AN EVALUATION OF A DURABLE FIRE RETARDANT (PHOS-CHEK® DFR) FOR FIRE PREVENTION AND THE USE OF A FIRE WEATHER INDEX SYSTEM TO PREDICT FIRE DANGER IN WOOD CHIP MULCH

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ABSTRACT

Climatic conditions at the Toronto International Airport during the 1978 growing season were determined to be a major factor in the occurrence of 12 fires in the hardwood chip mulch surrounding newly established landscape material. This study discusses the potential fire risks presented by a) a lighted cigarette in a wood chip mulch when the moisture content is reduced to less than 9.0% of fresh weight, and wind velocity is 16-20 km/hr, and b) an open flame when the moisture content is less than 5.2% and there is no wind. The Fire Weather Index system can be used to forecast fire danger in wood chips. Laboratory tests indicated that Phos-Chek® DFR, when applied to wood chips at a concentration of at least 37.5 g/L of water at 0.5 L/m^2, was effective in preventing ignition from a single lighted cigarette. The application of the fire retardant at concentrations of up to 300 g/L at 0.5 L/m^2 did not prevent the progression of a self-sustaining fire from untreated to treated wood chip mulch areas. Phos-Chek® DFR at the recommended concentration of 150 g/L and 0.5 L/m^2 could damage landscape plant material if applied when the current year's foliage and shoots are actively growing.

RÉSUMÉ

Les conditions climatiques à l'aéroport international de Toronto durant la saison de croissance 1978 furent identifiées comme facteur majeur ayant contribué à l'éclatement de 12 incendies dans le mulch fait de copeaux de feuillus entourant les arbres du paysage nouvellement établi. La présente étude traite des risques possibles d'incendie que présentent a) une cigarette allumée dans un mulch de copeaux de bois lorsque la teneur en humidité est réduite à moins de 9.0% du poids à l'état vert et que le vent souffle de 16 à 20 km/h; et b) une flamme découverte lorsque la teneur en humidité est de moins de 5.2% et qu'il ne vente pas. L'indice Forêt-Météo peut servir à prévoir le danger d'incendie dans les copeaux de bois. Des essais de laboratoire ont indiqué que le Phos-Chek® DFR, appliqué aux copeaux de bois à raison d'au moins 37.5 g/L d'eau à 0.5 L/m^2, était efficace pour prévenir l'allumage provenant d'une seule cigarette allumée. L'application du produit ignifuge à raison de 300 g/L à 0.5 L/m^2 n'a pas empêché la progression d'un feu autosuffisant à partir d'une aire dont le mulch était non traité à une aire traitée. Le Phos-Chek® DFR, selon la concentration recommendée de 150 g/L et 0.5 L/m^2, pourrait endommager les plants du paysage s'il était appliqué durant l'année où les feuilles et les pousses sont activement en croissance.

ACKNOWLEDGMENTS

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Frontispiece. Burning wood chip mulch in laboratory test tray.

TABLE OF CONTENTS

Cover photo: Damage to landscape plant material at Toronto International Airport caused by fire in wood chip mulch.

INTRODUCTION

Wood chips are commonly employed as a mulch for planting beds to control weed growth, retain soil moisture and improve the appearance of the landscape (Smith 1973). The recent landscape development contracts at the Toronto International Airport called for a wood chip mulch to be placed 0.08 m thick in designated areas (Anon. 1978a). The total area covered by the wood chip mulch was estimated at 38,000 m^2.[1]

From June to September 1978, a total of 12 fires occurred in this hardwood chip mulch. These fires ranged from approximately 2 to 8 m^2 in area and produced flames of up to 0.3 m high.[2] In some instances, the fires resulted in the destruction of landscape plant material and the airport fire department had to be called in to extinguish them. This is a service which the airport fire department is not normally expected to provide. The fires were not sufficiently large or intense to justify requests for assistance from the local municipal fire department.

This report outlines the results of a study conducted to determine the effectiveness of Phos-Chek® DFR[3], a diammonium phosphate-based compound, in preventing the ignition and subsequent burning of wood chip mulch materials. Ignition sources such as a cigarette, or a small flame such as a lighted match, are presumed to be the major causes of fires in this material at the Toronto airport. Additional laboratory tests were conducted to measure the possible phytotoxicity of this particular fire retardant to certain plant species, and to determine the drying rate of water-soaked chips. The weather records for the Toronto International Airport were examined and the Fire Weather Index and Fine Fuel Moisture Code were used to predict the fire danger rating for the period under review.

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[1]C. DeGroot, TMITC, Transport Canada, Toronto, Ontario, October 1978 (personal communication).

[2]J.S. Brister, TMITC, Transport Canada, Toronto, Ontario, 31 August 1978 (personal communication with KMS, Transport Canada, Ottawa, Ontario).

[3]The identification of commercial products is solely for the information of the reader and does not constitute endorsement by the Great Lakes Forest Research Centre.

MATERIALS AND METHODS

Ignition and Burning Tests

Hardwood chips were collected from the planting beds surrounding the aviation fuel tank farm at the Toronto International Airport in the fall of 1978. The chips were stored for approximately 4-6 weeks at 17-20°C and at 35-55% relative humidity.

To determine the rate of water loss from these chips at different drying temperatures, the stored chips were first soaked in tap water for 24 hours, and then subjected to drying. After the excess water was allowed to drain off, a 38 to 50 mm layer of chips was placed in each of four metal trays (610 mm long, 305 mm wide and 38 mm deep). Two trays were placed in a forced draft oven at 25-30°C, and the other two trays were left in ambient conditions where the room temperature was 17-20°C and the relative humidity was 35-55%. Two cross sectional samples of equal volume (approximately 220 cm^3) were taken periodically from each tray over a period of up to 26 days. The chip samples were oven dried to constant weight and the moisture content was calculated.

The weather data obtained from the Toronto International Airport weather station (Anon. 1978d) were used to calculate the daily Fire Weather Indices (FWI) and the Fine Fuel Moisture Codes (FFMC) for the period May to September 1978.

The pre-conditioned wood chips were loaded in the metal trays as previously described and were placed on a burning table in the Great Lakes Forest Research Centre's forest fire research burning laboratory (see Frontispiece). The burning room exhaust fan updraft was 152.4 m/sec, measured at 285 cm above the surface of the table. The room temperature at the time of the burns was approximately 21°C and the relative humidity ranged from 40 to 45%. Monsanto Canada Limited of Abbotsford, British Columbia supplied the required Phos-Chek® DFR fire retardant for these tests.

The treatments outlined on the following pages were designed to measure the differences in the ignition and burning rates between untreated wood chips and those treated with the retardant Phos-Chek® DFR. The effects of moisture content on ignition and burning rates were determined by using chips that were air and/or oven dried for various periods of time to produce a working range of wood chip moisture contents.

The hardwood chips that were collected for testing varied widely in size (Table 1). For consistency during testing and to simulate normal field conditions where small wood chips settle out leaving larger chips exposed on the surface, larger chips were used in all treatments except treatments 1 and 2, where unsorted samples of wood chips were used to approximate conditions existing when the mulch was first laid.

Table 1. Distribution of hardwood chip sizes in a sample 305 mm long by 305 mm wide by 50 mm deep.

Size category[a]	Hardwood chip		
	Weight range (g)	Volume range (cm^3)	% of sample (by weight)
Large	0.7 - 4.9	4.1 - 15.5	18.8
Medium	0.1 - 1.4	0.7 - 4.7	37.1
Small	0.1 - 0.5	0.3 - 1.4	44.1

[a] Size category: Large - chips retained on 36.67 mm sieve.

Medium - chips retained on 18.85 mm sieve but passed through 36.67 mm sieve.

Small - chips passed through 18.85 mm sieve.

A series of tests was conducted to determine if untreated and fire retardant treated hardwood chip mulch ignited and burned from a well established flame. The ignition source was a strip of absorbent cotton 30 cm long x 1 cm diam. first soaked in 95% ethanol and then placed across the end of each burning tray. The trays were placed on the burning table at a slope of approximately 14.6% so that the ignition end was at the lower level.

The strip of cotton in each tray was ignited along its length and allowed to burn until totally consumed. Observations on ignition and the rate of spread of any fire that occurred were measured and recorded for each test.

Air-dried chips were used in test treatments 1 and 3, but in test treatments 2 and 4 the moisture content of the chips had been further reduced by oven drying for 24 hours at 30°C. Treatments 5 and 6 were designed to determine if an area of wood chip mulch treated with fire retardant would prevent the spread of a fire from untreated chips. The chips used in these tests were oven dried at 30°C to ensure that ignition occurred. Phos-Chek® DFR was applied to half of each tray surface (0.093 m^2) by means of a small capacity (500 ml)

plastic hand sprayer. The fire retardant applied at a concentration of 150 g/L and at a rate of 0.5 L/m^2 (full strength, as recommended by manufacturer)[4] was used in treatment 5 while in treatment 6 it was applied at double the recommended strength. Following spray treatment, the wood chips in both trays were oven dried at 30°C for a further 18 hours. The ignition zone was at the far end of the untreated half of each tray.

A second series of tests was conducted using cigarettes or matches as ignition sources in both untreated and fire retardant treated wood chip mulch. For these tests, three of the burning trays described previously were each divided into two sections of equal size, 305 mm by 305 mm. The trays were then placed in a flat position on the burning table so that the centre of each tray section was 40 cm from a fan during the test period. At that distance the fan (25.4 cm diam.) produced a windspeed of approximately 16-20 km/hr. With the fan blowing, up to three lighted cigarettes (84 mm long, including filter) were placed in succession in the centre of each fuel section. If the wood chips caught fire, the fan was turned off and the combustion time of the fuel was noted. Fuel beds that failed to ignite were subjected to ignition attempts in still air conditions by successive deposition of six lighted, wooden "strike anywhere" matches, 50 mm long at mid-centre.

Treatments 7, 8 and 9 were designed to determine the effect of fuel moisture content at three different moisture levels on the ignition and burning characteristics of untreated wood chip mulch. The chips in treatment 7 were oven dried at 105°C for 24 hours, those in treatment 8 were first air dried and then oven dried for 24 hours at 30°C, and those in treatment 9 were air dried. Treatments 10, 11 and 12 were designed to measure the effects of the retardant on ignition. The tray sections of wood chips were oven dried at 30°C for 24 hours, surface treated with Phos-Chek® DFR at a concentration of 37.5 g/L and a rate of 0.5 L/m^2 (treatment 10), at 75 g/L and 0.5 L/m^2 (treatment 11) and at 150 g/L and 0.5 L/m^2 (treatment 12). Following retardant spraying, the chips were dried at 30°C for an additional 18 hours.

Toxicity Tests

Glass petri dishes (9 cm diam.) were lined with No. 1 Whatman filter paper discs and sufficient water was added to saturate them. The

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[4]R.S. Deakin, Monsanto Canada Limited, Abbotsford, British Columbia, 8 December 1978 (personal communication).

filter paper was kept moist throughout the experiment. Twenty-five seeds of each of two species of vegetables, 'Great Lakes' lettuce (*Lactuca sativa*) and watercress (*Lepidium sativum*), were planted separately in each petri dish, with four replications per species. The petri dishes were placed under greenhouse conditions where the mean daily temperature was approximately 20°C and the day length was 12 hours.

Phos-Chek® DFR was sprayed on ungerminated seeds and also on 4-day-old seedlings at a rate of 0.5 L/m^2 and at three different concentrations: 37.5 g/L, 75 g/L and 150 g/L. The effects of the fire retardant on germination and plant growth over a period of 16 days were observed and recorded.

The effects of Phos-Chek® DFR on woody plants were determined by spraying 2-month-old potted mugho pine (*Pinus mugho* Turra var. *mughus* Zenari) and Colorado spruce (*Picea pungens* Engelm.) seedlings and 4-month-old English oak (*Quercus robur* L.) and memorial rose (*Rosa wichuriana*) at a rate of 0.5 L/m^2 and a concentration of 150 g/L. Four pots of each species were subjected to treatment, placed under the above noted greenhouse conditions and observed over a period of 31 weeks.

RESULTS

Ignition and Burning Tests

The relationship of the moisture content of water-soaked wood chip mulch to drying time, under 25-30°C and 17-20°C conditions, is shown in Figure 1. The regression for each of the two drying temperatures is as follows:

Temperature 1 (25-30°C)
Log MC_1 (moisture content, percent oven-dry weight = 2.350 - 0.152 ND_1 (number of days' drying)
(R^2 = 0.960)

Temperature 2 (17-20°C)
Log MC_2 = 2.267 - 0.047 ND_2
(R^2 = 0.925)

The chip mulch dried according to an exponential relationship (Van Wagner 1979). At oven temperatures of 25-30°C the chips dried to their equilibrium moisture content (EMC) of 5.3% (oven-dry weight) in 9 days and at 17-20°C they dried to an EMC of 9.6% in 26 days.

A monthly summary of the temperature, windspeed and rainfall data for the period May to September 1978 at the Toronto International Airport is presented in Table 2. The weather at the airport during this period was generally hot, dry and windy. Approximately 45% of

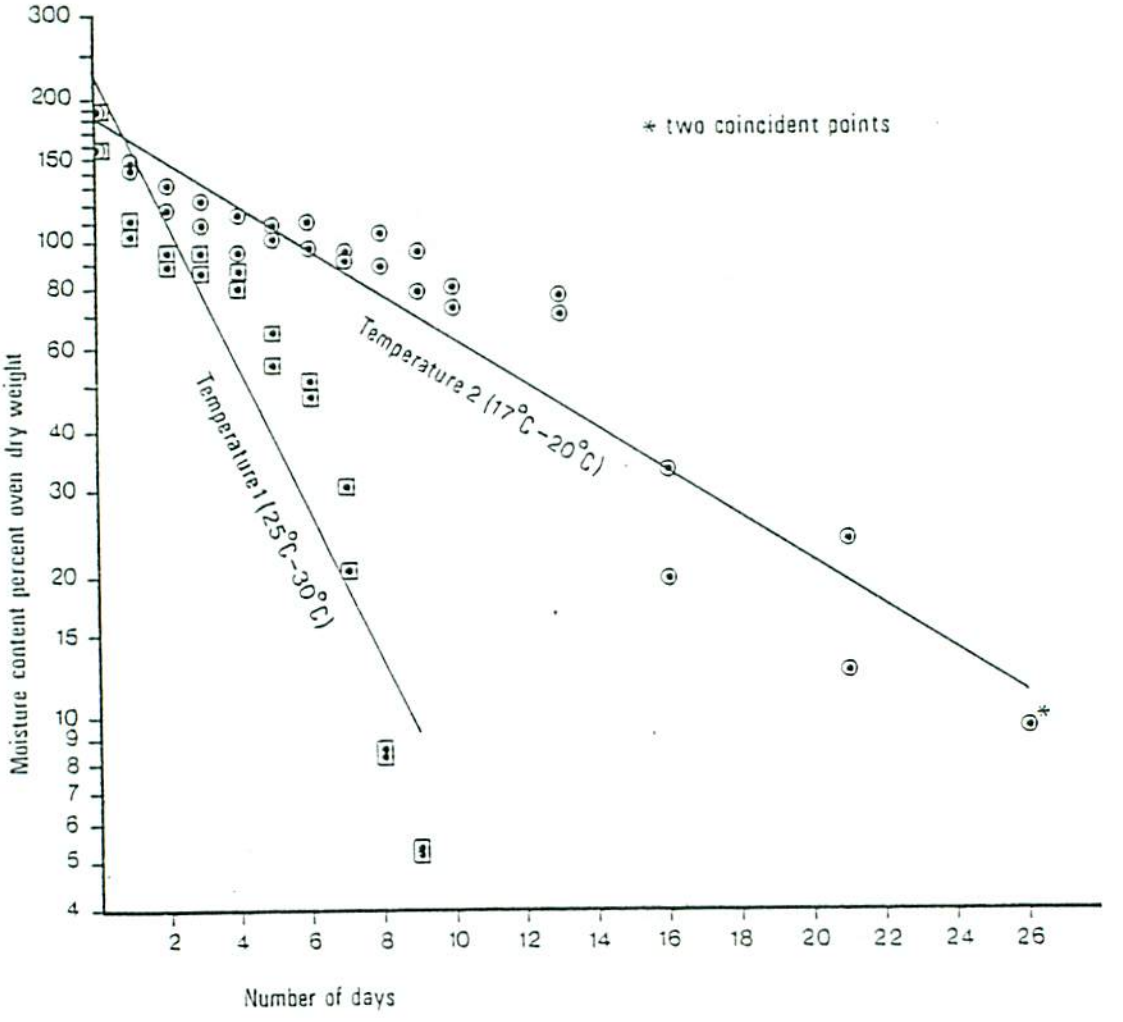

Figure 1. Drying rates of water-saturated hardwood chip mulch at two different temperatures.

the days had a maximum daily temperature of 25°C or greater. During the summer months of June, July and August almost 60% of the days had a maximum daily temperature of 25°C or greater. Windspeeds of 10 km/hr or greater occurred on approximately 60% of the days from June through September. During this period, almost 26% of the days had average

Table 2. Temperature, windspeed and rainfall data for Toronto International Airport (May to September inclusive).

Climatic factor	May	June	July	August	September	Total
Maximum daily temperature (1978):			(Number of days per month)			
25-29°C	6	10	12	15	4	47
≥ 30°C	2	3	10	5	2	22
Average daily windspeed (1978):						
10-15 km/hr	8	9	16	8	11	52
≥ 16 km/hr	12	12	6	3	7	40
				(mm)		
Monthly total rainfall						
1978	68.2	25.2	52.5	63.6	134.3	338.8
Normal	72.6	61.2	74.9	73.2	63.2	345.1

windspeeds equal to or greater than 16 km/hr. The monthly total rainfall from May through September was below average, with the driest months being June, July and August when rainfall was almost 37% below normal.

The daily FWI and FFMC at the Toronto International Airport for the period 27 April to 30 September, 1978 are presented in Figures 2 and 3. April 27 was the first day that the FWI could be calculated in 1978 and 30 September was arbitrarily selected as the end of the fire season in this area. The FWI reached extreme levels in April, June, July, August and September with the peak occurring during the 23-day period between 28 June and 20 July when the FWI was extreme every day but two. The FFMC followed a similar pattern during this period with 21 days having FFMC values of high or extreme. It is evident from Table 3 that during the 1978 fire season, the FWI was high or extreme for approximately 53% of the days, while the FFMC was high or extreme for almost 41% of the days.

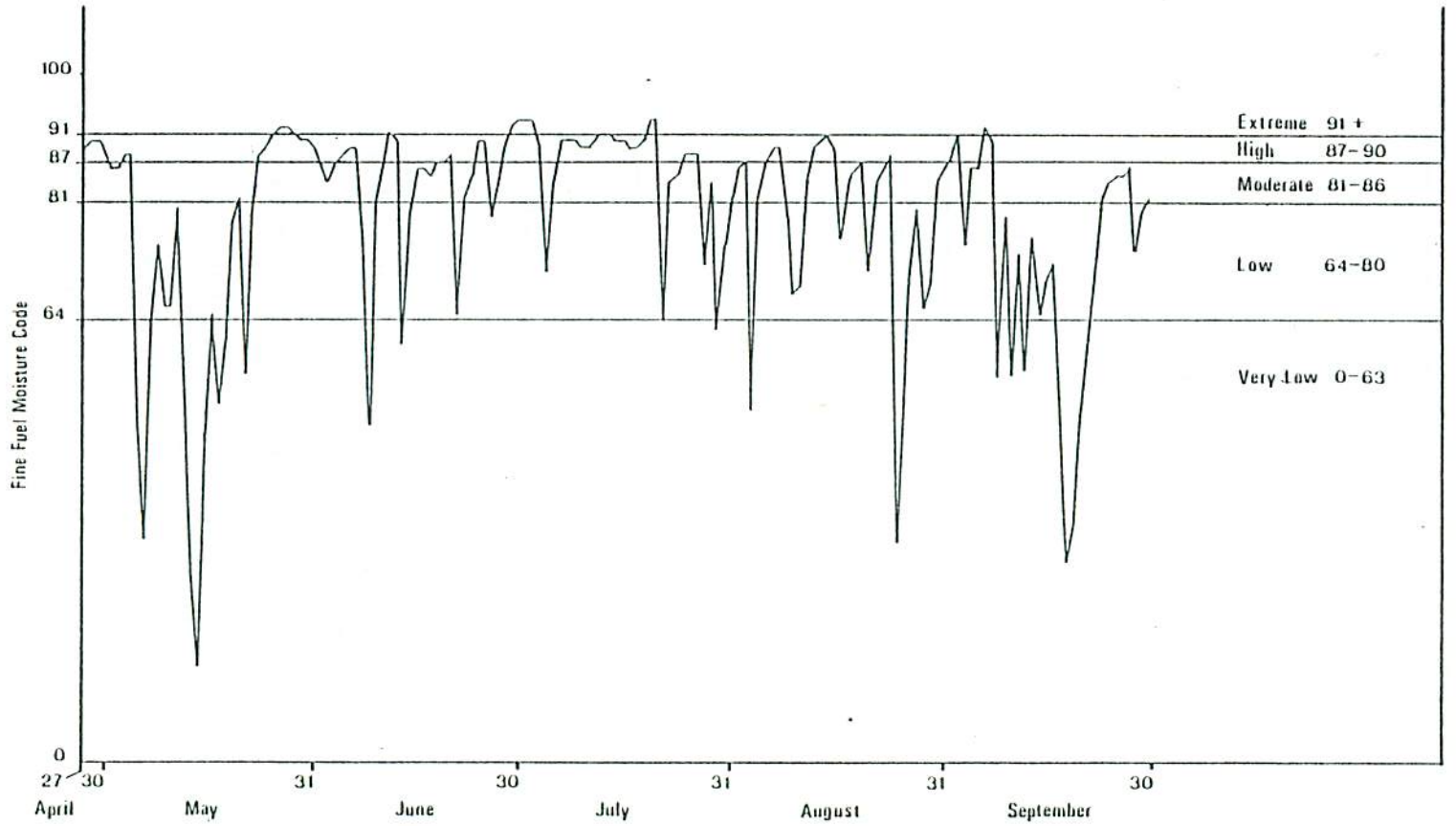

Figure 2. Fine Fuel Moisture Code, Toronto International Airport, 1978.

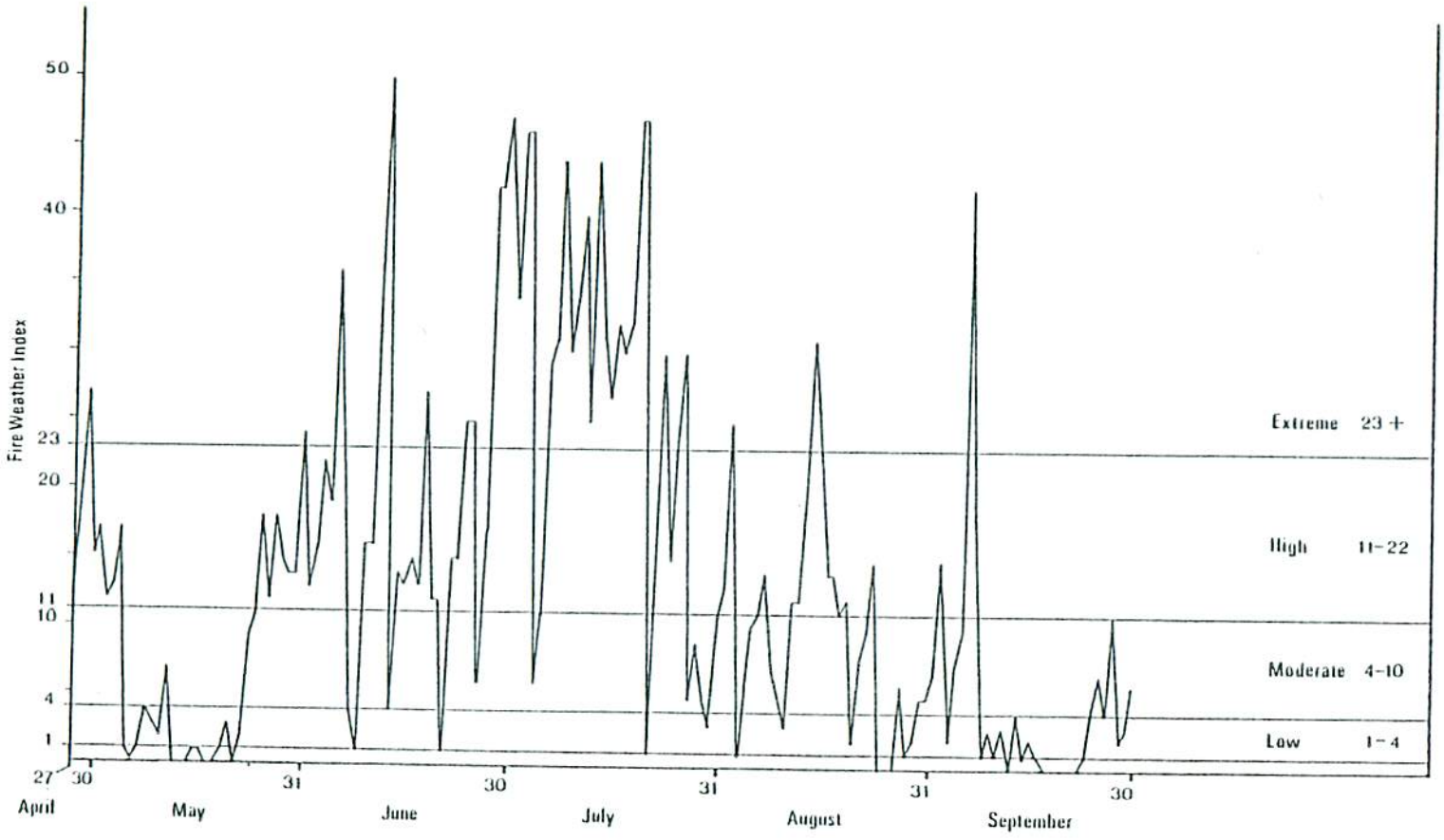

Figure 3. Fire Weather Index, Toronto International Airport, 1978.

Table 3. Distribution of daily Fire Weather Index and Fine Fuel Moisture Code danger classes at the Toronto International Airport, for the period 27 April to 30 September 1978.

	Fire Weather Index		Fine Fuel Moisture Code	
Fire Danger Class	Number of days	Percent occurrence	Number of days	Percent occurrence
Very Low	17	10.8	24	15.3
Low	29	18.5	35	22.3
Moderate	28	17.8	34	21.6
High	47	30.0	48	30.6
Extreme	36	22.9	16	10.2

The unsorted mixture of hardwood chips (treatment 1), which had a moisture content of 16.1%, did not ignite and burn when exposed to the ethanol flame under no-wind conditions (Table 4). Similarly, the sorted large chips of treatment 3 did not burn when their moisture content was 11.9%. The unsorted chips of treatment 2 and the sorted chips of treatment 4 ignited and burned completely at moisture contents of 4.6 and 5.2%, respectively.

Although the fire in the wood chips was set evenly along one end of the burning tray, the flame front progressed more rapidly at mid-bed than it did along either edge. The traditional bow front associated with narrow fire fronts was prominent in all trials but when the fire smoldered this pattern was much less evident. To account for the uneven rate of fire spread across the fire bed width, the rate of spread of the leading edge of the flame front was determined by timing it as it proceeded from the ignition point to where the flames died out, and by measuring the time required for all the wood chips to ignite within a particular section of the burning tray. The rate of spread of the flame front in treatments 4, 5 and 6 is shown in Figure 4, while the rate of spread of the fire in these treatments is indicated in Figure 5.

Treatment 5, the application of the fire retardant Phos-Chek® DFR at full recommended strength (concentration 150 g/L; application rate 0.5 L/m^2), did not prevent the spread of the flame front from the untreated to the treated section of the tray. The rate of spread of the flame front was reduced from 20.3 mm/min through the untreated chips to 7.1 mm/min through the treated chips, a reduction of approximately 65%. The areal spread of the fire was also reduced by 65%.

Table 4. Results of ignition tests on hardwood chips exposed to lighted strip of absorbent cotton, soaked in 95% ethanol.

Treatment number	Fuel type	Fire retardant treatment	Moisture content (% of oven-dry weight)	Observations
1	unsorted mixture of chip sizes	untreated	16.1	Fuel would *not* burn.
2	unsorted mixture of chip sizes	untreated	4.6	Flames spread over entire tray and burned chips to ashes in *36 min, 45 sec*; average rate of spread of the flame front was 20.0 mm/min.
3	sorted, large chips	untreated	11.9	Fuel would *not* burn.
4	sorted, large chips	untreated	5.2	Flames spread over entire tray and burned chips to ashes in *40 min*; average rate of flame spread was 21.0 mm/min.
5	sorted, large chips	Phos-Chek® DFR; conc. 150 g/L, application rate 0.5 L/m^2; fire retardant applied to ½ surface area of chips	4.5	Flames spread over entire tray and burned chips to ashes in *72 min*--both treated and untreated sections; average rate of spread of the flame front was 10.5 mm/min (20.3 mm/min for untreated section and 7.1 mm/min for treated section).
6	sorted, large chips	Phos-Chek® DFR; conc. 300 g/L, application rate 0.5 L/m^2; fire retardant applied to ½ surface area of chips	5.0	All fuel burned in *3 hours, 26 min*--both treated and untreated sections; average rate of spread of the flame front was 10.7 mm/min (16.9 mm/min for untreated section and 4.2 mm/min for treated section); the flames went out when they had progressed 8 cm into treated section; the chips continued to smolder and the fire spread throughout the entire tray and burned chips to ashes.

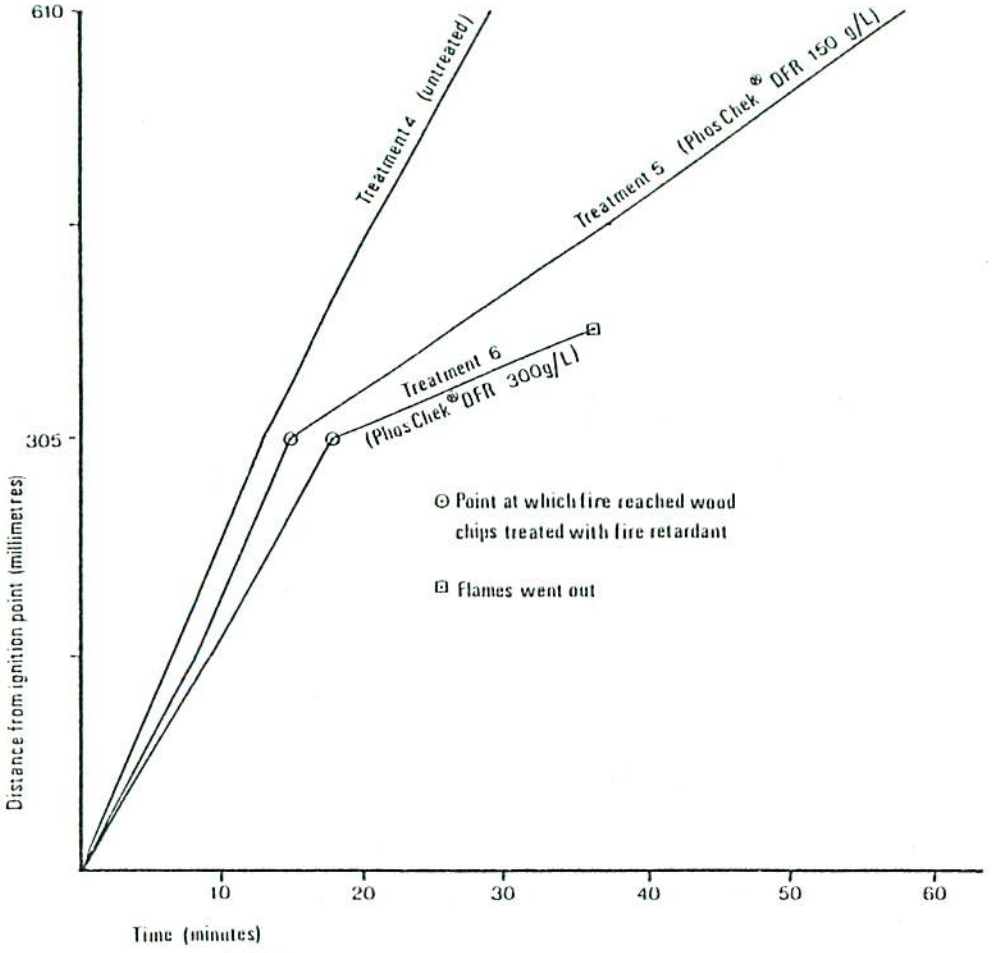

Figure 4. Rate of spread of flame front in untreated and Phos-Chek® DFR fire retardant treated hardwood chip mulch, ignited by a strip of absorbent cotton soaked in 95% ethanol.

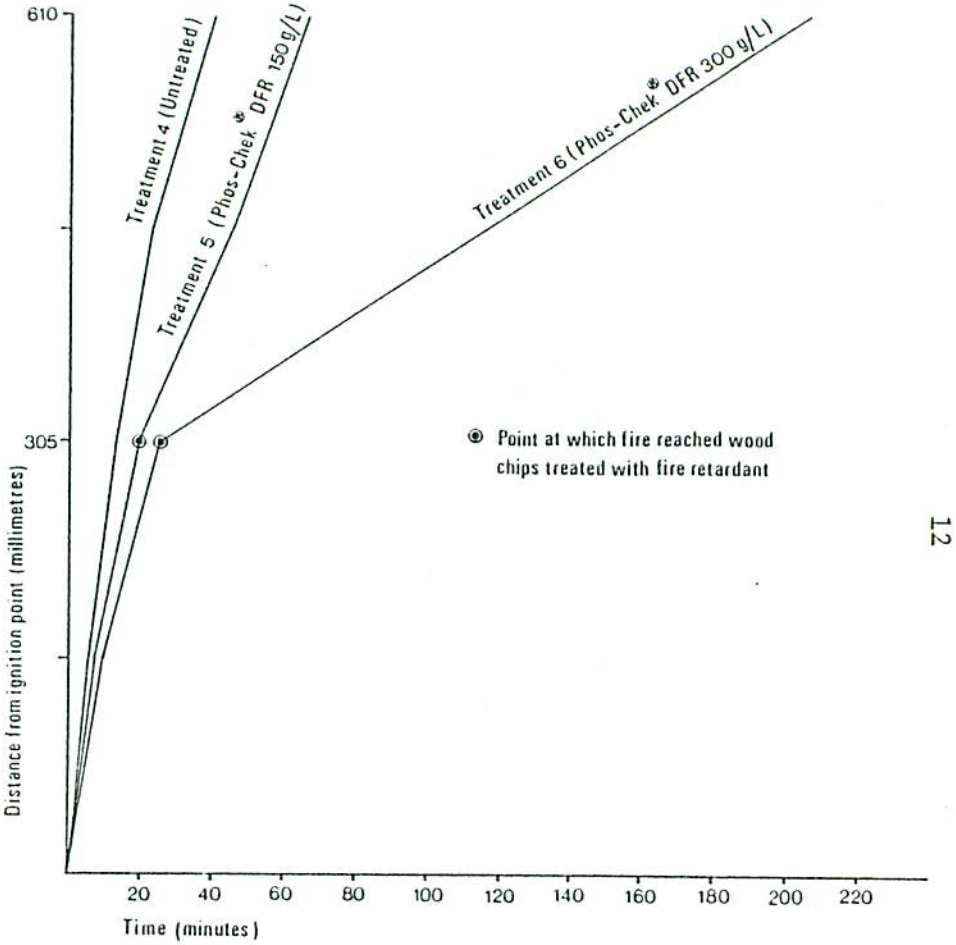

Figure 5. Rate of spread of fire (i.e., time required for all of the wood chips in each quadrant of the tray to ignite) in untreated and Phos-Chek® DFR treated hardwood chip mulch, ignited by a strip of absorbent cotton soaked in 95% ethanol.

The average coverage of 50.3 cm^2/min in the untreated section was reduced to an average of 17.4 cm^2/min in the treated section. Increasing the application of Phos-Chek® DFR to twice the recommended strength (treatment 6) did not prevent the fire from penetrating into the treated chips, but the flame did go out by the time it had progressed to approximately one-quarter the distance across the treated chips. The fire continued to smolder in the treated chips until they were reduced to ashes. Areal spread of the fire was reduced by 86%, from 37.2 cm^2/min in the untreated section to 5.2 cm^2/min in the treated section. The data in Table 5 confirm this: once the hardwood chips ignited, they were almost entirely consumed, whether or not they were treated with fire retardant.

Combustion times for the external ignition sources, a lighted cigarette and a lighted wooden match, were approximately 7.5 min (induced wind velocity of 16-20 km/hr) and 44-55 sec (no-wind conditions), respectively.

Table 5. A comparison of the quantities of hardwood chips consumed by fire in untreated chips and chips treated with Phos-Chek® DFR.

	Percentage of original chip weight consumed	
Treatment	Untreated	Treated
4	89.4	[a]
5	96.2	91.6
6	96.3	93.3
7	91.6	[a]
8	92.5	[a]
9	96.5	[a]
10	[b]	91.3
11	[b]	93.7

[a] No treated chips in tray
[b] No untreated chips in tray

Untreated hardwood chips, with moisture contents of 0, 4.1, and 9.0% (treatments 7, 8 and 9, respectively, Table 6), were ignited by a single lighted cigarette but the length of time required for ignition to take place increased with fuel moisture content increase. Ignition delay time was 4½ min at 0% mc and 6¾ min at 9.0% mc. The time required to ignite treated and untreated chips and the time required to burn all of the chips are illustrated in Figure 6.

Table 6. Results of ignition tests on sorted, large hardwood chips exposed to lighted cigarettes and matches (windspeed until ignition, 16-20 km/hr)

Treatment number	Fire retardant treatment	Moisture content (% of oven-dry weight)	Observations
7	untreated	0.0	*First* cigarette; chips glowing in approximately *1 min*; at *4 min, 15 sec* chips burst into flame (cigarette 2/3 burned); all chips burned to ashes in *16 min*.
8	untreated	4.1	*First* cigarette; chips glowing in approximately *1 min*; at *5 min, 40 sec* chips burst into flame (all of cigarette burned); all chips burned to ashes in *16 min*.
9	untreated	9.0	*First* cigarette; chips glowing in approximately *3 - 4 min*; at *6 min, 45 sec* chips burst into flame (all of cigarette burned); all chips burned to ashes in *33 min*.
10	Phos-Chek® DFR ($\frac{1}{2}$ recommended strength); conc. 37.55 kg/L, application rate 0.5 L/m^2	4.1	*First* cigarette; chip surface blackened only; *Second* cigarette; chips glowing in approximately *10 min*; at *11 min, 50 sec* chips burst into flame; all chips burned to ashes in *38 min*.
11	Phos-Chek® DFR ($\frac{1}{4}$ recommended strength); conc. 75.0 g/L, application rate 0.5 L/m^2	4.1	*First* cigarette; chip surface blackened only; *Second* cigarette; chips glowing in approximately *9 min*; at *14 min, 30 sec* chips burst into flame; all chips burned to ashes in *34 min*.
12	Phos-Chek® DFR (full recommended strength); conc. 150 g/L, application rate 0.5 L/m^2	4.1	*First* cigarette; chip surface blackened only; *Second* cigarette; chip surface blackened only; *Third* cigarette; chip surface blackened only after approximately *30 min*.
12a	Same as treatment 12	4.1	Lighted wooden matches were added to the treated chips from Treatment 12 (no wind); on *sixth* match added to same spot, an area of 6 sq. cm caught fire but flames went out approximately *1 min* after ignition; the remainder of the chips did *not* burn.

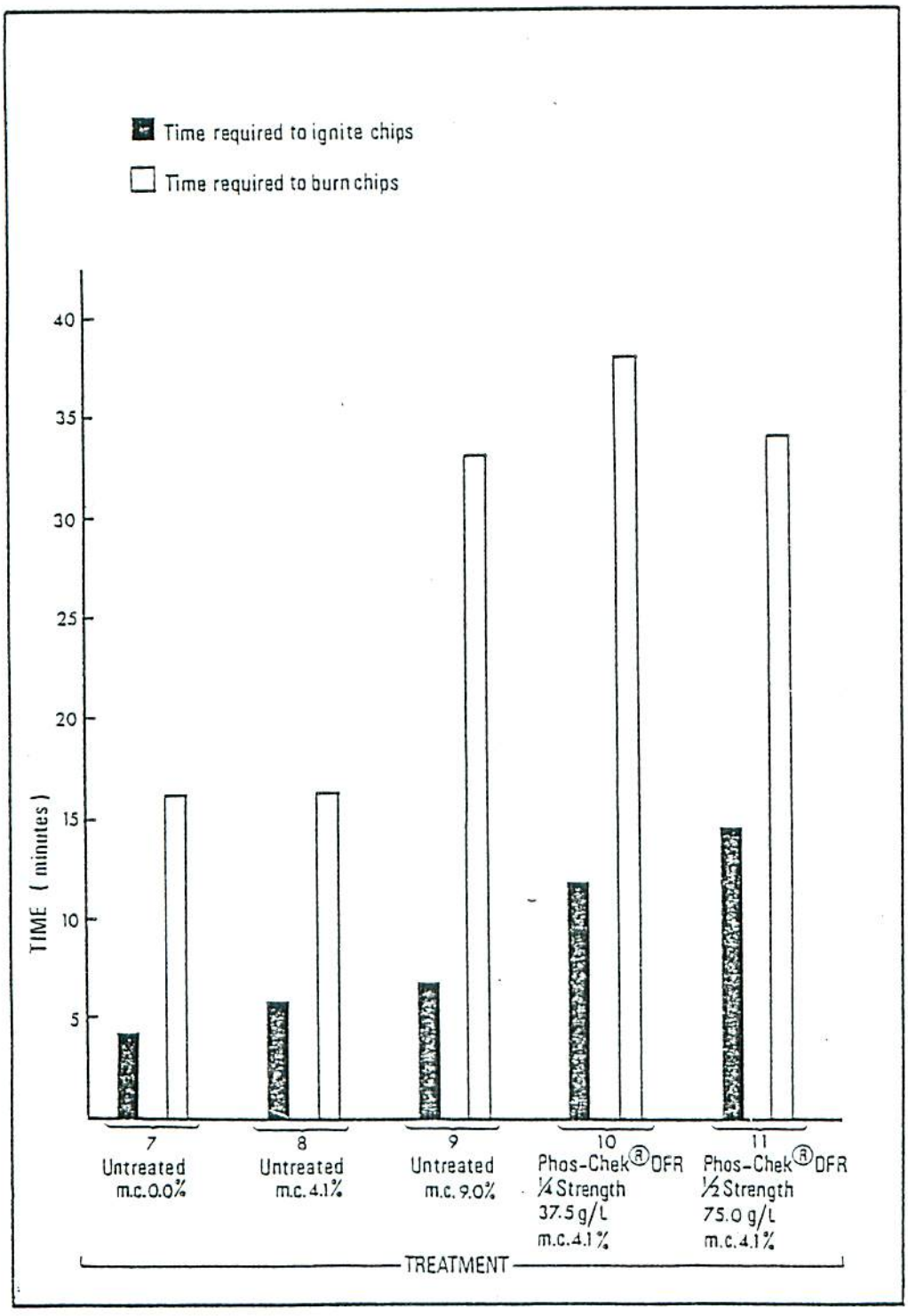

Figure 6. Histogram showing relationships of chip dryness and concentration of Phos-Chek® DFR fire retardant application to time required to ignite fuel with lighted cigarette, under 16-20 km/hr wind conditions and time required for 930.25 cm^2 of wood chips to burn to ashes.

None of the treated chips were ignited by only a single lighted cigarette, regardless of the concentration of Phos-Chek® DFR applied. When the application was one-quarter (treatment 10) and one-half the recommended strength (treatment 11) the treated fuel ignited and burst into flames after the addition of a second lighted cigarette.

The hardwood chips treated at the recommended level (concentration 150 g/L, application rate 0.5 L/m^2, treatment 12) did not ignite after the addition of three consecutively lighted cigarettes. Similarly, the consecutive addition of six lighted wooden matches to the hardwood chips (treatment 12a) produced only a spot fire approximately 6 cm^2 in area. The flames died shortly after ignition by the sixth match and no chips were consumed beyond the initial ignition point.

Toxicity Tests

No lettuce or watercress seeds germinated during the 16 days following treatment with any of the concentrations of Phos-Chek® DFR. Untreated (control) seed had a germination rate of 97% for the lettuce and 98% for the watercress.

The results of the application of retardant to 4-day-old lettuce and watercress seedlings are shown in Table 7. Seedlings of both species treated with Phos-Chek® DFR at a rate of 0.5 L/m^2 and at concentrations of 150 g/L and 75 g/L had 100% mortality by the fourth day after treatment. Seedlings treated with concentrations of 37.5 g/L had 100% mortality by the twelfth day following treatment. There was no mortality among the untreated seedlings during the 12-day period.

The treatment of the four species of trees and shrubs with Phos-Chek® DFR at a rate of 0.5 L/m^2 and at a concentration of 150 g/L resulted in the formation of a light-grey film over most of the upper leaf and needle surface area as well as portions of the main stem. The light-grey film began peeling off four days after treatment.

Necrosis was evident within one week of the retardant application to the English oak, mugho pine and rose seedlings. It was particularly visible on the edges and tips of the youngest needles and leaves. The Colorado spruce showed only slight traces of necrosis. Terminal growth dieback was observed on three of the four English oak seedlings.

Thirty-one weeks after treatment, 7 of the 16 mugho pine seedlings were dead. Of these, five died within 2 weeks following application. There was no mortality among any of the other species during this period and none of the surviving plants appeared to express any obvious symptoms of an adverse reaction to the application of the retardant. The three affected English oak recovered from terminal dieback by initiating new leaders from lateral buds.

Table 7. Effect of the application of the fire retardant Phos-Chek® DFR to lettuce and watercress seedlings.

Treatment	Percentage of seeds germinated and alive													
	Lettuce							Watercress						
	Days since treatment							Days since treatment						
	0[a]	2	4	6	8	10	12	0[a]	2	4	6	8	10	12
Control	97	97	97	97	97	97	97	95	95	95	95	95	95	95
Phos-Chek® DFR (*full recommended strength*; concentration 150 g/L, application rate 0.5 L/m^2)	95	95	0	0	0	0	0	96	96	0	0	0	0	0
Phos-Chek® DFR ($\frac{1}{2}$ *recommended strength*; concentration 75 g/L, application rate 0.5 L/m^2)	93	93	0	0	0	0	0	98	98	0	0	0	0	0
Phos-Chek® DFR ($\frac{1}{4}$ *recommended strength*; concentration 37.5 g/L, application rate 0.5 L/m^2)	94	94	94	15	13	3	0	96	96	96	23	4	1	0

[a]4-day-old seedlings

DISCUSSION

Fires in wood chip mulch have been reported in a number of locations in southern Ontario. Two of the 10 agencies contacted by Transport Canada reported infrequent incidences of fires in wood chip mulch[5].

The Department of Public Works reported the occurrence of a few small smudge fires during spring and fall. The National Capital Commission noted that several fires were deliberately started by vandals and one fire was purportedly caused by a cigarette. The only fire reported by Ontario Hydro, Niagara Region,[6] was one caused by a burning cigarette butt.

While fires in wood chip mulch do not appear to be a common or widespread problem, the number of fires that were reported at the Toronto International Airport in 1978 indicate the probability of a continuing, serious fire risk in that particular location. Although the exact cause of the 1978 fires is unknown, very likely the majority of these fires were ignited by cigarettes or other smoking materials thrown from moving vehicles. The fires shown in Figure 7 were relatively close to roadways. In one case the fire occurred near a bus stop, and could have been caused by a cigarette discarded by a passenger waiting to board.

The results of this study indicate that it is possible for a lighted cigarette to start a fire in hardwood chip mulch when the moisture content of the chips is equal to or less than 9.0% (oven-dry weight) and the windspeed at time of ignition is 16-20 km/hr. Once ignited, the fires continued to burn without the influence of wind. When the moisture content of the chips was below 5.2%, an open flame ignited the fuel under no-wind conditions. Booth (1978) was unable to ignite wood chips with a lighted cigarette in a laboratory experiment conducted under no-wind conditions when the moisture content of the chips ranged from 2.9 to 20.5%, but the chips did ignite when the ignition source was a lighted match, and the moisture content of the chips was less than 5.2%. The chips continued to burn with a self-sustaining flame when the moisture content was less than 3.2%.

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[5]M.C. Ringham, KMS, Transport Canada, Ottawa, Ontario, 11 August 1978 (personal communication with TMITC, Transport Canada, Toronto, Ontario).

[6]A.C. Zwart, Ontario Hydro, Hamilton, Ontario, 2 January 1980 (personal communication).

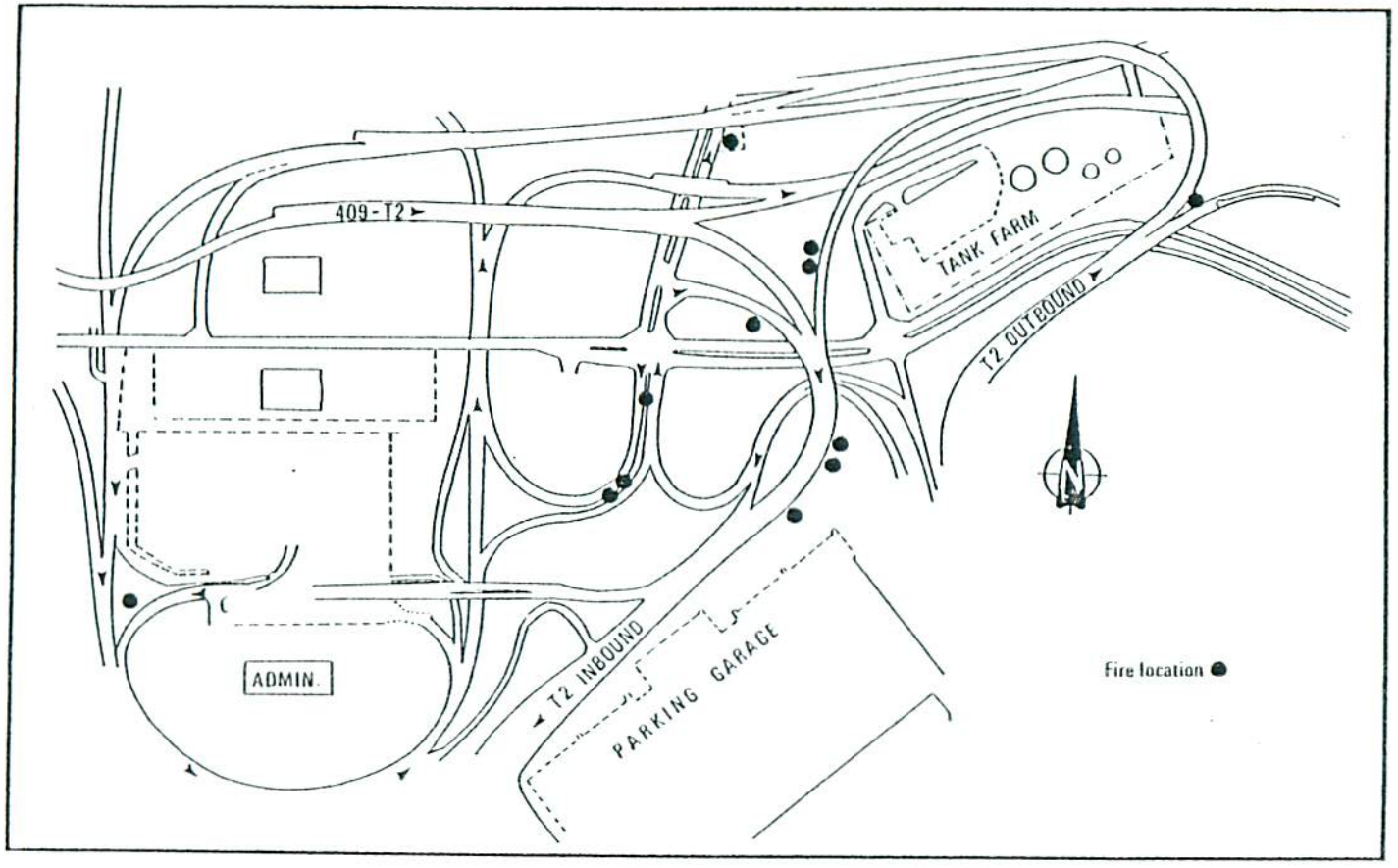

Figure 7. Location of fires in hardwood chip mulch at the Toronto International Airport in 1978.

In general, there may be a fire risk when the moisture content of the hardwood chip mulch is reduced to less than 9.0% under wind conditions of 16-20 km/hr, or to less than 5.2% under no-wind conditions. The potential to ignite and burn exists in the mulch in both the unsorted and sorted chips. The moisture content of water-saturated chips was reduced from 175% to 5.3% in 9 days at an oven temperature of 25-30°C, and zero wind velocity. Therefore, chips exposed to outdoor conditions will likely dry out relatively quickly after a rainfall.

Weather conditions at the Toronto International Airport in the summer of 1978 were conducive to the periodic drying out of the hardwood chip mulch. The combination of warm to hot, windy days and lower than normal amounts of rainfall during the summer months brought the moisture content of the wood chips down below the critical levels indicated above.

Fire danger can be determined from current daily weather data for forest conditions by the calculation of the Fire Weather Index (FWI) (Anon. 1978c). The probability of fire occurrence increases with FWI class increases (Stocks 1974). In addition, a direct exponential relationship exists between the Fine Fuel Moisture Code (FFMC) and relative fire occurrence. FFMC is a measure of the cumulative effect of rainfall and drought plus the influence of the current mid-day temperature, the relative humidity and the windspeed on the relative ease of ignition and flammability of fine fuels. Therefore, FFMC should also give a good indication of the potential danger of fire in the wood chip mulch.

The FWI and FFMC were high to extreme for a good portion of the time from 27 April to 30 September, 1978, particularly from June through August. Consequently, the probability was very high that during this period a potentially severe fire hazard situation existed very frequently in the mulch. The exact occurrence time was known for four of the 12 reported fires: the fire reported on 9 June occurred when the FFMC was moderate and the FWI was high; the two fires detected on 30 June occurred when both the FFMC and FWI were at extreme levels. Similarly, the last reported fire of the season (6 September) was on a day when the FFMC and FWI were both extreme. It appeared that both the FFMC and FWI could be used to measure the fire danger potential in wood chip mulch.

Chemical fire retardants have been developed to control forest and brush fires (Anon. n.d.) but the majority of these retardants are water soluble and therefore have a relatively short effective life. Phos-Chek® DFR is classified as a durable fire retardant which can withstand up to 210.8 mm of rainfall when applied on logging slash.[7]

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[7] R.S. Deakin, Monsanto Canada Limited, Abbotsford, British Columbia, 8 December 1978 (personal communication).

Preliminary field work indicated that a reduction of 60% and 100% in flaming was achieved when the retardant was applied to logging slash at concentrations of 150 g/L at 0.5 L/m^2 and 750 g/L at 0.5 L/m^2, respectively.[8]

Phos-Chek® DFR is a diammonium phosphate-based compound with additives which reduce corrosion of spray equipment and retard leaching. The compound is considered to be practically non-toxic if ingested in single doses and exposed to single dermal applications (Anon. 1978b).

Phos-Chek® DFR prevented the ignition of the mulch by a glowing source such as a cigarette. A concentration of 37.5 g/L, applied at a rate of 0.5 L/m^2, appeared to be sufficient to prevent ignition by a single cigarette, but when two or three lighted cigarettes fell consecutively on the same spot, a concentration of 150 g/L applied at a rate of 0.5 L/m^2 was required to prevent ignition under wind conditions of 16-20 km/hr. Under field conditions this latter concentration should offer protection from ignition by a small open flame such as a lighted match.

To prevent ignition and burning, all of the chips within a specific high fire hazard area must be treated before Phos-Chek® DFR can prove effective. If a self-sustaining fire became established under field conditions in an untreated area of the mulch, its progression into the treated zone would not be stopped by Phos-Chek® DFR, when applied at a concentration of 300 g/L, and at a rate of 0.5 L/m^2. Although the flames may go out, the fire would likely continue to smolder in the treated chips at a much reduced rate of spread.

The total area of hardwood chip mulch established under recent landscape development contracts at the Toronto International Airport was estimated at 30,000 m^2.[9] At a rate of $6.29/kg FOB, Abbotsford, British Columbia[10] it would cost approximately $17,000 per year to treat the entire mulched area with Phos-Chek® DFR at the

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[8]Anon. 1977. Monsanto Canada Limited, Abbotsford, British Columbia (unpublished data).

[9]C. DeGroot, TMITC, Transport Canada, Toronto, Ontario, October 1978 (personal communication).

[10]R.S. Deakin, Monsanto Canada Limited, Abbotsford, British Columbia, 19 October 1978 (personal communication).

full recommended strength of 150 g/L applied at 0.5 L/m^2. While a reduction of the concentration of the retardant by one-half or one-quarter would reduce the costs accordingly, a reduction to one-quarter of the recommended strength would offer protection from ignition only from a single smoldering source such as a burning cigarette.

A containment concept was developed by Monsanto researchers to provide a reduction in the rate of spread of fires in logging slash, as well as a reduction in the quantities of fire retardant required for a specific area (Anon. 1977). The concept involved the matrix application pattern of the fire retardant. A low concentration rate was used on the majority of their test plot areas while a higher concentration was used in a small band around the plots. This principle could possibly be adapted and applied to the situation at the airport. A high concentration of the fire retardant could be applied to potentially high risk areas or to sections of the mulched beds and a lower concentration could be applied to the remainder of the area.

The amount of rainfall that occurred during the fire season may limit the use of Phos-Chek® DFR. The normal total rainfall from May to September at the Toronto International Airport is 345 mm (Table 2) with 209.3 mm (average) falling in the mid-summer period of June to August. It was demonstrated that Phos-Chek® DFR could withstand 210.8 mm of rainfall when applied to logging slash at a concentration of at least 150 g/L and at a rate of 0.5 L/m^2,[11] but its durability on hardwood chip mulch is unknown. Tests conducted on aspen excelsior, a fuel somewhat similar to wood chips, indicate that leaching of the retardant occurred at a slow enough rate to afford a single season of retardation.[12] It is likely that disturbance of the mulch by weeding or any other means would also have an immediate and long-term effect on the usefulness of the retardant treatment, especially if the retardant were applied at less than the recommended strength. The selection of the concentration of the retardant to be applied and the timing of the application could be critical to the success of the treatment.

The timing of the application of retardant to wood chips *in situ* may also be critical for the avoidance of phytotoxic effects on plant

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[11]R.S. Deakin, Monsanto Canada Limited, Abbotsford, British Columbia, 8 December 1978 (personal communication).

[12]C.W. George, USDA Forest Service, Intermountain Forest and Range Experiment Station, Missoula, Montana, 23 March 1979 (personal communication).

material. A report on Phos-Chek®, a retardant similar in nature to Phos-Chek® DFR, indicated that it had an adverse effect on grasses, trees and broad-leaf plants, if applied after the plants had broken dormancy (Anon. n.d.). The application of the retardant resulted initially in fertilizer burn on all plant material tested, particularly the broad-leaf species, but the treatment was not permanently harmful.

The toxicity tests conducted in this study indicated that Phos-Chek® DFR, applied at the recommended concentration and rate of 150 g/L and 0.5 L/m^2, damaged newly developed portions of plant material, particularly if applied when the current year's foliage and shoots were actively growing. The death of approximately 44% of the 2-month-old mugho pine confirmed that mortality of some young plants will occur if the entire plant is coated, but the majority of the plants tested did not succumb and in fact exhibited no visible toxicity-related symptoms, other than terminal growth disruption of the English oak.

Most landscape plant material at the Toronto International Airport would likely be large enough and well enough established to recover from adverse effects following the application of Phos-Chek® DFR early in the growing season. The growth forms of some species could be disrupted.

The light-grey residue that the Phos-Chek® DFR formed on fuel surfaces was not aesthetically pleasing. The manufacturer indicated that the color could be altered to some extent by adding brown pigments,[13] but irrespective of the color, spray that lands on the foliage will be very obvious until it falls off, unless it blends in with foliar color.

CONCLUSIONS

The weather at the Toronto International Airport during a major portion of the 1978 growing season was conducive to the development of hazardous fire conditions in the hardwood chip mulch. Daily determinations of FWI and particularly FFMC classes could prove useful for monitoring fire danger potential in this type of fuel.

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[13]R.S. Deakin, Monsanto Canada Limited, Abbotsford, British Columbia, 8 December 1978 (personal communication).

Under prolonged hot and dry climatic conditions, the hardwood chip mulch presents a significant fire hazard if the moisture content of the chips is equal to or less than 9.0%, for a single lighted cigarette can cause ignition. Phos-Chek® DFR, applied as a spray to the surface of the chips at concentrations of 37.5 g/L or higher and at a rate of 0.5 L/m^2, provided ignition protection from a glowing source such as a cigarette. The application of retardant at a concentration of 150 g/L and at a rate of 0.5 L/m^2 was sufficient to reduce the risk of fire from a small flame such as a lighted match. An application of Phos-Chek® DFR at a concentration of up to 300 g/L and at a rate of 0.5 L/m^2 did not prevent the progression of fire from untreated chips to treated chips. The adverse effects of Phos-Chek® DFR when applied at the recommended concentration of 150 g/L and at a rate of 0.5 L/m^2 were predominantly limited to growth and development alterations during the period when the plants are actively growing. The effectiveness and suitability of this retardant treatment for the prevention of fires in wood chip mulch are limited by such factors as weathering, application and chemical costs, color imparted to chip surface and plant materials, application techniques and timing and phytotoxicity to landscape plant material.

Further study is required to develop a more effective, cost-efficient retardant for use on wood chip mulch. Effectiveness and durability may be increased and application costs reduced by impregnating chips with a suitable retardant prior to distribution.[14] The biodegradability of the mulch should also be measured because fire danger will likely be reduced as the chips decompose.

Combustible mulching materials present a serious fire hazard if an ignition source is available and the climatic conditions are favorable. FWI and FFMC can be used to monitor potential fire danger in wood chip mulch on landscaped planting sites. Fire suppression capabilities should be developed in landscape maintenance operations to protect high-value plants.

In the planning and management of landscape projects, consideration must be given to the potential flammability of materials specified for mulching. Although wood chip mulch can be rendered non-combustible *in situ* through the use of a suitable fire retardant treatment, a more efficient and effective system would be to utilize nonflammable mulch materials in all locations that present a potentially high fire risk.

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[14]R.G. Newstead, Northern Forest Research Centre, Edmonton, Alberta, 27 March 1979 (personal communication).

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