2-d	1-d	1-m			
P.'Northwest'	5	F	1-c	1-c,1-m				1-c	
P.petrowskyana	5		1-c,1-m	1-c,1-d	1-d		1-d		
P.'Saskatchewan'	5	1-c		2-c	1-d				
P.'Sargentii'	5	F3-d	1-c,1-m	1-d,1-m	1-c				
P.'Tristis #1'	5	F1-6,3-d	1-c,2-d		2-d		1-d	1-c	
P.'Vernirubens'	5	F2-c,2-d		6-c					
P.'Volunteer'	5			2-c					1-c
		MS 510 1966 Hadashville, Man. Cleared field. No fertilizer applied.				MS 510 1966 Riding Mountain N.P., Man. Bulldozed field. No fertilizer applied.			
P.'berolinensis'	10								
P.'Brooks #1'	10			F	6-d			1-c,2-d	
P.'cardeniensis'	10			F				1-c,1-d	
P.'FNS #44-52'	10				4-d				
P.'Gelrica'	10			F				1-c	
P.'Northwest'	10			F	1-d				
P.petrowskyana	10			F	2-d			1-d	
P.'Saskatchewan'	10								1-c
P.'Tristis #1'	10			F	1-d				
P.'Vernirubens'	10								
P.'Volunteer'	10			F				1-d	1-c

cont.

TABLE 4. continued

	Number of trees		1969 Autumn	1970 Spring	1971 Spring	1970 Autumn	1970 Spring
			NOR 044 1968 Bird's Hill Winnipeg, Man. Cultivated field. Fertilized annually.			NOR 044 1970 Oliver Nursery Edmonton, Alta. Cultivated field. Fertilized annually.	
P.'deSelys'		10		2-c,5-d	1-d		
P.'FNS #44-52'		10			1-c		
P.'Gelrica'	40					F*	40-d
	60					F	60-d
P.'Northwest'		10	3-c				
	60					-	-
P.'Tristis #1'		10		3-c	1-c,1-d		
	30					-	1-c
P.'Vernirubens'		10	1-c	2-c,2-d	1-d		
	80					F	80-d
P.'6-22'		10	1-c	1-d	1-d		

Process of Development of Dieback and Target Canker

Phloem and xylem are vulnerable to freeze-killing during the developmental and maturation cycles. Development of the phloem in April exposes the phloem to frost injury earlier by four to six weeks than that of the xylem which begins to develop in May. Similarly phloem and xylem are vulnerable during the autumn transition because their late maturation coincides with killing frost; the most common loci are leaf and bud traces. Damage to the bark may also occur during the winter months when very warm day temperature is succeeded by cold night temperature.

Bark and sapwood in current shoots show no visible difference in susceptibility to freeze-killing particularly if wood and buds are immature and leaves are green. In older wood, sapwood is less susceptible to killing as long as it is nourished and protected by undamaged bark. Nourishment and protection cease when the storage capacity of the bark, regardless of thickness, is reduced. Phloem and xylem are no longer able to rejuvenate readily. In decreasing order of sensitivity to frost-killing, the tissues are phloem rays, cortex, cambial region rays, pith, and phloem and xylem parenchyma in the cambial region. Thus, frost-killing has the greatest impact on tissues most active in storage and rejuvenation occurring in the zone between the cortex and the phloem. The impact of the damage on subsequent development of new phloem and xylem is, therefore, in inverse proportion.

Dieback

The first developmental stage of dieback after a killing frost in autumn is necrosis and dark discoloration of the leaves, petioles and lateral and terminal buds of immature tips of shoots and leaders. By early April, progressive necrosis of the cambium, phloem and sapwood often extends three feet from the tip down the shoot. Occasionally, even two-year-old wood may be affected. All tissues turn black or a dark gray within one or two days after injury.

Tips of current shoots not visibly damaged in the autumn become winter-killed during April of the spring transition when developing phloem is most vulnerable. They turn a light yellowish brown contrasting them with the black necrotic shoots killed during the fall. A frost band girdling the shoot or stem appears as a bleached narrow band of scar tissue, mostly periderm and a raised ridge of bark protecting the new sapwood. The new increment of wood helps to separate the scar from the dieback. Branches and stems with progressive dieback may have several frost bands of scar tissue separating parts killed in previous years. Below the lowest frost band on a branch, brown scabby bark forms at the crotch; it is recognizable by thickened bark at the still living basal part and junction of the main stem.

Further weakening of the still living part of a branch or shoot occurs in May when killing frost coincides with xylem development. The injuries in the sapwood result in abnormal tissues that become saturated with brown gum visible in sectional view as a brown ring. Similar injuries occur in the leaf and bud traces. Damage adds greatly to failures of buds to break in May and June, while those that do are slow to develop, often producing small chlorotic leaves which wilt and die in July. Surviving spindly shoots die back in the fall.

Honeycombing of frost-killed tissues of the bark often results in blistering and peeling of the periderm

Target Canker

Scabby bark

One of the first stages of target canker development is scabby bark formed after the onset of incipient injury in April during the development of the phloem. Injuries also occur in September and October during maturation of tissues. The first indication of it on the second or third day is a localized discoloration of the upper segment of living bark in the crotches, nodal and internodal points and in occlusion tissue of pruning wounds. Discolorations are golden brown with a dark brown centre and extend in depth to the phloem fiber bundles. The lesion remains intact until a new periderm and phloem form below the injured zone, thus making it appear as a convex excrescence.

Fissures develop in necrotic tissues within weeks as a result of a new increment of wood and inner bark. These often aid in the drainage of gummy resins that accumulate in dead tissues. In subsequent years, injuries enlarge the lesion radially and laterally. New periderms enclose laminations of weak phloem in oblique and lens-like pockets down to the cambium which becomes vulnerable to frost-killing. Thick excrescences of phloem rays develop here and often project through the thick rhytidome.

Initiation of the canker by outright killing of cambium.

Frequently an initial elongate canker, the smallest measuring 5 to 10 mm, results when an area of cambium, phloem and wood parenchyma are killed outright. The margin of the necrotic lesion is recognizable as a bleached band of cortex and phloem often uniquely honeycombed in radial view. Drying of the bark and wood results in deep cracks formed within weeks of initiation of the lesion. New periderm develops slightly beyond the outer margin of the frost band. It spans diagonally across the new phloem as well as previous year's phloem and cortex and becomes continuous with the healthy periderm. The non-functional elements of the previous year become obliquely aligned as a result of wedging by the new phloem and ray excrescences.

Sapwood rejuvenation and death at the zone of occlusion.

Once the canker is initiated, outgrowth of sapwood and bark at its margin tends to be centripetal during seasons of vigorous and centrifugal during seasons of weak growth response. In centripetal outgrowth, the first tissues to be formed near the cambium are those of the bark that encloses the advancing lens of sapwood in ever thickening layers of phloem. The lens of sapwood, mostly springwood, often turns radially inwards at the edge. If complete occlusion of the canker is attained, the lens of bark beneath the sapwood becomes a permanent bark pocket, distinguishable by brown discoloration and periderm that faces the dead sapwood. Since the cambium does not reform frequently in partial occlusions, the sapwood in each successive terrace becomes weaker and recedes to the outer margin in the zone of higher localized cambial activity. Such outgrowths or terraces often become necrotic each year after freeze-killing in autumn. Diagonal periderm developed in the spring helps to protect the healthy phloem from dying back. The central area of the canker invariably appears sunken as a result of partial displacement by current growth increment in each succeeding terrace.

Further development of target canker is impeded for several years by an oblique or vertical bridge on the opposite side of the still living stem and by parabollically shaped woody buttresses at the opposite ends of the bridge. The buttresses face away from each other and obliquely down and around the stem. Their development is basipetal in the lower and basifugal in the upper apices. Within the vertical bridge, the sapwood develops poorly, accounting for frequent irregular thin edges; whereas phloem develops into an exceptionally thick ridge of bark. The lateral spread of the sapwood below the canker is always more vigorous and extensive on that side of the acute angle formed by the edge of the canker and the oblique bridge. Stronger buttressing at the lower end of the bridge often results in sharp bending of the stem, especially a fast growing branch or leader. Once the upper part declines in vigor, it is not uncommon for dieback to overtake and girdle the stem just below the canker.

Bark and Wood Anatomy

Bark Anatomy

In radial sections of stem segments from dieback and canker caused by freeze-killing in autumn, damaged parenchymata in the cambium, cortex and phloem become physically disorganized by crushing, collapse and honeycombing with the grain of the wood and across. Disintegration of cellular contents results in inter- and intra-cellular occlusion with gummy resin found to be concentrated in these cells. On the living side of the woody stem adjacent to the canker or dieback, new periderm and phloem tend to enfold the edge of current sapwood resulting in a raised ridge-like band.

Radial sections of scabby bark in 2-year-old wood show honeycombed dead groups of brown and greenish cells of the cortex and phloem with granular disorganized cell contents, except for starch granules in parenchyma freeze-killed in autumn. Below the scabby bark a second periderm forms in the phloem and cortex without exfoliation of the original one. Succeeding periderms consist of the same number of cork cell layers or several times more than in the original one. Accompanying them are wedges of rejuvenation tissue, contributed about equally by the cortex and the phloem ray proliferation, which push fibers into oblique alignment. In older wood, enlargement of the lesion and thickness of scabby bark follows each freeze-killing of the phloem alternating with new periderms that enclose a lens-like lamination of dead tissues annually for three to four years. Except for the fiber bundles and periderm, enclosed dead tissues discolor with subsequent saturation, by brown gummy resin. The usual cells occurring in laminations are dead parenchymato .s cells with dark granular contents. Fiber bundles and callosed sieve elements may also be abundant. With few exceptions, cells in scabby and necrotic bark resemble the normal ones more closely than those produced at the receding edge of the target canker.

The cambial ray initials at the interface of phloem and xylem bordering the canker proliferate to produce ray excrescences consisting of isodiametric parenchymatous cells that result in a thick layer of occlusion tissues integrading laterally with normal phloem. In radial view, the small cells aligned longitudinally have simple pits and measure

16-20x30-40μ. Sieve elements and cambial initials are absent. Ray parenchyma, retaining their normal orientation throughout the excrescence are less conspicuous and shorter than normal, each measuring 15-20x40-50μ. Disorganization, dark pigmentation and death of the protoplasm results in loss of cell contents through gum cavities formed by fissuring. Each segment of phloem excrescence produced annually is isolated from the healthy phloem increment by a diagonal periderm. The segments recede basifugally in terraces and weaken the adjacent living phloem which becomes killed in the autumn.

Wood Anatomy

In radial sections of stem segments from dieback and necrotic lesion caused by freeze-killing in autumn, there are no changes in anatomy and alignment of tissues in current sapwood. Therefore, there is often a predominance of fusiform and septate parenchyma and gelatinous fibers. Parenchyma are thin-walled and unlignified with the exception of small groups which lignify without appreciable expansion in any direction to form scalariform and reticulate vessels.

It is not unusual to find necrotic bud and branch traces and cambia in radial sections of poorly developed xylem in stem segments after frost injury in autumn. Late forming occlusion tissues originate in the following growing season from cells of rays adjacent to the dead zones of tissues resulting in frost-ring of the sapwood. It is also in this region of the stem that bark scab and target canker begins to form. Unlike canker with necrosis down to the cambium, it soon bridges the partial break in the annual growth ring of the sapwood. However, the tissues contrast sharply with those of springwood and summerwood regardless of sectional views. They are readily recognizable by their marked departure in alignment, by twisting and turning of the elements and larger diameter of cells. It is for this reason that these tissues are cut progressively more obliquely and transversely in both radial and tangential sections.

Frost-ring tissue usually occurs in the springwood and occasionally in the summerwood. The first tissues to be formed have their origin in the xylem ray which proliferate to form aggregate, multiseriate and uniseriate rays as well as parenchyma with callosed reticulate wall thickenings. Interspersed amongst these are cells of cambial origin, such as, a few septate parenchyma, short vessels and tracheids all of which become dominant as soon as the cambium is reestablished. Ray parenchyma tend to retain the isodiametric form of the ray initials and frequently are angular and globose. Tracheids frequently have fine bands of spiral thickenings and are variously bent, forked, atenuated at apices or one end angular and blunt or rounded and clavate. Vessels also stand out because of their lateral proliferations, forking, and scalariform to reticulate pitting. They vary in size and shape from clavate to fusiform to cylindric. Presence of attenuated border pits and callos distinguishes these conducting elements from adjacent normal ones.

Another extreme variation of wood anatomy occurs at the margins of the canker where cells of the cambium and rays produce the multiple growth layers of occlusion tissues or the receding lenses of growth rings representing weaker developed tissues. In the latter, margins of the woody terrace invariably consist of isodiametric parenchymatous cells that measure 12-15x40-50μ, are rectangular in shape, and remain thin-walled and unlignified. Parenchymatous cells have simple pits and originate from ray initials. Except for the xylem rays, the vessels, tracheids and fibers do not differentiate.

Basifugally beyond this lens of parenchymatous cells, occlusion tissues show a wide range of development and maturation. Cambium cuts off cells to the inside and forms atypical xylem intergrading with the normal one radially and longitudinally. Ten weeks after xylem development becomes normally active in May, occlusion tissues consist of some fusiform parenchyma cells, vessels and gelatinous fibers. Alignment of tissues becomes quite complex, involving some overlapping, twisting and turning of the elements, and resulting in an interlocking grain of wood. Observations show that even after four months, reorientation of the elements does not occur. Towards the end of November, all cells are thin-walled except for the gelatinous fibers and callosed vessels. Commonly observed is the presence of spiral tracheids, with mostly fine bands of secondary thickening in the walls. The vessel segments are atypical, however, in that the end walls are definitely more oblique than usual and the perforations between vessel segments tend to be lateral. Moreover, vessel segments are shorter than those of the typical vessels. Xylem rays are multiseriate and terminal parenchyma may be up to 12 cell-layers deep. Besides cankers and dieback, distribution of the latter anomalous woody tissues also occurs at junctions of new leader with the previous leader serving a secondary role as a thick branch, usually at an angle more acute than the normal one.

Influence of Soil Characteristics on Growth Response

The ability of frost injured trees to rejuvenate depends on the growth response during the month of June for aspen and during the month of July for Aegieros poplar. Fertility and moisture of the soil are an important influence on growth and rejuvenation response. Field experience at Bird's Hill and Oliver shows that soil moisture is ample due to timely precipitation, but soil fertility (Table 5) is inadequate for most trees that have been damaged or are at the initial stage of establishment.

Very sharp differences can be picked out in the fertility of adjacent soil types by observing the growth and behavior of trees during and after establishment. However, the best current shoot increment in a normal year on anomalous soils is 12 to 30 inches and it drops to a few inches in winter-damaged trees. Demonstrations at Bird's Hill and Oliver show that it is not unusual for the same hybrid poplar to obtain a growth height of 60 to 70 inches annually on soils fertilized each season. By training and fertilizing, full grown trees are now possible in six years. Whereas trees dependent entirely on natural fertility require 10 to 15 years to attain the same height.

Inadequate root formation and penetration and patchy growth of trees is a common problem in soils with a high percentage of sodium salts imparting a blocky structure. When dry, the soil cracks into extremely hard clods. Growth of young trees is retarded, and immature spindly current shoots are subject to freeze-killing in the autumn. Harmful effects persist making it difficult to produce 3-year-old nursery stock free of truncated crowns, a condition when the leader fails to develop while branches compete with each other for height. When transplanted on

TABLE 5

Chemical analyses of samples at 2 depths of A horizon at poplar progeny tests

Location and Progen test	Carbonates % calcite	Depth "	pH	Organic matter %	Texture	Cond. mmhos.	Pounds per acre			Sodium (Na)
							Nitrogen (N)	Phosphorus (P)	Potassium (K)	
Hadashville										
MS 510 1965	Low	Ap 6"		Low	VFS	.3	3	34	60	
	Abundant	Ap 12		Low	VFS	.3	30	39	56	
MS 510 1966	Abundant	A 6	7.1	Very high	P	.3		4	98	
	Abundant	A 12	7.1	Abundant	VFS	.1	Very low	Very low	Very high	
	Low	A 6	7.2	Very high	DP	.3		1	24	
	Abundant	A 12	7.1	Very low	VFS	.1	Very low	Very low	Low	
Riding Mountain N.P.										
MS 510 1965	Low	A 6	6.5	Medium	VFSC	.3		3	484	
	Low	A 12	6.5	Low	C	.2	Very low	Very low	Very high	
MS 510 1966		A 6	6.5	Medium	VFSC	.2		1	342	
		A 12	6.8	Low	C	.3	Very low	Very low	Very high	
		A 6	6.3	Medium	VFSC	.1		2	324	
		A 12	6.0	Low	C	.1	Very low	Very low	High	
Oliver Tree Nursery										
NOR 044 1970		Ap Composite	5.4	Medium		.3	24	33	679	high

similar soil, such trees usually show a slow response to training and fertilizing. In demonstration plots at Oliver, P. 'Northwest' and P. 'Tristis #1' show better response to fertilizer and training than P. 'FNS #44-52', 'P. Gelrica' and P. 'Vernirubens'.

Behavior of Introduced Clones and Native Species

Introduced Clones

Russian Poplar

The oldest clone in use, Russian poplar attains a height of about 30 feet when fully grown. Generally known to be a hardy clone, it responds well on better soils with a high water table and suitable drainage. On sites less favorable to tree growth, the new shoots freeze-back occasionally during the autumn. Russian poplar does poorly on shallow and solonetzic soils; consequently trees deform readily through leader dieback and formation of epicormic branches near target cankers throughout the living portion of the main bole. The clone responds favorably to pruning and retraining timed with application of fertilizer and watering in late June.

Northwest Poplar

Planted since 1910, Northwest poplar is one of the hardiest clones growing on a variety of soils. It's performance in growth height, form and resistance to winter injury is best on loam and clay loam soils with better than average moisture holding capacity. On shallow and solonetzic soils, young trees respond favorably to nitrogen and phosphorus fertilizer. Because they are inclined to grow with an open crown, Northwest poplar requires pruning and training in the first 3 to 4 years. Patchy growth with evidence of stunting is often a good indicator of faulty fertility of the soil.

Berlin lombardy poplar

One of the first clones to be planted in the prairies, it does not perform as well as either Russian or Northwest poplar. Nurserymen find it difficult to produce commercially salable stock because of its inability to recover quickly from freeze-killing. On shallow and solonetzic soils with poor fertility, the clone does not thrive, declines rapidly in vigor and becomes readily susceptible to severe dieback and target canker. The clone appears to thrive satisfactorily in well irrigated soil of good fertility provided in amenity plantings.

Brooks poplar

In the nursery, young late developing shoots frost-kill readily in the fall. Healthy trees respond favorably in amenity plantings to fertilizer and irrigation, but they tend to be subject to severe dieback and target canker soon after growth is checked. On shallow and solonetzic soils, they are slow to respond to fertilizer and irrigation. A common structural defect of the crown is forking and competition of lowermost branches with the leader. Pruning of these branches before they get too large helps to correct the form of the tree. On better than average soil, Brooks poplar grows fast and is winter hardy.

FNS #44-52

A fast growing tree, FNS #44-52 grows best on loam to clay loam soils with ample moisture. On solonetzic soils, trees with winter damage to buds and shoot tips respond quickly to fertilizer and irrigation or ground water and recover the same year without interruption in vigor and cycle of growth. They attain a height of 30 feet within six years and maintain a straight, slender form with careful pruning in late June to release a few of the lowermost branches in the first three years of development. The clone is a varaceous feeder and develops a massive root system quickly. It is intolerant to severe root pruning and cultivation damage. Weak trees winter-kill readily if no remedial measures are taken.

Wheeler poplar

The clone appears to be slow to root and grow, and, as a result, it has a tendency to retain green foliage into late fall. This can be a problem with most clones if cuttings are of inferior quality are used for planting. New shoots of young plants in the nursery frequently freeze-back after the first hard fall frost. Loss of leader and close-branching results in open-headed young trees. Developing trees have a slender crown and should respond to careful pruning, retraining, fertilizing and irrigation.

Tristis #1

In quality, the clone is favorable in amenity plantings in spite of the fact that it has not been planted out as extensively as Northwest, Brooks and FNS #44-52. It roots, grows and rejuvenates rapidly and is equal in winter hardiness to Northwest poplar. In its early development, it is a closely branched tree and is inclined to fork or form an open headed crown following leader dieback. With adequate moisture, trees respond quickly to fertilizing and pruning and attain slender crowns as in FNS #44-52.

Vernirubens

Over the past five years, progeny tests in the Winnipeg area show that the clone is adaptable to planting on loam and clay loam soils and that their performance is equal to that of FNS #44-52 in height growth and winter hardiness. Trees have a slender crown and close branches, and respond rapidly to fertilizer and irrigation or ground water. Pruning is required in the first three years for suitable training. Their performance on solonetzic soils at Edmonton was not as favorable because of susceptibility to winter dieback. The clone appears to be more sensitive than 'Gelrica', Griffin, Berlin lombardy and FNS #44-52.

Native species

Aspen

In the forest and parkland, aspen is a dominant hardwood species, reproducing naturally by suckering from roots. Trees are slow-growing and deteriorate rapidly from abuse and loss of site quality, particularly if soils are shallow, saline and nutritionally poor. When fully grown, stems attain a maximum height of 25 feet and are stunted, typical of scrub trees on slopes, shallow depressions or potholes. Frequently, current reproduction from root suckers is susceptible to frost-killing in the autumn and spring. Dieback and target canker is a common defect in the parkland.

Balsam poplar

It is a pioneer tree of aluvial soils found in moist flood plains along streams and in coulees. Balsam poplar hybridizes readily when it grows in close proximity to plains cottonwood; P.x jackii is one of the clones. Dieback is a major defect. Although balsam poplar forms occlusion wood readily in stems affected by frost injuries, oblique clusters of epicormic branches tend to develop in the same wood. As branches die back, new ones form from adjacent epicormic buds. This condition leads to stem and crown deformity in older maturing trees. Scabby bark is very common in *P. balsamifera* and in *P. x jackii* in particular.

Discussion

This report has established that frost injury to immature buds and shoots occurs during the autumn transition when still living green leaves are freeze-killed; but injury to mature buds occurs during the spring transition when they are in a state of alternate quiescence and leafing out. This has often resulted in late and sparse leafing out followed by wilting whenever bud traces have been damaged. Subsequent serious damage to the bark and sapwood had lead to canker and dieback development and to early deformation of the crown by forking. In the former damage, three distinct groups of woody tissues were affected by freeze-killing: the sapwood on the inside, the cambium in the middle, and living bark on the outside. The order of susceptibility was found to be bark, sapwood and cambium. Decreasing order of susceptibility of rejuvenating tissues has been from that of the most actively proliferating cortex parenchyma and phloem ray to the proliferating xylem ray. These tissues have been found to be poorly developed and differentiated. However, tissues developed by the reestablished cambium have also been found to be defective and poorly differentiated, resulting particularly in weaker, shorter fibers, smaller vessels, and in a marked tendency toward spiral tracheids and reticulate and scalariform vessel elements. Long after reestablishment of the cambium, ray initials continued to play an increased role in the development of vascular tissues. They were observed as massive excrescences in the phloem and as aggregates of multiseriate and diffused cells in the xylem.

Thus, winter injury has had two types of impact on living tissues: necrosis of storage parenchymata and the inability of the cambium to survive. Untimely reestablishment has resulted in insufficient development and maturation of vascular tissues. The storage and vascular tissues have always been interdependent. In view of the evidence, the ability of the host to survive the impact has depended on growth factors first and on species and clones second. Because of the short growing season, it would be in the tree's favor to have only one sharply defined growth layer, preferably developed within the normal growth cycle. Climatic deviations favoring multiplicity of growth layers would, therefore, expose the additional increment to damage from sudden freezing.

Incidentally, the same abiotic disease problem existed from the time hybrid poplar were introduced into the Prairie Region just before the turn of the century (Saunders 1904). One practical suggestion reported by Ross (1910, 1939) was to avoid late season planting of cuttings and prolonged cultivation because of late fall growth and susceptibility of the new wood to frost damage. Delayed planting would usually occur when the Continental Arctic air masses caused extremely prolonged winters or when other seasonal work took priority. Prolonged cold winter conditions have characterized the north and eastern part of the region; their effects in the southwesterly direction toward the Rocky Mountains are modified by early warming spells. The latter part of the region has had greater risks of sudden freeze-killing by equally brief but extreme wind-chill temperatures below or above the supercooling temperature required to kill cells.

Application

Practical remedial measures for winter injury are prevention and rejuvenation. The primary goal should be prevention in the first year after planting out cuttings or rooted stock. The first prerequisite is to have a soils analyses well in advance of planting. Poor physical condition of the soil is often a limiting factor in planting out and in establishment. To correct it, the most practical method is to incorporate fiber by proper cultivation well in advance of tree planting. It helps to plant only healthy cuttings and rooted stock; and planting should cease no later than the third week in May to allow sufficient time for June shoots and roots to develop. Clonal selection is desirable only if preference is placed on shape of crown and purpose of wood usage. It does not necessarily minimize problems of establishment and winter hardiness except in soils with a high sodium content where the preference should be placed on 'Northwest' and 'Trist #1' and with 'FNS #44-52', 'Gelrica' and 'Brooks' as second choice.

Once the June shoots are established, emphasis should be on rejuvenation to encourage a normal cycle of growth during July. Nutritional requirements for hybrid poplar are met by applying a correct fertilizer last week in June when new shoots stimulate root development. Whereas aspen requires the application of fertilizer a month earlier. Thereafter, established trees require fertilizer each year for as long as there is a need before they are full grown. It is essential to begin pruning and training last week in June of the second year of growth to permit rapid occlusion of wounds during July. Each succeeding lowermost whorl requires pruning in the next two years. Subsequently, a general sanitation pruning of dieback of branches and leaders, and of target canker is effective in maintaining amenity plantings. Such remedial measures allow for fast growth of new leader without much loss of form, permits early training and with less chance of branchiness and forking. Mature trees are more difficult and costly to prune and train with little assurance that trees will regain form. Pruning and training of aspen should be done a month earlier.

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