PRESCRIBED BURNING OF BOREAL MIXEDWOOD SLASH IN THE ONTARIO CLAY BELT REGION

D.J. McRAE

GREAT LAKES FOREST RESEARCH CENTRE

CANADIAN FORESTRY SERVICE

GOVERNMENT OF CANADA

1985

INFORMATION REPORT O-X-367

Catalogue No. Fo46-14/367E
ISBN 0-662-13990-9
ISSN 0822-210X

Additional copies of this publication are available at no charge from:

Great Lakes Forest Research Centre
Canadian Forestry Service
Government of Canada
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

ABSTRACT

Results and analysis of an experimental burning study on fire behavior in boreal mixedwood slash in northern Ontario's Clay Belt Region are presented. Horizontal discontinuity in this fuel type makes fire spread difficult when the fire danger rating is low to moderate. Poor drainage caused by a clay soil parent material disrupts normal duff drying processes. Fire behavior parameters, such as fuel consumption, rate of spread and frontal fire intensity, and their relationship to the Canadian Forest Fire Weather Index System, are discussed in detail.

RÉSUMÉ

On présente les résultats et l'analyse d'une étude de brûlage expérimental portant sur le comportement du feu dans des rémanents de bois mixte boréal de la région argileuse du nord de l'Ontario. La discontinuité horizontale de ce type de combustible rend difficile la propagation d'un incendie lorsque le niveau de danger de feu est de faible à modéré. Le mauvais drainage causé par une matière apparentée au sol argileux perturbe les processus normaux d'assèchement de l'humus. On discute en détail certains paramètres du comportement du feu, comme la consommation de combustible, la vitesse de propagation et l'intensité du front d'incendie, ainsi que de leur rapport avec l'Indice Forêt-Météo de la méthode canadienne.

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude to members of the Great Lakes Forest Research Centre Forest Fire Research Unit for experimental burn preparation and monitoring, and to fire management staff of the Ontario Ministry of Natural Resources (Kapuskasing District; Northern Regional Fire Centre, Timmins; Aviation and Fire Management Centre, Sault Ste. Marie) for the planning and conduct of these experimental fires. Special thanks are due to R.W. Burke and V.H. Wearn (Kapuskasing), W.E. Belisle (Northern Regional Fire Centre), P.C. Ward and R.J. Drysdale (Aviation and Fire Management Centre). Technical review by Z. Chrosciewicz, Fire Research Scientist, Northern Forest Research Centre, B.J. Stocks, Head, Forest Fire Research Unit, Great Lakes Forest Research Centre, and J.D. Walker, Program Manager, Fire and Remote Sensing, Petawawa National Forestry Institute is appreciated. Credit is due to T.W. Blake, Great Lakes Forest Research Centre, for data compilation and preparation of illustrations.

TABLE OF CONTENTS

Cover photo: Aerial view of 1979 boreal mixedwood slash experimental burning plots.

INTRODUCTION

The boreal mixedwood forest, by virtue of its high productivity, offers a strong argument for intensive forest management (Ketcheson 1981). McClain (1981) reports that 45% to 50% of northern Ontario's productive forest land could be classed as boreal mixedwood forest. This type of forest is defined in terms of sites that support, or could support, good growth of five main tree species[1]: balsam fir (*Abies balsamea* [L.] Mill.), black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce (*P. glauca* [Moench] Voss), trembling aspen (*Populus tremuloides* Michx.), and white birch (*Betula papyrifera* Marsh.). Therefore, it excludes sites such as wet, poorly drained lowlands (generally pure black spruce), dry sand plains (generally pure jack pine [*Pinus banksiana* Lamb.] or jack pine-black spruce), and excessively drained shallow soils on rocky ridges (generally jack pine and/or black spruce).

A regeneration problem after logging does exist in this forest type, and was identified at the Ontario Ministry of Natural Resources (OMNR) Forest Regeneration Conference held in Thunder Bay (Anon. 1978a). Problems involving post-cut site conditions of heavy logging residue and excessive residual trees, especially in the area of the Clay Belt Region of Ontario, were noted and the necessity for improving site preparation techniques was pointed out. Forest management personnel were convinced that the increased use of prescribed fire as a site preparation tool to clear logging residue for easier planting would alleviate some of the regeneration problems present in this area.

The OMNR District of Kapuskasing, a district with a large boreal mixedwood forest in the Clay Belt Region, exemplifies the severity of this regeneration problem. The annual cutover in this district is between 12,000 and 14,000 ha. Of this cutover, only 36.5% is regenerated to potentially productive forests. Of this 36.5%, about 21.5% is due to district efforts and 15% to natural regeneration (Virgo 1979). To forest managers working in northern Ontario's Clay Belt Region, regeneration represents a very important and complex problem (Virgo 1975). The sites with peatland black spruce are generally difficult and expensive to treat artificially (Ketcheson 1975). Prescribed fire has been used as the major site preparation tool for a number of years in this district because of the difficulties in treating many areas economically with mechanical site preparation machinery.

Prescribed burning is defined by the Canadian Committee on Forest Fire Control (Anon. 1976) as:

> "the burning of forest fuels on a specific area under predetermined conditions so that the fire is confined to that area to fulfill silvicultural, wildlife management, sanitary or hazard reduction requirements."

---

[1] Weingartner, D.M. and Basham, J.T., *Ed.* 1979. Forest management and research needs in the boreal mixedwood forest of Ontario. Unpublished file report prepared by the Spruce-Fir-Aspen Forest Research Committee, Canada-Ontario Joint Forestry Research Committee. 90 p.

In Ontario, the primary use of prescribed burning is for silvicultural purposes, namely, site preparation for planting and seeding.

This paper reports on a 5-year study that was undertaken in the Clay Belt Region to investigate fire behavior on prescribed burns in the boreal mixedwood slash fuel type. No quantitative information had been gathered on prescribed burning in boreal mixedwood slash in Ontario prior to this study and a lack of prescribed burning guidelines resulted in some failures in past burns conducted in this fuel type. The relationships between fire weather as expressed by the component codes and indices of the Canadian Forest Fire Weather Index (FWI) System (Anon. 1978b) and fire behavior and fuel consumption measured on the burns were evaluated in detail in this study.

STUDY AREA

This study was carried out during the summers of 1979 to 1983 in the OMNR District of Kapuskasing (Fig. 1), which is situated in the Clay Belt Region. New sites were selected each year so that experimental burns were always conducted in fresh slash less than one year old. Heavy shrub and herbaceous growth one year after cutting precluded a burning program because the vegetation hindered fire spread. On all sites, tree-length harvesting had taken place the previous autumn or winter.

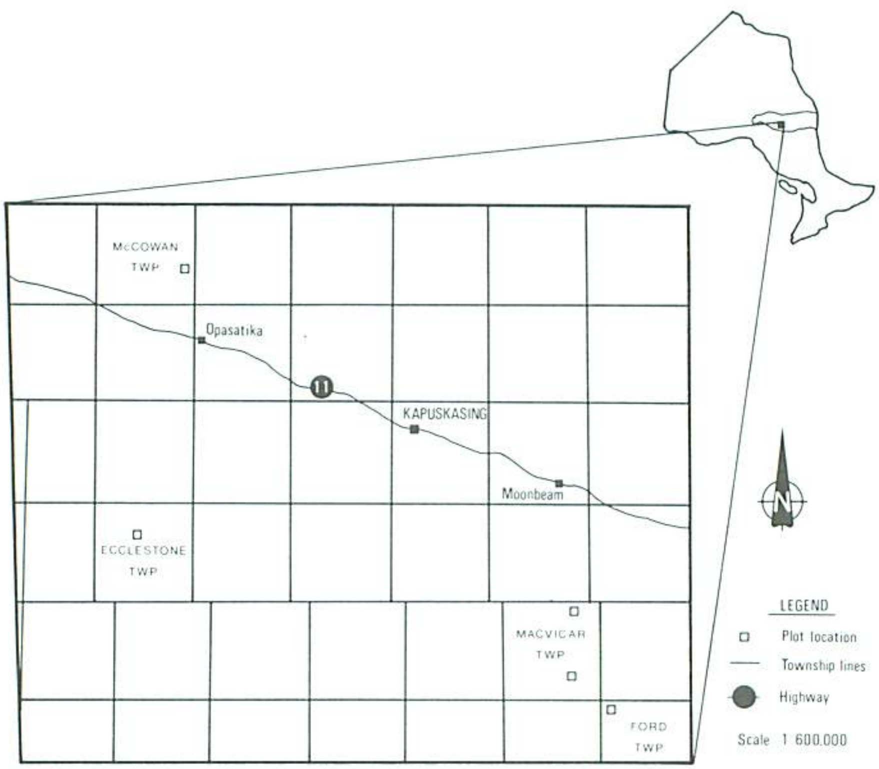

Figure 1. Experimental burning plot locations in the Clay Belt Region of Ontario.

Prior to harvesting, cutover areas selected for this experimental burning program were classified as the mixedwood-herb rich or the hardwood-alder operational group as defined by Jones et al. (1983). These two operational groups were selected for study since major emphasis within the Clay Belt Region is on regenerating these two groups because of their high site productivity.

After cutting, the logging residue included slash of black spruce, white spruce, balsam poplar *(Populus balsamifera* L.), trembling aspen, balsam fir and white birch in varying proportions. Some residual poplar trees were left after logging (Fig. 2). Soils were calcareous, fine, loamy clays with an average organic layer 14 cm deep. The soils were classified as rapidly to moderately well drained (see Jones et al. [1983] for further site descriptions). Figure 3 shows the two sites burned in this study as they would appear on a landscape profile. The sites appear from middle slope to the crest of the relatively flat Clay Belt terrain.

Figure 2. Typical view of boreal mixedwood cutover site showing slash and residual poplar.

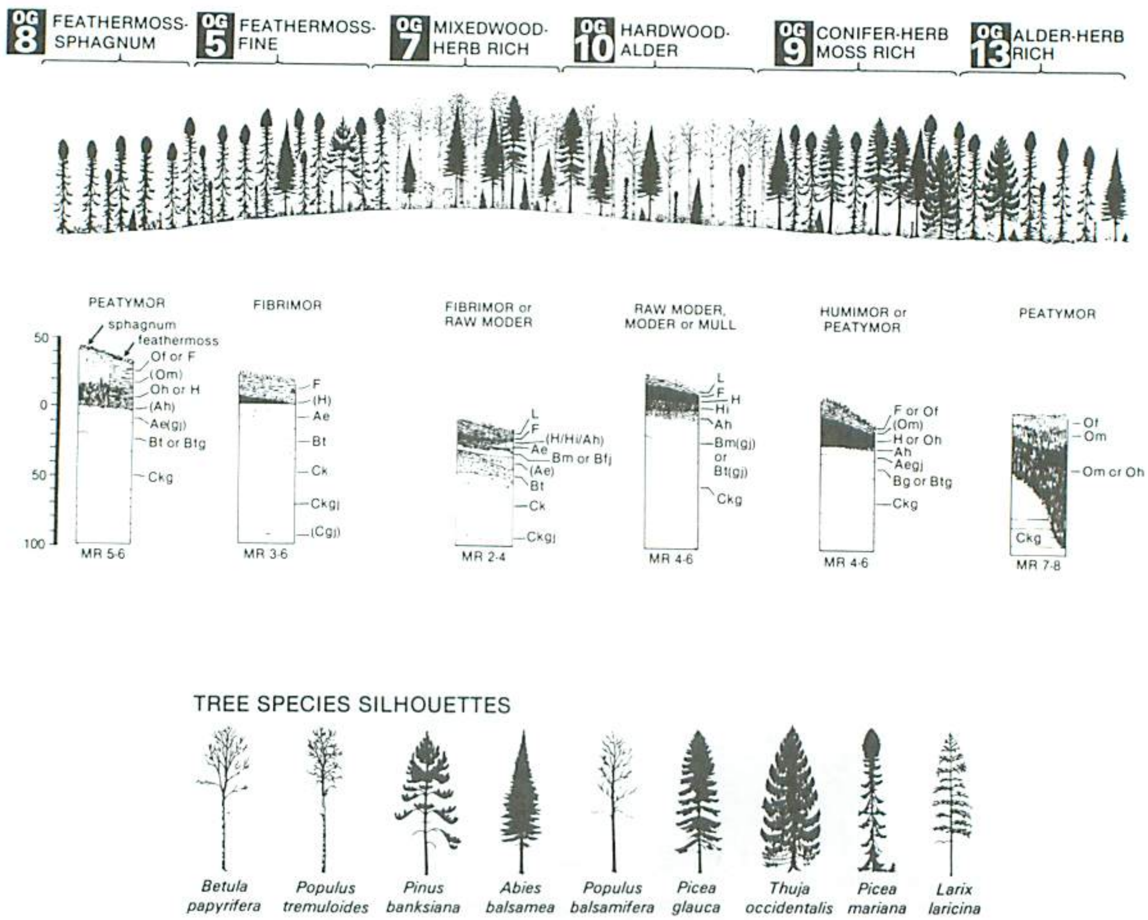

Figure 3. Schematic landscape cross-section for fine loamy-clayey soils of the Clay Belt Region (from Jones et al. 1983, reproduced with permission from the authors). Experimental burns were located within operational groups 7 and 10.

PROCEDURES

Experimental burning plots were located so that plot dimensions were roughly 200 m x 200 m, or 4 ha in size. A 4-m wide fireline was bulldozed around each plot for control purposes. OMNR fire control personnel were on hand at all burns for ignition, control, and suppression purposes.

The plots were delineated into 25-m x 25-m blocks to produce 49 sampling points. A modified version of the line-intersect fuel sampling method (McRae et al. 1979) utilizing a 15-m line was randomly located from each sampling point, and slash fuel loadings were calculated from these data. Four depth-of-burn pins were located on each sample line. After each burn, the depth of duff remaining to mineral soil was measured. The loading of organic material consumed by the fire was calculated from the average depth of burn by means of bulk density values of the different duff layers which, in turn, were determined from core samples taken from four plots.

Plots were burned by a strip headfire technique, with strips approximately 50-75 m apart (Fig. 4). To prevent control problems, each section was allowed to burn out before another strip was ignited. Wires attached with string to stakes at known points within each plot were used to measure rate of fire spread. Each wire was run from a stake over a sawhorse located outside the burn area and weighted to fall when the fire reached the stake and burned through the string. Rate of fire spread could be calculated from times recorded at which each weight fell. Fire progress was recorded by means of slides and motion pictures.

A weather station was established early each year near the plots designated for burning, and weather at 1300 hr was measured daily for calculation of the component fuel moisture codes and fire behavior indices of the FWI System (Van Wagner 1974, Anon. 1978b).

Because of the importance of shrubs and herbaceous plants in affecting fire spread, biomass was sampled prior to each burn by removing all material on a number of 0.5-m^2 plots. Postcut increases in biomass were plotted to show how biomass changed as the fire season progressed.

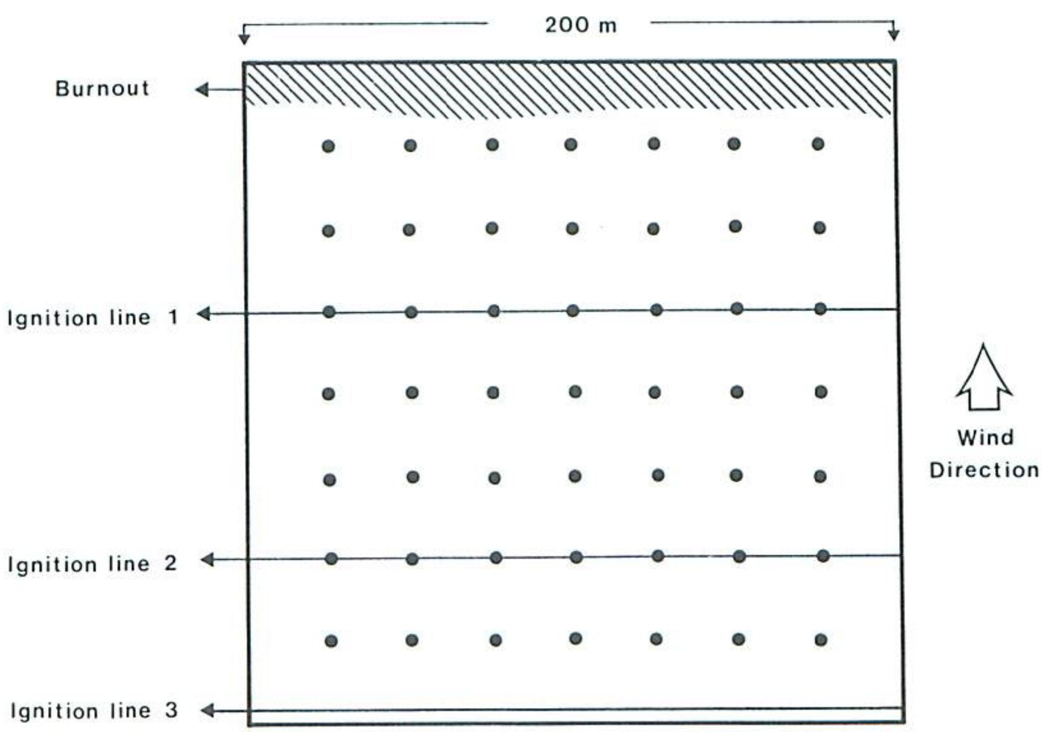

Figure 4. Overhead view of a plot showing ignition sequence (strip headfire technique).

RESULTS AND DISCUSSION

During the 1979-1983 fire seasons, 11 experimental burns and two burn-out operations (79-3, 79-4) were conducted and monitored in the boreal mixedwood slash fuel type (Table 1). Burns were carried out under a range of weather conditions, as reflected by the FWI System. As a result of unusually dry weather in 1981, experimental burns conducted that year had a Buildup Index (BUI) of up to 97. Plot means were used for all regression analysis work rather than individual observations for each plot so as to reduce variablility of data.

Boreal mixedwood slash is a very discontinuous fuel type with breaks in fuel distribution which create barriers to fire spread. Areas with a high proportion of spruce and fir prior to harvesting tend to have continuous slash beds after harvesting, while areas with a concentration of poplar or birch have less continuous slash beds. This fuel continuity problem is compounded by the very poor drainage characteristic of the Clay Belt Region. The clay mineral soil impedes water flow into the ground, causing pools of standing water to occur in many depressions of the duff surface (Fig. 5). Only during lengthy summer drought periods does this situation disappear. The pools of water can at times cover critical surface fuel necessary to carry the fire.

Figure 5. Standing water caused by impeded drainage can be a problem to fire spread in boreal mixedwood slash.

Table 1. Fire weather and fire behavior data for experimental burns in boreal mixedwood slash (1979-1983).

Plot no.	Burn date	Ignition time	Temp. (°C)	R.H. (%)	Wind (km/hr)	Canadian Forest Fire Weather Index System						Total fuel consumption (kg/m²)	Rate of spread (m/s)[g]	Frontal fire intensity (kW/m)[h]
						FFMC[a]	DMC[b]	DC[c]	ISI[d]	BUI[e]	FWI[f]			
79-1	17/8/79	15:00	17.2	53	24.0	83.4	7.2	143.1	6.0	12.8	7.2	0.939	0.041	773
79-1	17/8/79	15:30	17.2	53	24.0	83.4	7.2	143.1	6.0	12.8	7.2	1.493	0.042	1259
79-2[i]	2/8/79	15:30	26.1	29	12.0	88.9	22.2	157.6	6.7	32.8	13.0	3.085	0.188	11647
79-2	2/8/79	16:00	26.1	27	12.8	89.4	22.3	157.6	7.5	33.0	14.3	1.163	0.094	2196
79-2	2/8/79	16:30	26.1	27	12.0	89.3	22.3	157.6	7.0	33.0	13.6	1.408	0.045	1272
79-3[j]	13/6/79	15:00	21.1	22	8.0	88.9	12.4	46.9	5.4	15.0	7.2	-	-	-
79-4[j]	13/6/79	14:00	19.4	24	8.0	88.0	12.0	46.6	4.8	14.6	6.3	-	-	-
80-1[k]	24/8/80	15:00	21.1	83	11.0	85.8	20.5	194.8	4.1	32.5	8.6	-	-	-
80-2	27/7/80	14:30	25.6	26	8.0	92.5	28.0	146.0	8.9	37.9	17.4	1.539	0.037	1144
80-2	27/7/80	15:00	25.6	26	6.0	92.5	28.0	146.0	8.0	37.9	16.0	1.785	0.023	825
81-1	19/7/81	16:30	28.9	36	10.1	92.6	69.4	343.5	9.9	92.2	29.4	2.622	0.058	3054
81-1	19/7/81	18:00	28.3	35	8.8	92.6	69.4	343.4	9.4	92.2	28.4	2.125	0.067	2859
81-1[i]	19/7/81	18:30	28.9	35	9.0	92.6	69.5	343.5	9.4	92.3	28.4	1.850	0.208	7728
81-2	30/7/81	17:30	27.8	28	11.8	90.5	69.3	407.2	8.2	97.2	26.6	3.737	0.044	3302
81-2	30/7/81	18:45	27.8	27	12.8	90.8	69.3	407.2	9.0	97.3	28.3	2.900	0.055	3203
81-2	30/7/81	19:30	27.8	28	11.5	90.5	69.3	407.2	8.2	97.2	26.6	1.383	0.116	3222
81-3	26/6/81	14:00	22.2	30	7.7	90.5	30.1	196.9	6.7	43.6	15.2	2.090	0.081	3400
81-3	26/6/81	14:30	22.8	29	9.1	90.8	30.3	197.0	7.4	43.8	16.3	1.542	0.071	2199
81-3	26/6/81	15:00	22.8	27	11.8	90.3	30.4	197.0	9.1	43.9	19.1	1.105	0.032	710
81-4[k]	13/7/81	15:30	21.6	46	16.0	80.8	45.8	294.2	3.0	65.0	10.1	-	-	-
81-4	14/7/81	15:00	22.8	42	17.6	87.4	48.8	302.2	7.0	69.6	20.1	2.250	0.201	9083
82-1[k]	18/8/82	16:00	20.0	60	4.0	88.0	20.5	191.2	3.9	32.4	8.4	-	-	-
83-1[k]	18/8/83	19:00	27.0	40	0.0	88.3	33.1	284.4	3.4	51.3	9.6	-	-	-

a Fine Fuel Moisture Code
b Duff Moisture Code
c Drought Code
d Initial Spread Index
e Buildup Index
f Fire Weather Index
g Metres per second
h Low heat of combustion used to calculate frontal fire intensity was 20083 kJ/kg.
i The values for this plot were not used to calculate equations (13) and (14). Slash fuel beds on these plots were abnormally continuous. The data presented here show that at times more extreme fire behavior can be expected in local pockets of this fuel type.
j These fires were burn-out operations in which only depth of burn was monitored.
k These burns were unsuccessful because of poor fire spread.

Preburn slash loading for the 0- to 6.9-cm size class averaged 1.661 kg/m^2 ($S_{\bar{x}}$ = 0.234) with a range of 1.237 to 2.074 kg/m^2 (Table 2). There was no strong relationship between slash loading and slash depth for the 0- to 6.9-cm size class. The slash loading for fuel particles ⩾ 7.0 cm was more variable, averaging 3.301 kg/m^2 ($S_{\bar{x}}$ = 0.992), with a range of 1.772 to 4.981 kg/m^2 (Table 2). Some large fuel particles could be classified as partially available for combustion (e.g., spruce, fir, rotten pieces), while other large fuel pieces (e.g., poplar, birch) are generally unavailable for combustion because of higher moisture content levels resulting from lack of curing time since harvest.

In the analysis of slash consumption any sample lines that were completely unburned were not considered in the study. Partially consumed sample lines were included in the analysis. Table 2 shows slash fuel consumption for slash between 0 and 6.9 cm and slash ⩾ 7.0 cm in diameter. Among components of the FWI System, the BUI was found to correlate best with slash fuel consumption. These equations were:

$$C_1 = 1.020 + 0.0019\ BUI \qquad R = .03 \qquad N = 7 \quad (1)$$

$$C_2 = 0.168 + 0.0078\ BUI \qquad R = .88 \qquad N = 7 \quad (2)$$

$$C_3 = 1.190 + 0.0096\ BUI \qquad R = .79 \qquad N = 7 \quad (3)$$

where: C_1 = slash consumption (kg/m^2) for slash pieces between 0 and 6.9 cm in diameter,

C_2 = slash consumption (kg/m^2) for slash pieces ⩾ 7.0 cm in diameter,

C_3 = slash consumption (kg/m^2) for all slash pieces,

BUI = Buildup Index, and

R = Correlation coefficient (Draper and Smith 1981).

The addition of preburn slash loading as an independent variable in the slash consumption prediction equation resulted in improved accuracy. The new equations were:

$$C_1 = -0.207 + 0.0017\ BUI + 0.255\ L_1 \qquad R = .99 \qquad N = 7 \quad (4)$$

$$C_2 = -0.322 + 0.0030\ BUI + 0.839\ L_2 \qquad R = .91 \qquad N = 7 \quad (5)$$

$$C_3 = 1.090 + 0.0046\ BUI + 0.142\ L_3 \qquad R = .88 \qquad N = 7 \quad (6)$$

where: L_1 = preburn slash loading (kg/m^2) for slash pieces between 0 and 6.9 cm in diameter,

L_2 = preburn slash loading (kg/m^2) for slash pieces ⩾ 7.0 cm in diameter, and

L_3 = preburn slash loading (kg/m^2) for all slash pieces.

Table 2. Distribution of slash loadings.

Plot[a]	Preburn: Slash loading (kg/m²) 0-6.9 cm	Preburn: Slash loading (kg/m²) ≥7.0 cm	Slash depth (cm)	Postburn: Slash consumption (kg/m²) 0-6.9 cm	Postburn: Slash consumption (kg/m²) ≥7.0 cm	Percentage of area burned[b]	BUI[c]
79-1	1.818	1.772 (17%)[d]	19	0.997 (54.8%)[e]	0.252 (14.2%)[e]	58	12.8
79-2	2.074	2.481 (22%)	20	1.846 (71.6%)	0.488 (19.7%)	75	33.0
80-1[f]	1.642	3.465 (34%)	17	-	-	15	32.5
80-2	1.491	2.401 (58%)	13	0.944 (63.3%)	0.320 (13.3%)	63	37.9
81-1	1.737	3.002 (49%)	22	1.349 (77.7%)	0.667 (22.2%)	87	92.2
81-2	1.544	4.731 (61%)	21	1.112 (72.0%)	1.078 (22.8%)	88	97.2
81-3	1.474	3.296 (38%)	21	0.847 (57.5%)	0.601 (18.2%)	65	43.8
81-4	1.807	3.379 (18%)	27	1.128 (62.4%)	0.768 (22.7%)	63	69.6
82-1[f]	1.237	4.981 (45%)	15	-	-	24	32.4
83-1[f]	1.783	3.505 (36%)	29	-	-	41	51.3
Average	1.661	3.301 (38%)	21	1.175 (65.6%)	0.596 (19.7%)	-	-

[a] Plots 79-3 and 79-4 were not considered because they were a portion of burn-outs for other plots and only depth of burn was measured.

[b] Percentage of area burned based on total percentage of line intersect sample line lengths burned per plot.

[c] Buildup Index.

[d] Percentages within parentheses represent the proportion, by weight, of the ≥7.0-cm size class consisting of poplar.

[e] Percentages within parentheses represent slash consumption as a percentage of preburn slash loadings.

[f] These burns were unsuccessful because of poor fire spread and had little slash consumption.

Equation 4 shows that preburn slash loading for fuels between 0 and 6.9 cm is more important than the BUI in predicting slash consumption. This is not surprising since, on the average, 66% ($S_{\bar{x}}$ = 0.08) of the preburn slash between 0 and 6.9 cm on all plots was consumed by the prescribed fire. The importance of preburn slash loading was also observed for equation 5 (slash pieces ⩾ 7.0 cm in diameter), where the average slash consumption for all plots was 20% ($S_{\bar{x}}$ = 0.05). The high dependence of slash consumption on preburn slash loadings rather than on the BUI relates to the green state of the slash. Heavy fuels cut the previous autumn or winter dry out very little prior to summer burning and correlate poorly with the FWI System. Figure 6 shows the changes in appearance of the slash complex from photographs of pre- and postburn conditions.

Preburn duff loadings in this fuel type were found to be heavier than those reported earlier (McRae et al. 1979) (Fig. 7). The equation for this relationship based on six bulk density averages calculated for different depths from 39 composite samples from four plots (79-1, 79-2, 80-4, 81-2) is:

$$Y = .35\ X^{1.68} \qquad S = .99 \quad N=6 \quad (7)$$

where: Y = preburn duff loading (kg/m^2),

X = duff depth (cm), and

S = "S" (Payandeh 1981)

The data for duff loadings came from composite samples of four soil and duff samples, each 5 cm in diameter, taken for a soil nutrient study of the burns. The sample size was much larger than that described in the earlier report. This larger sample size and a strong S of .99 (Payandeh 1981) would warrant the use of the new equation in determining preburn duff loadings in this fuel type.

Depth-of-burn data were gathered from 10 burns (Table 3). Regression analysis produced the following predictive equations for estimating depth of burn from codes and indices of the FWI System:

$$Y = .955 + .049\ DMC \qquad R = .78 \quad N = 10 \quad (8)$$

$$Y = .588 + .010\ DC \qquad R = .83 \quad N = 10 \quad (9)$$

$$Y = .883 + .036\ BUI \qquad R = .79 \quad N = 10 \quad (10)$$

where: Y = depth of burn (cm),

DMC = Duff Moisture Code,

DC = Drought Code, and

BUI = Buildup Index.

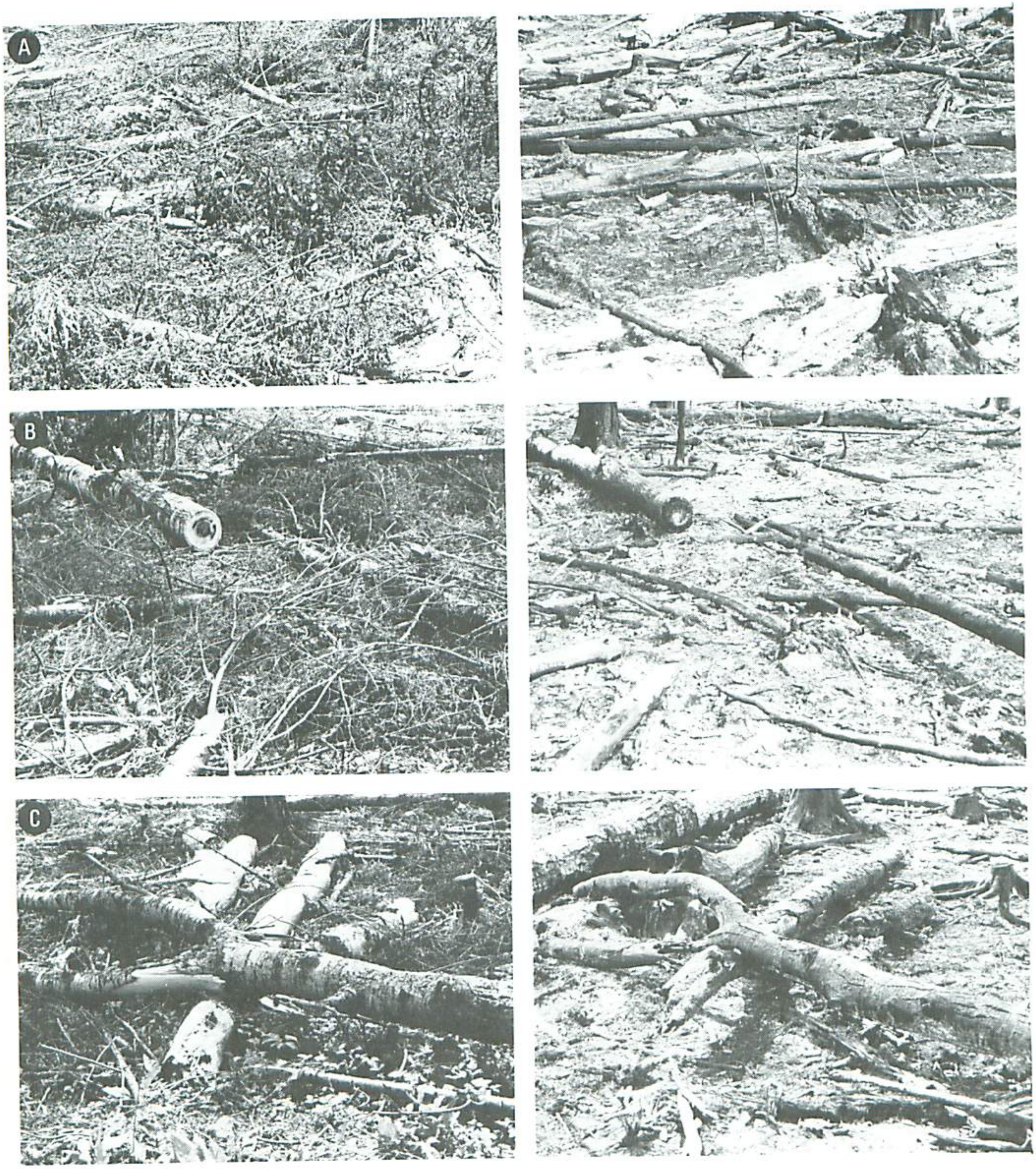

Figure 6. Preburn and postburn slash on three sample lines on plot 81-2, consisting of (A) spruce/fir mixture, (B) fir/poplar mixture and (C) poplar.

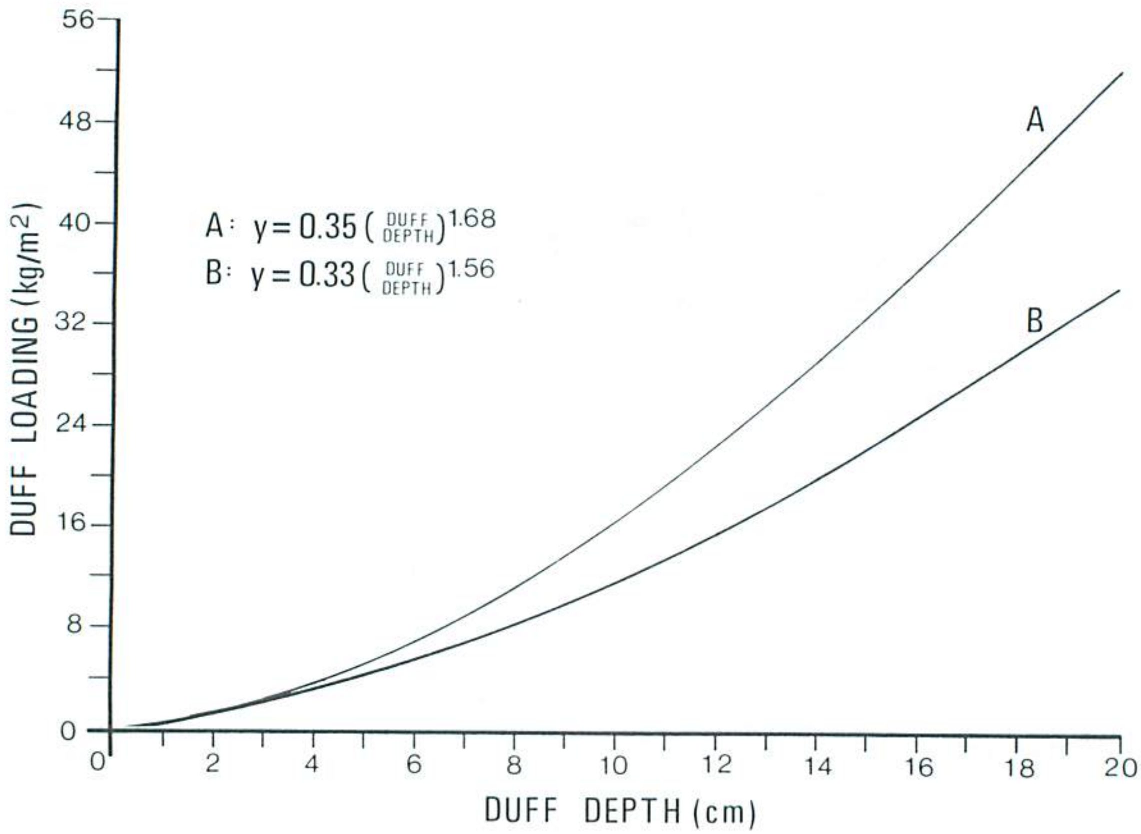

Figure 7. The relationship between duff fuel loading and duff depth in the boreal mixedwood slash fuel type (Line A). Line B represents the relationship presented for upland black spruce by McRae et al. (1979).

Table 3. Distribution of duff fuel loadings.

Plot	Preburn duff depth (cm)	Preburn duff loadings (kg/m^2)	Depth of burn (cm)	DMC[a]	DC[b]	BUI[c]
79-1	17.5	42.9	2.1	7.2	143.1	12.8
79-2	13.3	27.0	2.7	22.2	157.6	33.0
79-3	-	-	1.2	12.4	46.9	15.0
79-4	-	-	1.4	12.0	46.6	14.6
80-2	9.2	14.6	1.8	28.0	146.0	37.9
81-1	14.5	31.3	4.3	69.4	343.5	92.2
81-2	15.5	35.0	5.3	69.3	407.2	97.2
81-3	18.4	46.7	1.4	30.3	197.0	43.8
81-4	17.6	43.3	1.8	48.8	302.2	69.6
82-1[d]	13.3	27.0	-	20.5	191.2	32.4
83-1	9.7	15.9	3.8	33.1	284.4	51.3

[a] Duff Moisture Code

[b] Drought Dode

[c] Buildup Index

[d] This burn was unsuccessful because of poor fire spread.

Earlier studies in jack pine slash used linear regression equations to predict depth of burn (Stocks 1972, Chrosciewicz 1978a, 1978b). The following two predictive equations, which use non-linear regression techniques, proved best for estimating depth of burn in boreal mixedwood slash:

$$Y = 1.1353 + 0.2461e^{0.0070 \times DC} \quad S = .77 \quad N = 10 \quad (11)$$

$$Y = 1.8705 + 0.0095e^{0.0604 \times BUI} \quad S = .72 \quad N = 10 \quad (12)$$

where: Y = depth of burn (cm),

DC = Drought Code, and

BUI = Buildup Index.

In this study, no difference in depth of burn was observed until a certain duff dryness plateau was reached, above which depth of burn increases appreciably. This plateau coincides approximately with a DC of 200 or a BUI of 50.

In both cases (linear and nonlinear), the DC correlated slightly better with depth of burn than did the BUI. This is not surprising as the DC better represents the deeper, compacted duff layers (Van Wagner 1974). In the Clay Belt Region, little subsurface drying occurs below 2 cm until the deeper duff layers become dry. These layers are usually dry when the DC surpasses 200 or the BUI is above 50. Under spring conditions the duff is saturated as water from snowmelt and early rains accumulates at the duff-clay soil interface. Very little water percolates into the clay soil and, as a result, the duff layer does not become dry until substantial drying conditions prevail later in the summer. As long as excessive moisture (water) is present above the clay mineral soil, a wick reaction occurs, and results in the movement of moisture from the wetter, deeper duff layers to surface duff layers where it evaporates.

In the past, provincial fire personnel in Ontario have always used the BUI in making depth-of-burn predictions (Stocks 1972, McRae 1980) and, since the two nonlinear depth-of-burn equations (11 and 12) have similar S values, it is probably best to continue to make predictions with the BUI equation (equation 12) in Ontario. This would prevent any confusion among personnel who tend, as a result of provincial fire behavior training courses, to associate BUI with depth of burn.

In Figure 8, the depth of burn found for the boreal mixedwood is compared with that found for jack pine (Stocks and Walker, 1972). This jack pine curve was incorporated into Supplement ONT-1 to the Canadian Forest Fire Danger Rating System (Stocks 1972) and was utilized for predicting depth of burn on all prescribed burns in Ontario prior to 1980 in the absence of specific data for other slash fuel types. Figure 8 shows that burn depths in jack pine slash duff are significantly greater than in boreal mixedwood at comparable BUIs over 30.

The narrow range in ISI values (Table 1) encountered in this study, in combination with the horizontal fuel discontinuity, did not permit the development of rate of spread predictions based on ISI. However, a predictive equation based on wind speed and BUI has been developed in which:

$$R = -3.24 + 0.571W + 0.0182\ BUI \quad R = .66 \quad N = 14 \qquad (13)$$

where: R = rate of spread (m/min),

W = wind speed (km/hr), and

BUI = Buildup Index.

This equation is for fire spread in average slash conditions in which slash loadings for the 0- to 6.9-cm size class diameters are less than 2 kg/m^2 and horizontal fuel continuity is broken. The combination of wind and BUI is not surprising. Wind, of course, is the main vehicle for fire spread. BUI, on the other hand, could be viewed as the restrictive agent. Low BUI values signify that many areas will be wet, especially in low depressions. As the BUI increases, these areas begin to dry out and increase the fuel continuity, allowing for better and faster fire spread.

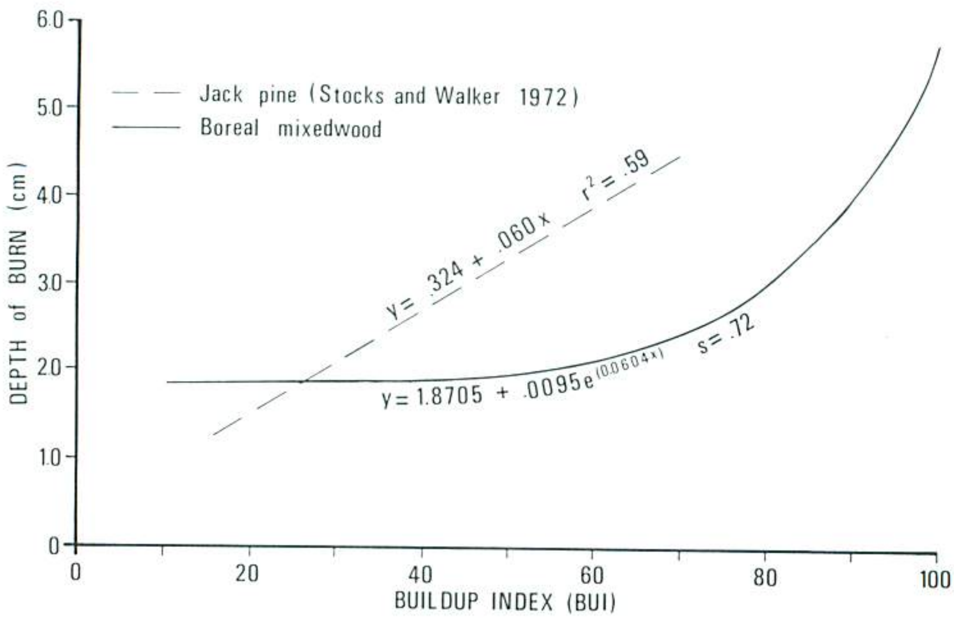

Figure 8. Relationship between depth of burn and BUI for boreal mixedwood and jack pine slash.

Four burns (Plots 80-4, part of 81-4, 82-1 and 83-1) were not successful because of their inability to spread after ignition (Table 1). These burns had the lowest ISI values during the study program. A value of 4.5 or lower in the ISI appears to signify a fire's inability to spread adequately. Figure 9 illustrates the increase in postcut herbaceous biomass (kg/m^2) as the burning season progresses. From a negligible amount in May, biomass increases slowly through June and July, escalating rapidly in August. The increase in biomass results in poor spread on burns conducted later than July. In the latter part of the season when shrub and herbaceous biomass is at a maximum, a minimum ISI of 6.0 may be necessary to sustain adequate fire spread.

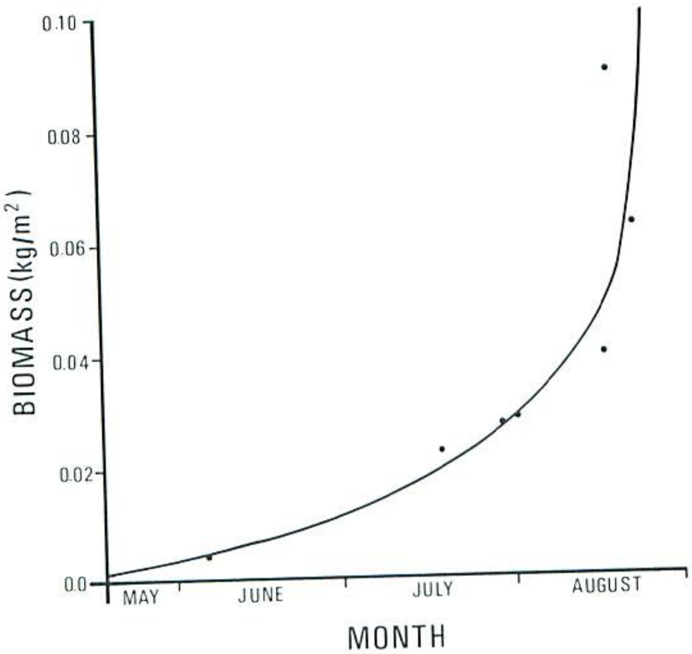

Figure 9. A biomass increase in shrub and herbaceous matter following autumn and winter harvests of boreal mixedwood stands.

Frontal fire intensities measured on these experimental burns (Table 1) were highly variable, ranging from 700 to 11,644 kW/m because of ranges found in available fuel and rates of spread. However, frontal fire intensity was found to be related to wind speed and the BUI by:

$$\text{Log } I = 2.54 + 0.0389W + 0.0061 \text{ BUI} \quad R = .75 \quad N = 14 \quad (14)$$

where: Log I = logarithmic values of frontal fire intensities (kW/m),

W = wind speed (m/sec), and

BUI = Buildup Index.

Wind speed and BUI are good choices since they relate to fire spread (equation 13) and available fuel (equations 6 and 12) and are key components in Byram's (1959) frontal fire intensity equation of:

$$I = Hwr$$

where: I = frontal fire intensity (kW/m),

H = low heat of combustion (kJ/m^2),

w = weight of available fuel (kg/m^2), and

r = rate of spread (m/sec).

CONCLUSIONS

An experimental burning program to investigate fire behavior and impact was conducted in boreal mixedwood slash fuel type in the Clay Belt Region of northern Ontario. The most notable feature of this fuel type is the variation in fuel continuity caused by the combination of changes in fuel type (spruce/fir vs. poplar slash), and poor drainage due to the flat terrain and clay mineral soil.

Although slash consumption was found to be related to the BUI and preburn loading, percentage of slash consumed varied remarkably little regardless of BUI level. An average of 66% of the preburn slash between 0 and 6.9 cm in diameter and 20% of the preburn slash $\geqslant$ 7.0 cm in diameter was consumed. Depending largely on actual slash fuel loading, consumption is reduced by the high moisture content of larger slash pieces cut two to three months earlier in some cases.

Depth of burn was found to be well related to both the DC and the BUI. In the Clay Belt Region in particular, no appreciable subsurface duff drying can occur until standing water from the lower duff layers disappears as a result of a wick-type upward transmission and evaporation effect. This effect disappears at about a DC of 200 or a BUI of 50 when drought type conditions start to prevail.

Rate of spread and frontal fire intensity were found to be best related to a combination of wind speed and BUI. These two variables are most suitable for this relationship because they can be used to explain fire spread even in fuel types such as boreal mixedwood slash which have poor fuel continuity.

It was found in this study that prescribed burns in Ontario's Clay Belt Region should be conducted earlier in the fire season rather than later to permit adequate fire spread, which is otherwise impeded by herbaceous and shrub growth. This growth increases dramatically in August. In the past, the foliar moisture content of the surrounding forest has been used as a criterion for safe burning. High foliage moisture content in late summer (Van Wagner 1967) may reduce fire control problems attributable to crowning. However, this has drastically reduced the available burning period and, as a result, the objectives of the burns have not been met. No severe spotting problems occurred during any burns done with a BUI of less than 70 and an ISI of less than 8.

Often, prescriptions have been developed and prescribed burns have been conducted in the boreal mixedwood slash fuel type under fire danger conditions that were too low to meet objectives. To ensure that the objectives of fire spread and fuel consumption are met, prescribed burn planners should plan burns under higher FWI System codes and indices.

LITERATURE CITED

Anon. 1976. Glossary of forest fire control terms. (3rd ed.) Can. Comm. on For. Fire Control. Natl. Res. Counc. Can., NRCC No. 15520. 44 p.

Anon. 1978a. Proceedings of Ontario conference on forest regeneration. Ont. Min. Nat. Resour., Toronto, Ont. 123 p.

Anon. 1978b. Canadian Forest Fire Weather Index tables. Dep. Environ., Can. For. Serv., Ottawa, Ont. For. Tech. Rep. 25. 48 p.

Byram, G.M. 1959. Combustion of forest fuels. p. 61-89 *in* K.P. Davis, *Ed.* Forest fire: control and use. McGraw-Hill, New York.

Chrosciewicz, Z. 1978a. Slash and duff reduction by burning on clear-cut jack pine sites in southeastern Manitoba. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-199. 11 p.

Chrosciewicz, Z. 1978b. Slash and duff reduction by burning on clear-cut jack pine sites in central Saskatchewan. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-200. 12 p.

Draper, N.R. and Smith, H. 1981. Applied regression analysis: second edition. John Wiley and Sons, New York. 709 p.

Jones, R.K., Pierpoint, G., Wickware, G.M., Jeglum, J.K., Arnup, R.W. and Bowles, J.M. 1983. Field guide to forest ecosystem classification for the Clay Belt, Site Region 3e. 123 p.

Ketcheson, D.E. 1975. Should we manage black spruce? p. 159-172 *in* Black Spruce Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. O-P-4.

Ketcheson, D.E. 1981. Some thoughts on the economics of boreal mixedwood management. p. 17-20 *in* Boreal Mixedwood Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-9.

McClain, K.M. 1981. Definition and distribution of the boreal mixedwood forest in Ontario. p. 5-9 *in* Boreal Mixedwood Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-9.

McRae, D.J. 1980. Preliminary fuel consumption guidelines for prescribed burning in Ontario slash fuel complexes. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-316. 25 p.

McRae, D.J., Alexander, M.E. and Stocks, B.J. 1979. Measurement and description of fuels and fire behavior on prescribed burns: a handbook. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-287. 60 p.

Payandeh, B. 1981. Choosing regression models for biomass prediction equations. For. Chron. 57(5):229-232.

Stocks, B.J. 1972. A burning index for jack pine logging slash. Suppl. ONT-1 to Can. For. Fire Danger Rating System. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. 1 p.

Stocks, B.J. and Walker, J.D. 1972. Fire behavior and fuel consumption in jackpine slash in Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-169. 19 p.

Van Wagner, C.E. 1967. Seasonal variation in moisture content of eastern Canadian tree foliage and the possible effect on crown fires. Can. Dep. For. Rur. Dev., For. Br., Ottawa, Ont. Publ. 1204. 15 p.

Van Wagner, C.E. 1974. Structure of the Canadian Forest Fire Weather Index. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. 1333. 44 p.

Virgo, K. 1975. Practical aspects of regeneration in Ontario's Clay Belt Peatlands. p. 265-276 *in* Black Spruce Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. O-P-5.

Virgo, K. 1979. Site specific silvicultural prescriptions for the Clay Belt. p. 55-63 *in* Proceedings of the Second Ontario conference on forest regeneration. Ont. Min. Nat. Res., Kapuskasing, Ont.