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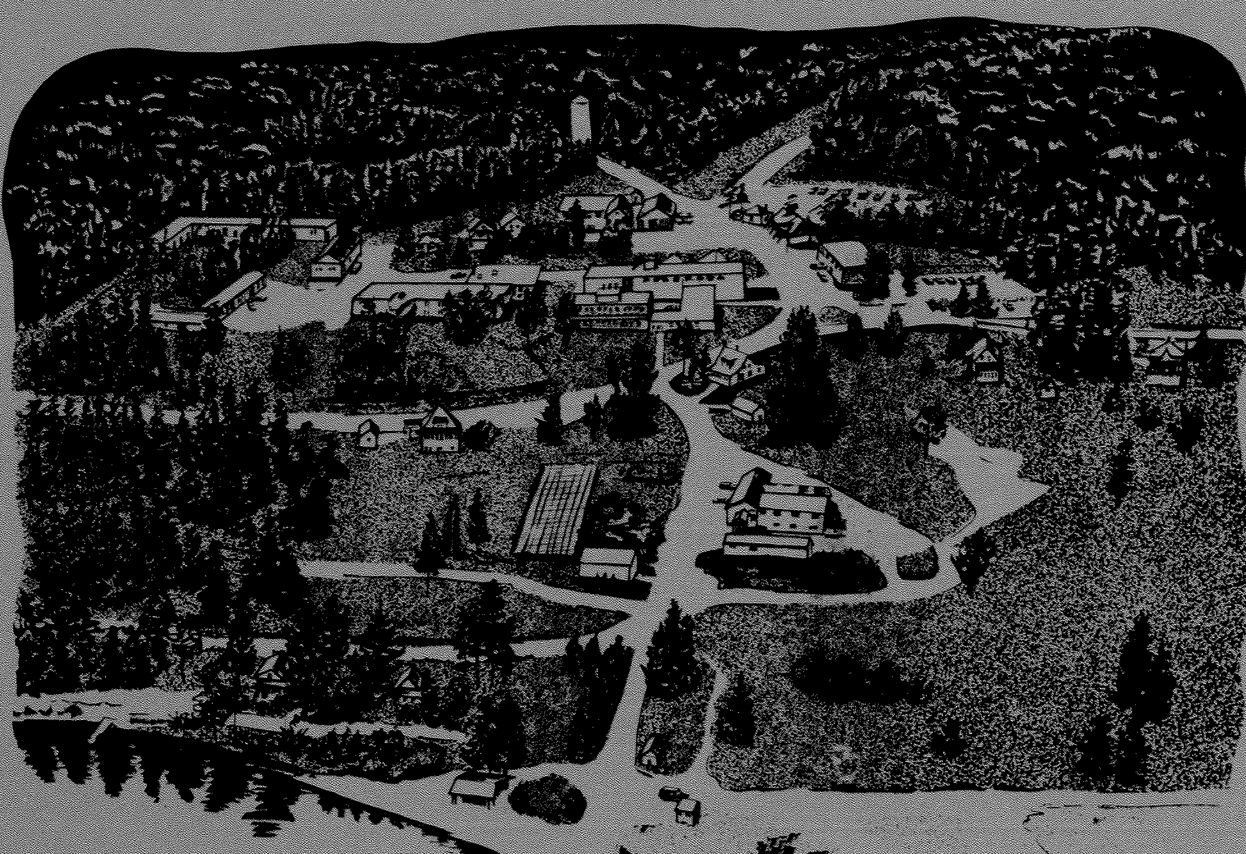

PETAWAWA FOREST EXPERIMENT STATION
CHALK RIVER, ONTARIO
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Introduction

The Canadian Forest Fire Weather Index (Anon. 1970) is, like almost all other indexes of fire danger, on a relative scale. The natural first question about it is: What does it mean in terms of real fire behaviour? Furthermore, this question will have as many answers as there are fuel or forest types. Those who had a hand in designing the Fire Weather Index (FWI) were fully aware of the limitations of a relative index, and envisaged the FWI as a first step only in the production of a complete Canadian Forest Fire Danger Rating System. This system would include the Fire Weather Index with the associated fuel moisture codes and subindexes as well as a set of absolute indexes of fire behaviour in the fuel types of greatest importance. These latter, called burning indexes, were to be based on observations of experimental fires set under a wide range of weather conditions, and were to provide a more-or-less permanent guide to fire behaviour in particular fuel types (Muraro 1969). Three so far have been produced (Muraro 1971, Quintilio 1972, and Stocks 1972). Each burning index, however, requires a fair amount of work and it will be some years before all the important Canadian fuel types have been properly covered. There is some point, then, in considering what can be done now to predict roughly how fire behaviour in some common fuel types varies with the FWI and its subindexes as an interim measure.

The present proposal follows up an idea expressed by J.A. Turner[1/] in a memo to J.C. Macleod dated July 31, 1970. (He suggested normalizing fire behaviour information for a group of fuel types in terms of dimensionless ratios of fire intensity versus drying time of main fuel component). The purpose of this report is to propose a mathematical format for estimating rate of forward spread in a family of fuel types, using only the Initial Spread Index (ISI) and Buildup Index (BUI) as independent variables, and requiring a very limited number of reliable data. Tentative results for a few common fuel types are presented as examples, mainly from eastern Canada.

Assumptions

The component of the Canadian Forest Fire Danger Rating System that best indicates rate of spread is presumably the Initial Spread Index (ISI). However, the ISI represents only a few days of weather history after rain, and the Buildup Index (BUI), which represents the increasing amount of fuel available as a dry spell lengthens, can therefore be presumed to have at least some effect on rate of spread as well. A convenient equation embodying these ideas is

$$R = a(ISI)^b \, (BUI/BUI_o)^c$$

where R is rate of forward spread,

BUI_o is a standard value, and a, b, and c are constants for a given fuel type.

The main part of this equation is the ISI power term with its constants a and b. This is a very flexible formula that yields

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a straight line on ordinary graph paper when b = 1, an upsweeping curve when b>1, and a flattening curve when b<1. It is, of course, a straight line on double-log paper at all values of b. The constant a sets the relative level of the whole equation.

The BUI term, in contrast, is intended to be a rather gentle effect. For present purposes, BUI_o was set at 40, which is a roughly normal value of this code for days on which fires occur in eastern Canada. Note that as c approaches zero, the value of the BUI term approaches 1 (i.e., no effect), no matter what the real value of the BUI. The value of c should always be less than, say, 0.5, and can be set at zero for fuel types in which the BUI has no effect on spread rate at all (e.g., grass).

For any given fuel type, the validity of the equation of course depends on reasonably good correlation between rate of spread and ISI. But, once the basic relation $R = a(ISI)^b$ is assumed, the only requirements are a few reliable spread values at opposite ends of the practical ISI range. The double-log straight line can then be drawn yielding a and b, and a value chosen for c to complete the prediction equation.

Data and Results

For 15 years, small experimental fires from 1/10 to 2 ha in area have been burned at Petawawa to study rate of spread and fuel consumption in relation to weather and fuel moisture content. Some 33 of these can be arranged in four series according to the fuel type as follows:

Red pine plantation, age 35 -- 11 fires

Jack pine stand, age 45 -- 8 fires

Red and white pine stand, age 90, brush understory -- 9 fires

Aspen stand, age 45, leafless -- 5 fires

The next step was simply to plot the observed rate of forward spread of the head fire against ISI. Because most of these fires burned in the low and moderate parts of the ISI range, three rates of spread from fairly well-documented wild fires that burned at high ISI were added. These were:

Jack pine stand - 12 m/min at ISI 25. Gwatkin Lake Fire, Petawawa, May 1964.

Red and white pine stand - 7.5 m/min at ISI 25. Carp Lake Fire, western Quebec, July 1963.

Aspen stand (leafless) - 10.5 m/min at ISI 25. Gwatkin Lake Fire, Petawawa, May 1964.

The ISI's for most of the Petawawa fires were based on wind readings taken at the fires and multiplied by a factor to represent standard open wind.

In addition to the fuel types listed above, equations for three more were derived from the literature: one for jack pine slash in Ontario, based on the burning index by Stocks (1972), one for spruce-fir slash in central British Columbia (from the burning index by Muraro, 1971), and another for grass (50% cured) based on an Australian grass fire index (McArthur 1962). All of these yielded fairly straight lines when plotted as rate of advance over ISI. (ISI for the grass index was worked out as well as possible from the basic relations in the index). Also, since values for the coefficient c (the BUI effect) could not be determined from the meager present data, some conservative values were estimated to complete the picture. All these results appear in Table 1 in the form of values of a, b, and c by fuel type for insertion in the basic equation. Graphs for the four Petawawa fuel types are shown in Figures 1 to 4, and all fuel types are grouped for comparison in Figure 5.

Interpretation

Because these curves are based on so few data, there is no point in quoting any statistics of probability or precision. Certainly these curves refer to continuous fuel and steady weather conditions, and probably represent the behaviour of the upper third or so of all spread rates reported in these fuel types. The spread rates are of course the linear rates of advance at the head of the fire, and some other means of calculating the area growth is required. The determination of fire intensity would require first an estimate of fuel consumption, which could probably be obtained by correlation with the BUI for each fuel type.

Additional information in the form of relatively few well-documented spread rates, especially at the high end of the range (e.g. Walker 1971, and Walker andStocks 1972), would probably do more to improve these curves than a mass of fire report data of low individual reliability. As more points became available, some measures of the range of possible spread rates at given ISI's could be stated, especially at the high end where a small logarithmic variation is large in the absolute sense.

The smooth curve resulting from a single equation does not allow for sudden increases in spread rate such as might occur when a fire crowns. However, suppose that, as the ISI rises, crowning first appears in fits and starts, until an ISI level is eventually reached at which crowning is continuous. A smooth transition could then be justified. This process would take place at spread rates between about 15 and 30 m/min in the conifer types.

The validity of these equations when extrapolated to very high ISI is very much open to question. Reliable spread rates at the top of the range are naturally difficult to get; for example, Simard (1972) gives data to indicate thatmost Canadian locations can expect an ISI over 40 on only about 2 fire-season days out of 1000. Nevertheless, fires occurring on such days are likely to be very important indeed. The most extreme documented example of fire behaviour in Canada is the 1968 Lesser Slave Lake Fire described by Kill and Grigel (1969), which spread 60 km in 10 hours (i.e. 100 m/min) at an ISI probably around 70. It burned in several northern Alberta forest types, including lodgepole pine which is similar to jack pine. The jack pine equation given in Table 1 matches this rate fairly well, but of course more examples would be desirable.

In conclusion, here is a proposed approach for the rough estimation of fire spread rates by fuel type, using a simple basic equation in terms of two main components of the Fire Danger Rating System, and requiring only a few good data to set up. Examples are supplied for several common fuel types, mainly in eastern Canada. This approach is not suggested as a replacement for the complete and definitive burning indexes, but rather to serve as an interim step until these are available for all important fuel types.

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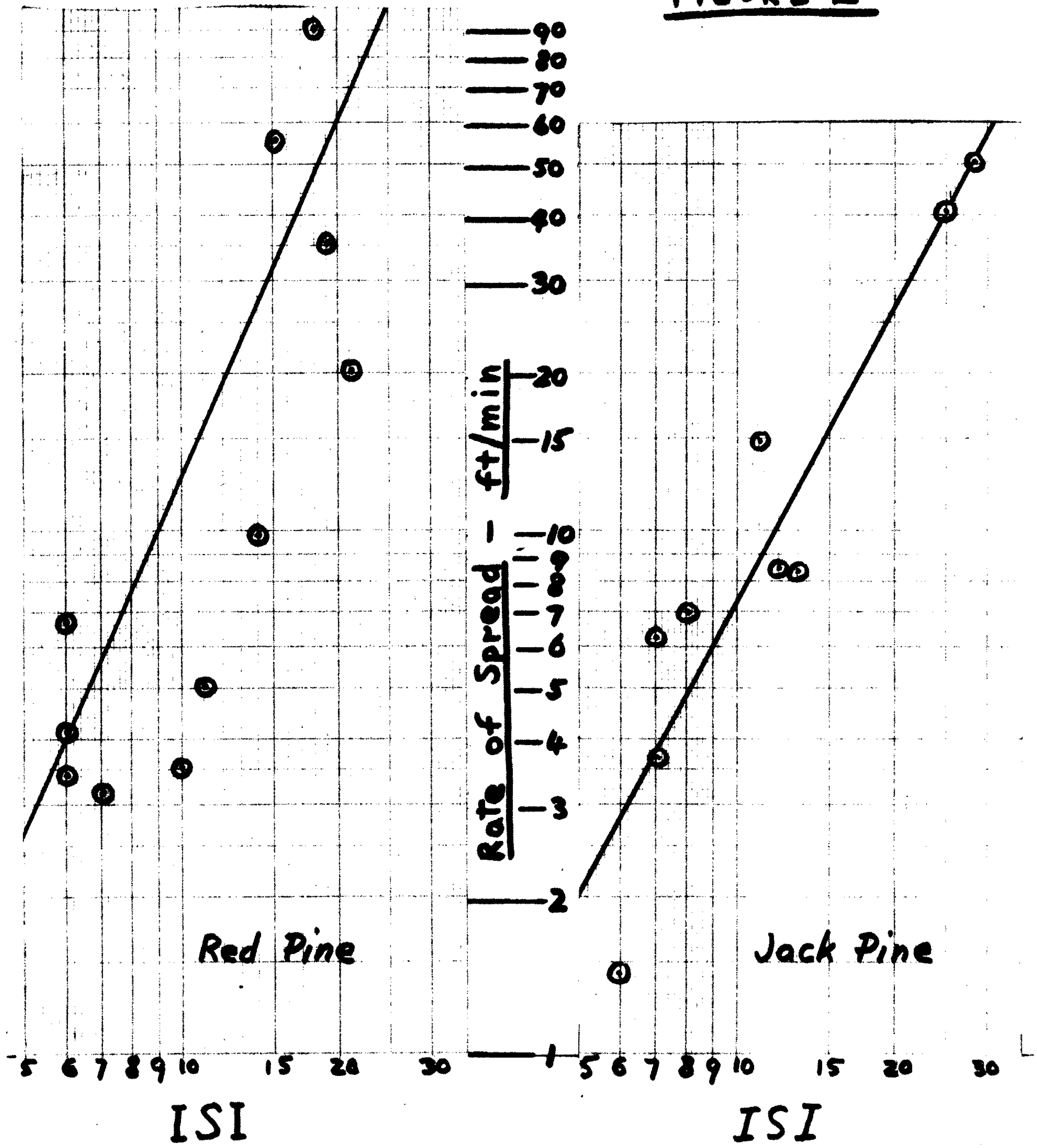
Table 1. Coefficients for rate-of-spread equation by fuel type (m/min).

Fuel Type	a	b	c
Red pine plantation	0.021	2.26	0.2
Jack pine	0.030	1.85	0.2
Red and white pine	0.020	1.84	0.3
Aspen (leafless)	0.249	1.01	0.1
Jack pine slash	1.34	1.00	0.4
Spruce-fire slash (B.C.)	0.109	1.75	0.4
Grass (Australia)	4.63	0.63	0

FIGURE 1

FIGURE 2

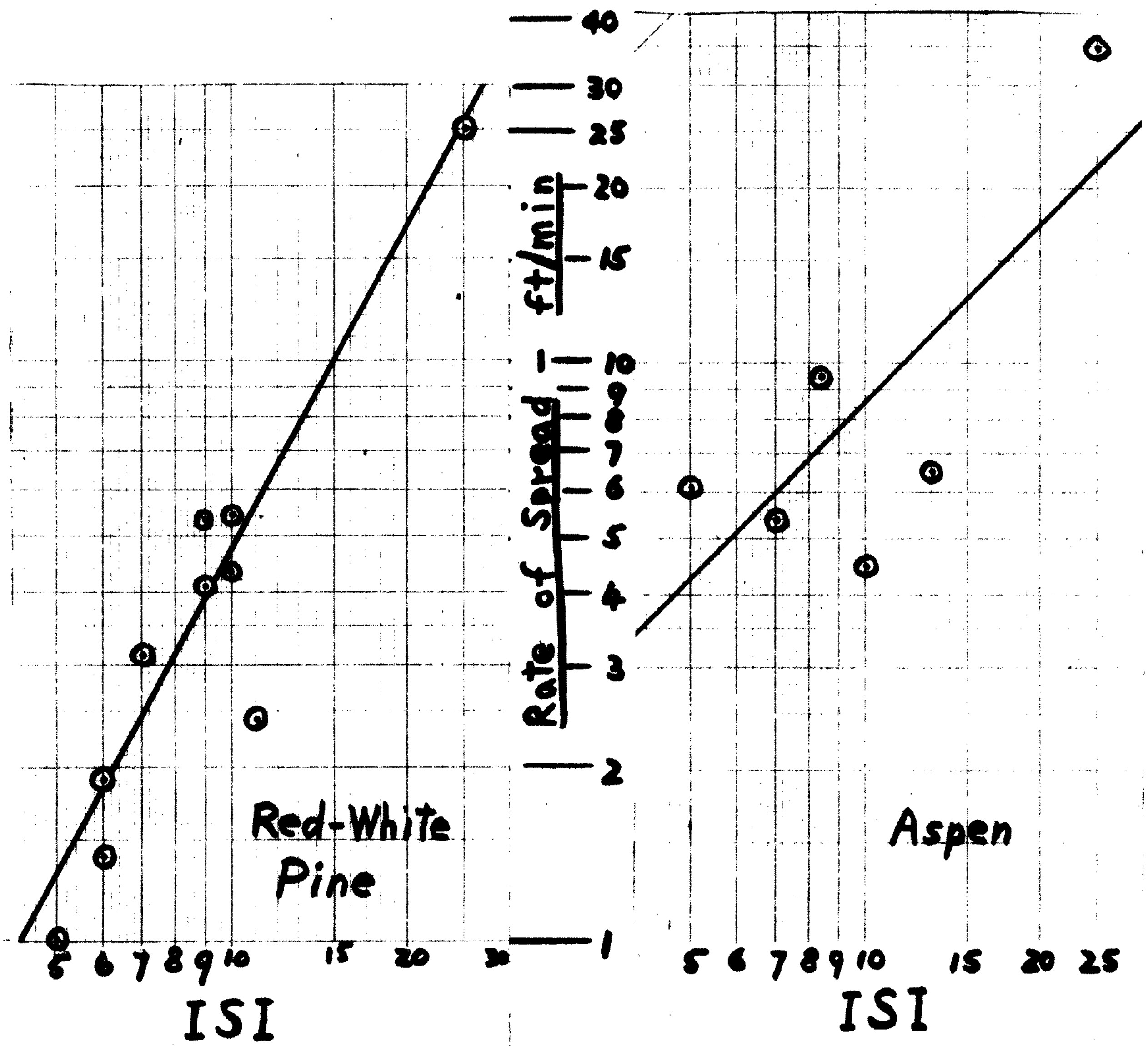


Figs. 1 and 2. Experimental Petawawa fires plotted as rate of spread versus Initial Spread Index (ISI) for red pine plantation and jack pine stand.

(For rate of spread in m/min, multiply by 0.3048).

FIGURE 3

FIGURE 4



Figs. 3 and 4. Experimental Petawawa fires plotted as rate of spread versus Initial Spread Index (ISI) for red-white pine and aspen stands.

(For rate of spread in m/min, multiply by 0.3048).

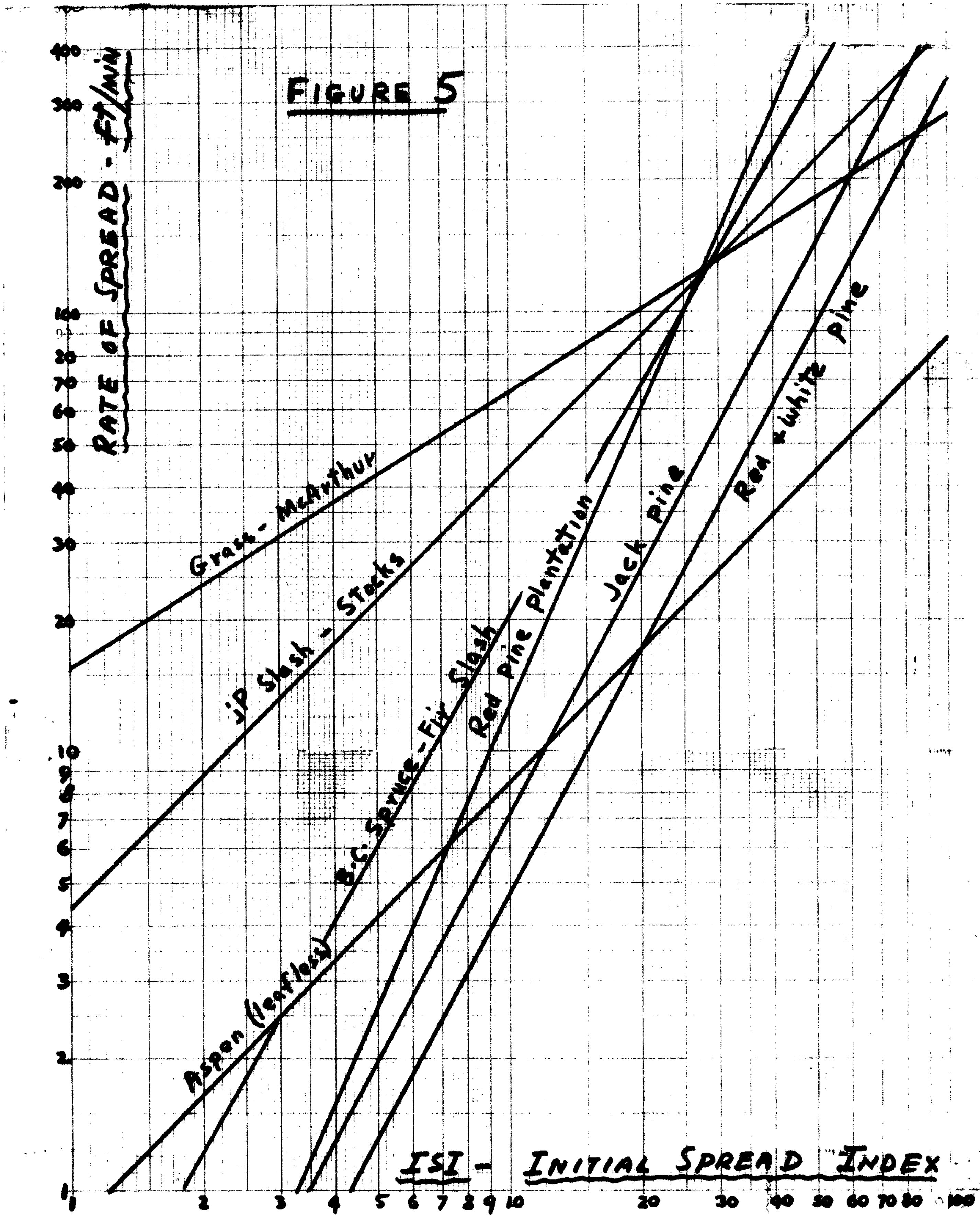


Fig. 5. Spread equations for seven fuel types plotted together. (For rate of spread in m/min, multiply by 0.3048).