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COMPARISON OF AMERICAN AND CANADIAN FOREST FIRE DANGER RATING SYSTEMS

by C.E. Van Wagner

PETAWAWA FOREST EXPERIMENT STATION
CHALK RIVER, ONTARIO
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INTRODUCTION

This report contains an analysis of the new U.S. spread index and describes its main points of difference from the Canadian system of forest fire danger rating. Although the U.S. index is intended as a measure of rate of spread only, while the Canadian danger index has a broader meaning, the two are similar enough that their components can be matched separately and the weight given to each separate influence compared.

Background information about the U.S. spread index was drawn from the U.S. Forest Service handbook (Anon., 1964) describing the new national system of fire danger rating. The spread index is identical throughout the country, although separate publications (e.g., Nelson, 1964) give directions for its use in particular regions. The comparison is made mainly with the B.C. Coast version of the Canadian system (Mactavish, 1965); it employs a numerical drying code that is easier to analyse than the code letters used to represent fine fuel moisture content in earlier versions. Danger tables for other parts of Canada would yield different numerical results but a similar pattern of comparison. Some field comparisons with the Ontario tables are presented based on fire weather records of the Petawawa Forest Experiment Station.

In order to keep this report as brief as possible, some acquaintance with the two systems of fire danger rating, and especially with the Canadian system, is assumed. A basic reference on the Canadian system is Forest-fire Research Note 12 (Beall, 1948) from which all modern versions are derived in part at least. The tables for determining fine fuel moisture content (Beall's tracer index) are used in all later danger tables, although in different code form. The regional versions of the Canadian system in current use are included in the reference list at the end of the report.

MEASUREMENTS REQUIRED

The Canadian system is based solely on weather readings: relative humidity (RH), wind speed and rainfall. The U.S. system uses these parameters as well as air temperature, but requires an observation of the state of minor surface vegetation before the tables can be used. Neither system uses fuel moisture sticks; each can therefore be entered with predicted weather data to yield fire danger forecasts.

The Canadian system is based on noon readings, but the resultant index applies to the mid-afternoon peak hazard period. Tables exist to give probable hourly index values during the subsequent 24 hours, but readings may be taken only at noon. In the U.S. system, readings may be made at any hour, and the index applies to that hour only; there is no predictive element. (One component of the U.S. system, the buildup index, can be computed at one standard hour only.) Each U.S. region establishes the hour at which standard readings are made.

In each system, weather readings are made in the open. Wind in the U.S. system is basically measured 20 feet above open ground, in the Canadian system 10 feet above treetops.

No readings are made during rain in the Canadian system. There are no specific instructions about rainy weather at reading time in the U.S. system; presumably readings are made regardless of rain.

REGIONAL VERSIONS OF CANADIAN SYSTEM

Before analysing the spread index together with the B.C. Coast index, and showing how it correlates with the Ontario index, a brief look at the different versions of the Canadian system is appropriate. While each version employs the same basic drying code (either in letter or number form), the danger tables are designed to cover the local range in fire behaviour as revealed in the test fire results. Thus, for a given set of weather conditions, the drying code number or letter will be the same, but the danger indexes different. These differences are illustrated in Table 1, which shows how the various regional danger indexes across Canada increase during a hypothetical series of 10 days at constant RH and wind commencing the day after a heavy rainfall. Three different RH-wind combinations were chosen, and the summer wind-corrected danger index tabulated for each region. The U.S. spread index at 75°F using the transition stage fine fuel table is included for comparison. It can be observed that the fastest rising index, that of Newfoundland, increases at more than twice the rate of the slowest, the B.C. Cariboo index. The spread index changes only when the buildup index enters a new class in the adjusted fuel MC table.

FINE FUEL MOISTURE CONTENT

Drying Rates

In the U.S. system, fine fuel is defined as material that loses 2/3 of its free excess moisture in 1 hour or less under a chosen set of standard drying conditions. Included are dead grass, ferns, some hardwood

Table 1. Increase in the various regional Canadian danger indexes[1] during a 10-day period at constant RH and wind beginning after a heavy rain, for three RH-wind combinations. Spread index tabulated for comparison.

Nfld.	N.B.	Ont.	Man.	Sask.	Alta.	Alta. East Sl.	N.W. Terr.	B.C. Cariboo	B.C. Coast	U.S. Spread
RH 33% - Wind 5 mph.										
1	1	1	2	2	0	1	0	0	0	8
5	6	6	5	6	3	4	1	2	3	8
8	9	9	6	7	5	5	3	4	5	8
11	10	10	7	9	5	5	4	5	5	11
13	11	11	9	10	6	5	5	7	7	11
13	12	12	10	10	6	5	5	7	7	11
13	12	12	10	10	6	6	6	7	8	11
13	13	13	11	10	7	7	7	8	8	11
14	13	13	11	10	8	8	8	8	9	11
14	13	13	11	10	9	9	9	8	9	11
RH 50% - Wind 11 mph.										
2	3	3	3	3	2	3	0	0	2	11
7	8	8	7	7	4	4	2	3	3	11
10	10	10	8	8	6	6	3	3	4	11
11	10	10	8	9	7	6	4	4	6	15
12	11	11	9	10	7	7	6	4	6	15
14	11	11	10	10	7	7	7	4	6	15
14	11	11	10	10	7	8	8	4	7	15
14	12	12	10	10	8	8	8	6	7	15
14	13	13	10	10	8	9	9	6	8	15
14	13	13	10	10	8	9	9	6	8	15
RH 70% - Wind 24 mph.										
4	5	5	5	4	3	3	2	0	2	13
7	8	8	7	7	5	5	2	2	3	13
9	10	10	8	8	5	5	3	3	4	13
10	11	11	8	10	5	5	4	4	5	13
12	12	12	9	10	7	7	5	4	5	13
14	12	12	9	10	7	7	5	4	5	13
14	12	12	9	10	7	8	7	4	7	13
15	14	14	10	10	8	8	8	5	7	17
16	14	14	11	10	9	9	9	5	8	17
16	14	14	11	11	9	9	9	5	8	17

1/ All corrected for wind according to Table 6 (Wind Velocity Correction) in B.C. Coast version.

leaves and fine twigs. For example, such fuel at 40 per cent moisture content (MC), if exposed to conditions resulting in a 10 per cent equilibrium moisture content (EMC), would lose 20 per cent in the first hour; its MC would be 11 per cent in 3 hours. Plotted as log MC over time, the slope of this drying behaviour is 0.48 units of log MC per hour. This is a rate five to ten times as high as obtained with $\frac{1}{4}$-inch layers of pine needles in the laboratory. In the determination of the spread index, however, fine fuel is assumed to be in equilibrium at all times. Thus the fine fuel moisture tables are actually tables of EMC, and depend only on temperature and RH; wind and rain do not enter into them. However, even such fast-drying fuel would require some time to reach EMC after thorough wetting by rain. For example, standard fine fuel at 100 per cent above EMC would take 3 hours to dry to within 4 per cent of EMC and 4 hours to within 1 per cent. The standard drying conditions, while not specified, are inferred to be about 80°F and 20 per cent RH, fairly severe by Canadian standards. Under normal Canadian weather conditions a standard U.S. fine fuel would approach equilibrium more slowly than the rate described above. Wind of course has an effect on drying time, and can only be ignored if continuous equilibrium is assumed.

Fine fuel MC in the Canadian system is determined from RH, wind and rainfall readings. The drying code number, whose values equal 105 minus MC, is reduced according to the amount of rain in the last 24 hour period, and requires from 3 to 10 days to reach equilibrium after a heavy rain, depending on wind and RH from day to day. The number of days required for equilibrium can be determined by starting at zero and repeatedly entering the drying code table with the same chosen wind-RH combination. The final equilibrium value is not necessarily a true EMC, since it is the result of a series of complex 24-hour cycles.

In the U.S. system, if rain is falling or has just ceased when the weather readings are taken, the RH will be higher than usual. Thus, although rain does not enter directly into the determination of fine fuel MC, it can contribute an indirect effect.

Neither system makes provision for the effect of insolation on exposed fine fuel. The U.S. fine fuel tables accommodate MC's as low as 1 per cent, which can only be reached in the shade at RH's below 5 per cent. The minimum MC in the Canadian system is 6 per cent.

It is obvious that the concepts of fine fuel in the two systems are quite different.

Herbaceous Stage and Seasonal Variation

No consideration is given to the state of minor surface vegetation in the Canadian system (except in the separate grass fire hazard tables). In the U.S. system separate fine fuel MC tables are provided for cured, transition, and green herbaceous stages. The three tables are spaced exactly 5 MC points apart. Since a moderate value in the cured stage table is only about 7 per cent MC, this arrangement places a great deal of weight on the proper choice of herbaceous state. While temperature and RH fix the MC quite precisely to with ½ or 1 point within each table, the user can only adjust for herbaceous state in jumps of 5 points. For example, for one common set of weather conditions, a spread index of 23 would result with the cured table, 14 with the transition table, and 8 with the green table. This is a considerably greater proportional change than results from switching from one season's danger table to another in the Canadian system.

Seasonal variation in the U.S. system results from the use of temperature and herbaceous state in the fine fuel moisture tables. Seasonal variation in the Canadian system is accomplished by providing a danger index table for each season.

DROUGHT AND BUILDUP INDEXES

Dry Weather Effects

Both systems contain a subsidiary index whose purpose is to account for the long-term effect of dry weather on heavy fuels or duff layers. These indexes are then given a certain weight in the determination of the final index. The U.S. buildup index increases every day by an increment (called the "drying factor") dependent on temperature and RH but not on the value of the index itself; the index can be interpreted as the number of days since rain, multiplied by a factor. The Canadian drought index advances one unit each day, and thus also approximates the number of days since rain. Both the buildup index and the drought index are therefore basically similar in their behaviour during dry weather.

The U.S. buildup index is said to be based on fuels or duff layers that lose 2/3 of their moisture above EMC in 10 standard days, which corresponds to a logarithmic drying rate of 0.0477 units of log MC per day. The constant daily increases in buildup index then suggest that the index values have a logarithmic relation to MC, such as $B.I. = 100 (\log MC_{max.} - \log MC)$, where $MC_{max.}$ is the maximum possible MC, say 300 per cent.

The Canadian drought index has a top limit of 25, while the U.S. buildup index is open-ended, and the tables accommodate values up to 400, i.e., 80 standard days of drying factor 5 without rain. The standard U.S. heavy fuel starting at, say, 200 per cent above EMC would require only 48 days to dry to within 1 per cent of EMC; buildup indexes of over about 250 therefore have little meaning with regard to the standard heavy fuel. In fact, in the determination of the spread index, the weight given to additional increments of buildup decreases as the buildup index rises and is slight above values of 200 or so.

Although the standard U.S. drying day has a drying factor of 5, an average day in most parts of Canada would yield a drying factor nearer to 3. On such a basis, the maximum drought index of 25 would be equal to roughly 75 on the buildup index scale. For heavy fuels as defined in the U.S. system, it is thus apparent that the drought index has too low an upper limit.

When both start at zero the buildup and drought indexes can be compared fairly well during a dry period. In wet weather, however, this rough 3 to 1 equivalence is thrown badly out of phase owing to the difference in their reaction to rain.

Rain Effects

Following a given quantity of rain, the U.S. buildup index is reduced by an amount dependent on the initial index. For example, a rainfall of 0.60 inch reduces an initial index of 95 by 62 points, but an initial index of 28 by only 14 points. Plotting successive values of the index for the same rainfall day after day results in decreasing curves of the approximate form

$$B.I. = \frac{1}{a + bT} \quad \text{where}$$

T is time in days.

This arrangement seems logical, since as the index rises a given scale interval represents less and less fuel moisture and should be offset by less and less rain.

The Canadian drought index, on the other hand, decreases a constant amount after rain regardless of index value. The curves of drought index over time in days for successive equal rainfalls are thus descending straight lines. Theoretically then, the drought index is not as well suited as the buildup index to represent heavy fuel moisture content; rather, it portrays better the behaviour of a simple reservoir that loses a constant amount of water daily and is replenished in additive fashion by rain.

The two indexes differ considerably in their sensitivity to given amounts of rain. The buildup index ignores the first 0.10 inch of rain and covers the range of 0.11 to 2.81 inches in 10 steps of increasing size. The drought index ignores only the first 0.05 inch and has 13 classes of 0.05 inch with a maximum recognized rainfall of 0.65 inch (0.55 inch in some versions). The buildup index also maintains higher relative values after rain. Assume, as suggested earlier, that the buildup index is roughly equal to three times the drought index. The maximum drought index of 25 is reduced to zero by any rain over 0.65 inch. However, a rain of 0.65 inch would reduce a buildup index of 75 (say drought 25) only to 29 (say drought 10), or a buildup index of 29 only to 14. This effect can cause wide departure from the simple 3 to 1 ratio.

Since rainfall does not enter into the fine fuel moisture tables of the U.S. system, it is apparent that no account whatever is taken of rains up to 0.10 inch in the determination of the spread index. The Canadian danger index, on the other hand, reacts to rains as small as 0.01 inch in the drying code table.

COMPONENTS OF SPREAD AND DANGER INDEXES

General

The U.S. spread index is determined by first adjusting the fine fuel MC according to the buildup index, and then entering the final table with adjusted MC and wind. In the Canadian system, fine fuel MC is combined with the drought index to produce a fire danger index directly. This index applies to moderate wind conditions, but can be corrected for wind if desired. Accepting the wind-corrected index as the final product, the Canadian system requires two applications of wind speed, once in determining fine fuel MC and once as a correction for fire behaviour.

It is of interest to examine the relative weights given to the several factors in the determination of each index. This is best done by plotting the two systems on comparable scales, the chosen equivalents being (a) buildup index equal to three times drought index, and (b) spread index 64 equal to wind-corrected B.C. Coast danger index 16. These values are partly arbitrary, but are based on roughly comparable results with similar fine fuel MC and wind. Other regional danger indexes would have lower spread index equivalents. Although the above spread and danger equivalents may be reasonably correct, the linear relationship will not necessarily apply at all points on the scales.

Drought Effects

The buildup index is reportedly given a weight of 10 per cent in the determination of adjusted fuel MC; how this is accomplished is not quite clear, since buildup index is not an arithmetical index of fuel moisture. It is apparent, however, that the buildup index carries much less weight in the U.S. system than does the drought index in the Canadian system. This can be shown readily by plotting spread or danger index over buildup or drought for constant fine fuel MC and wind, as in Figure 1. Taking buildup index as equal to three times the drought index, the slopes of the curves indicate that the drought index has a weighting about twice as great up to drought index 15 or buildup index 45. The U.S. curves gradually flatten at high buildup indexes, which seems logical. The Canadian curves end at a steep slope, again suggesting that an extension of the drought index might be desirable.

Wind Effects

In contrast to the drought effects, the relative weighting given to wind is higher in the U.S. system. The effects of wind can be pictured by plotting the final spread or danger index against wind at constant values of fine fuel MC and buildup or drought. For this purpose, no double wind entry need be made in the Canadian system, since the uncorrected danger index depends on the drying code without reference to how it was derived. From the typical curves shown in Figure 2, it is plain that at low MC wind has about twice the weight in the U.S. system that it has in the Canadian. In addition, the curves begin at a lower level in the spread index; thus, at zero wind and a fuel MC of 6 per cent, the maximum spread index is 18 on a

100-point scale, while the maximum danger index is 13 on a 16-point scale.

In both systems, the wind curves are nearly straight lines, and each index has a finite upper limit that cuts off the steeper curves at less than maximum wind speed. This effect occurs at much lower absolute danger in the Canadian system than in the American. An extension of the spread index to about 135 and of the danger index to about 22 would accommodate all curves to the respective wind limits of 30 and 35 miles per hour.

Fine Fuel Moisture Effects

The variation of the spread and danger indexes with fine fuel MC can be observed by plotting them against MC at constant drought and wind. Figure 3 contains two pairs of such curves, each for a different drought-wind combination. In each case the Canadian curve has roughly the same slope and shape as the U.S. curve, but lies somewhat above it; i.e., danger index maintains appreciable values at much higher MC than does the spread index.

The effects of fine fuel MC over a series of days after rain are quite different. Because fine fuel is considered always at equilibrium in the U.S. system, the spread index can have a high value immediately after rain. At constant atmospheric conditions, it can only rise with the help of an increasing buildup index (see Table 1). The Canadian danger index, on the other hand, increases slowly after rain, owing to the several days required to reach fine fuel EMC; thereafter, further increase is due to rising drought index.

FIELD COMPARISON AT PETAWAWA

From fire weather records at the Petawawa Forest Experiment Station, a comparison of the two systems was made using data for three years: 1961, 1964 and 1965. The first of these was on the average wetter than normal, the second drier than normal; the third contained several weeks of continuous high and extreme danger. For each day from May 1 to October 31, the spread index was determined, using only the transition stage fine fuel table. The danger index was computed with the Ontario (1956) tables, switching from the spring-summer danger table to the fall table on September 1 as prescribed, and correcting for wind as provided in the B.C. Coast tables. The two systems were then compared in three ways, using the pooled data for the three years together (552 days in all).

Buildup Index vs. Drought Index

Figure 4 shows the average value and range of the buildup index for each drought index level. The upward trend of average buildup index is fairly smooth, but the ranges at each drought index value are very wide. The reason for the wide spread is that, although daily increases in the two indexes maintain a fairly constant ratio during dry weather, the buildup index is less easily reduced to zero by rain. The most extreme example (see Figure 4) is the buildup index of 35 after a rain that reduced the drought index to zero.

Spread Index vs. Danger Index

Figure 5 shows the average value and range of the spread index for each level of the danger index. It is obvious that the two indexes are poorly correlated. The upward trend of spread vs. danger reverses at several points on the curve, and a wide range of spread index values can be obtained for any value of the danger index. For instance, the minimum tabled spread index of 1 occurred at danger indexes up to 7, and higher spread indexes sometimes occurred at danger 2 or 3 than at danger 14 or 15.

The spread index values are much lower than those obtained with similar danger index values in the B.C. Coast tables. This is because the Ontario version of the danger index rises faster for a given weather sequence than does the B.C. Coast version. The highest spread index found using the transition fine fuel table was only 36 during three years that included the severest fire weather likely to occur in this region. Using the cured stage fine fuel table, the equivalent spread index would be 53.

Each regional version of the Canadian fine danger system would yield a similar pattern of correlation, but at a different absolute level.

Spread Index vs. Fast-Drying Hazard Index

Figure 6 shows the average value and range of the spread index for each level of the fast-drying hazard index. This hazard index increases during dry weather faster than the danger index, and is less dependent on the drought index but more dependent on RH and wind. Since the discrepancies between spread and danger indexes are partly due to the greater weight given to drought in determining the danger index, it might be expected that the fast-drying hazard would match the spread index more closely. Again, however, the correlation is poor, mainly because of the different concepts of fine fuel MC. The average spread index rises smoothly from hazard index 10 upwards, but the ranges are still very wide. For example, the highest spread index at zero hazard exceeds the lowest spread index obtained at hazard index 16.

BASIC POINTS OF DIFFERENCE

1. The U.S. system assumes that fine fuel is always at equilibrium. Fine fuel according to the Canadian system dries slowly, taking several days to reach equilibrium.
2. The U.S. system ignores rains of 0.10 inch or less, and uses rain in the buildup index only. The Canadian system takes account of rains down to 0.01 inch, and applies rain to both fine fuel MC and drought.
3. The U.S. buildup index and Canadian drought index can both be pictured in terms of the number of days since rain, but their reaction to rain differs. In the buildup index, a given rainfall has more effect on a higher than on a lower initial index; the drought index decreases a constant amount regardless of initial index value.
4. In the U.S. system, buildup has considerably less weight than does drought in the Canadian.
5. Wind has considerably greater weight in the U.S. system than in the Canadian.
6. Fine fuel moisture content has about the same weight in both systems, but the fire danger index becomes appreciable at higher MC's in the Canadian system.
7. Seasonal variation in the U.S. system is covered by the use of temperature in the fine fuel MC tables, and by providing three such tables for different conditions of herbaceous vegetation. In the Canadian system the same drying code applies throughout the year and separate

danger tables are provided for each season.

8. The U.S. system can be applied at any hour of the day (except for the buildup index), but has no predictive element. The Canadian system is based on noon weather only, and the resultant index applies to the mid-afternoon period.

CONCLUSION

Each system has apparent weaknesses. In the U.S. system the assumption of continuous fine fuel equilibrium seems an over-simplification, and the choice of herbaceous state overly critical. Also, it seems unlikely that the same index could work well, even in a relative sense, for all the varied forest types in the country. One way to make the spread index more versatile might be to vary from region to region the present 10 per cent weight assigned to the buildup index.

The weakest link in the Canadian system is probably the drought index, which has too low an upper limit and does not react logically to rain. Other possible improvements might be a lower fine fuel MC limit (now 6 per cent), and an upward extension of the danger index scale. Use of temperature in the fine fuel drying code might also be desirable; separate seasonal danger tables can account for changing average temperature, but not for the effect of sharp day-to-day changes. (Temperature was included as a variable in the earlier Canadian danger systems, and reappears in a minor way in the B.C. Coast and Cariboo tables.)

There are several possible criteria of the validity of a fire danger index. Theoretically, each index value should represent the same fire behaviour in a particular fuel complex, no matter what weather history lies behind it. Empirically, the index should correlate well with such variables as the incidence rate of fires and their average size after a given time since ignition. From any of these viewpoints, there are enough structural differences between the new U.S. and the current Canadian fire danger rating systems that both can hardly be valid for the same forest and fuel types. The U.S. spread index seems best suited to an open forest where the principal fine fuel is well-exposed dead herbaceous matter, where wind and sunlight can enter freely, and where small rainfalls are quickly evaporated. The Canadian danger index seems more applicable to a closed forest where the fine fuel is mainly litter rather than dead minor vegetation, where there is an appreciable duff layer, and where wind and sunlight below the canopy are much reduced. A final conclusion is that, wherever in Canada the two indexes are compared, poor correlation between them can be expected.

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Ontario
Manitoba
Alberta East Slope

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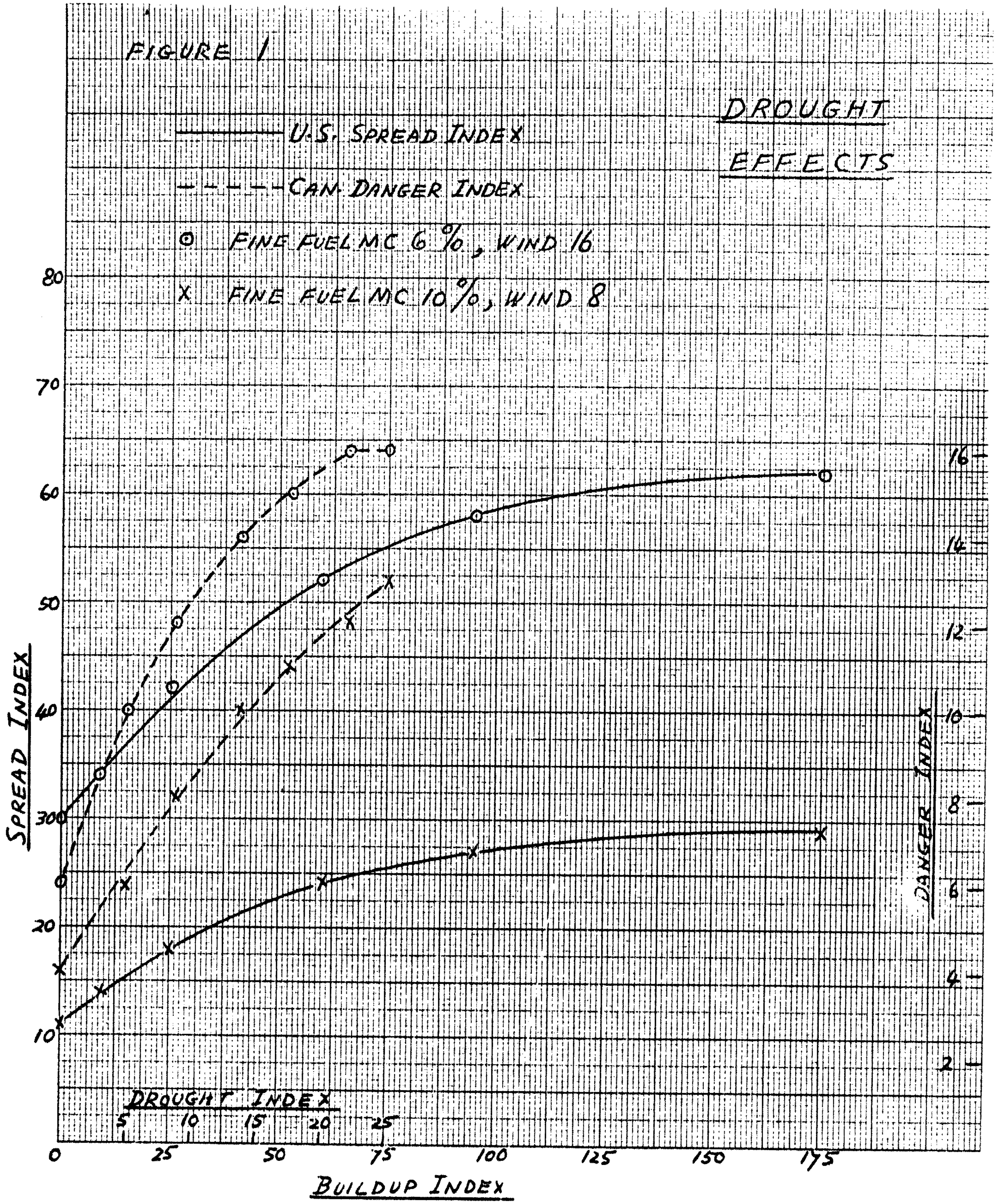

Figure 1. Effects of drought (or buildup) on the U.S. spread index and the B.C. Coast wind-corrected danger index, for two combinations of fine fuel MC and wind speed.

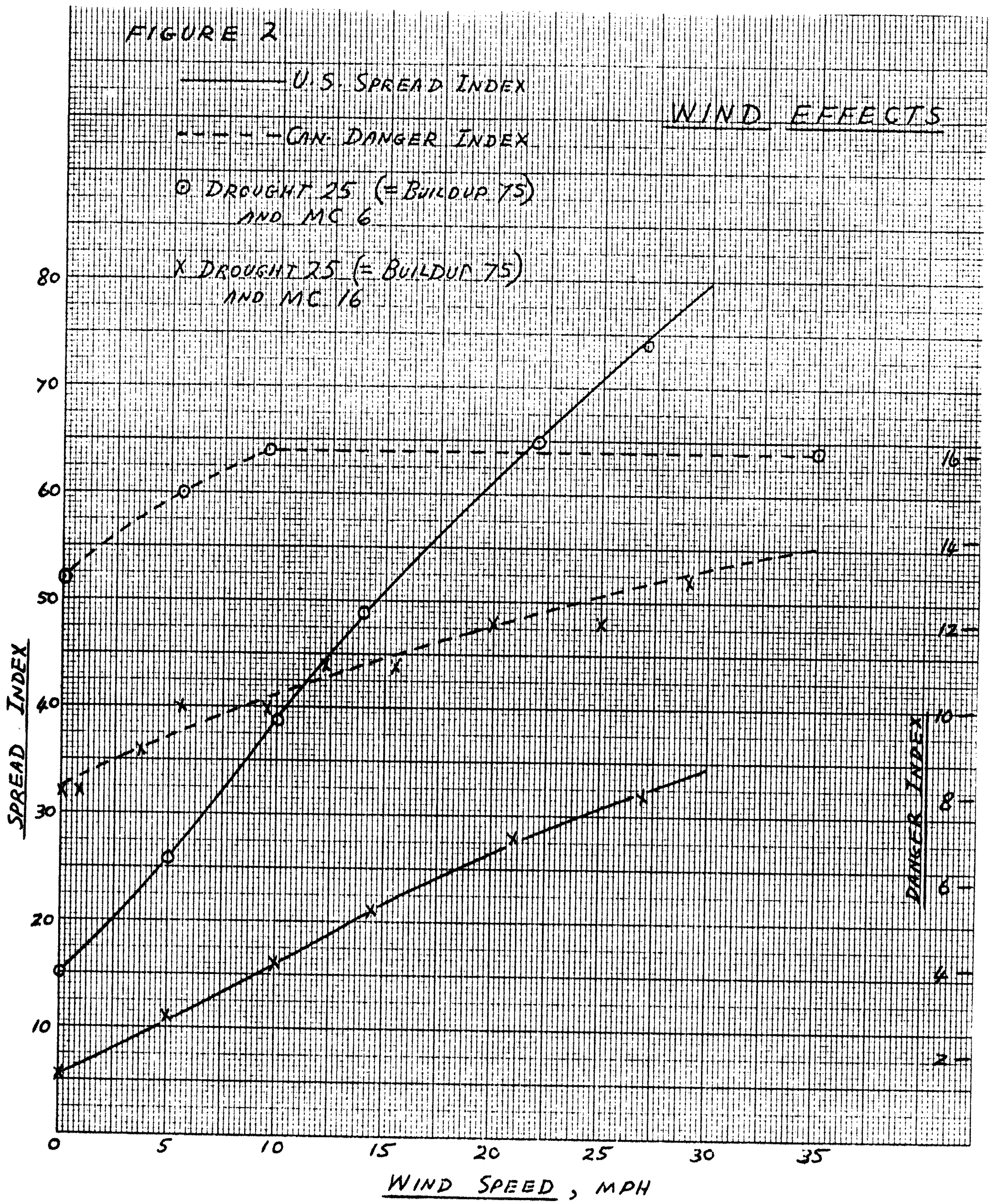

Figure 2. Effects of wind speed on the U.S. spread index and the B.C. Coast danger index, at drought 25 (= buildup 75) and two values of fine fuel MC.

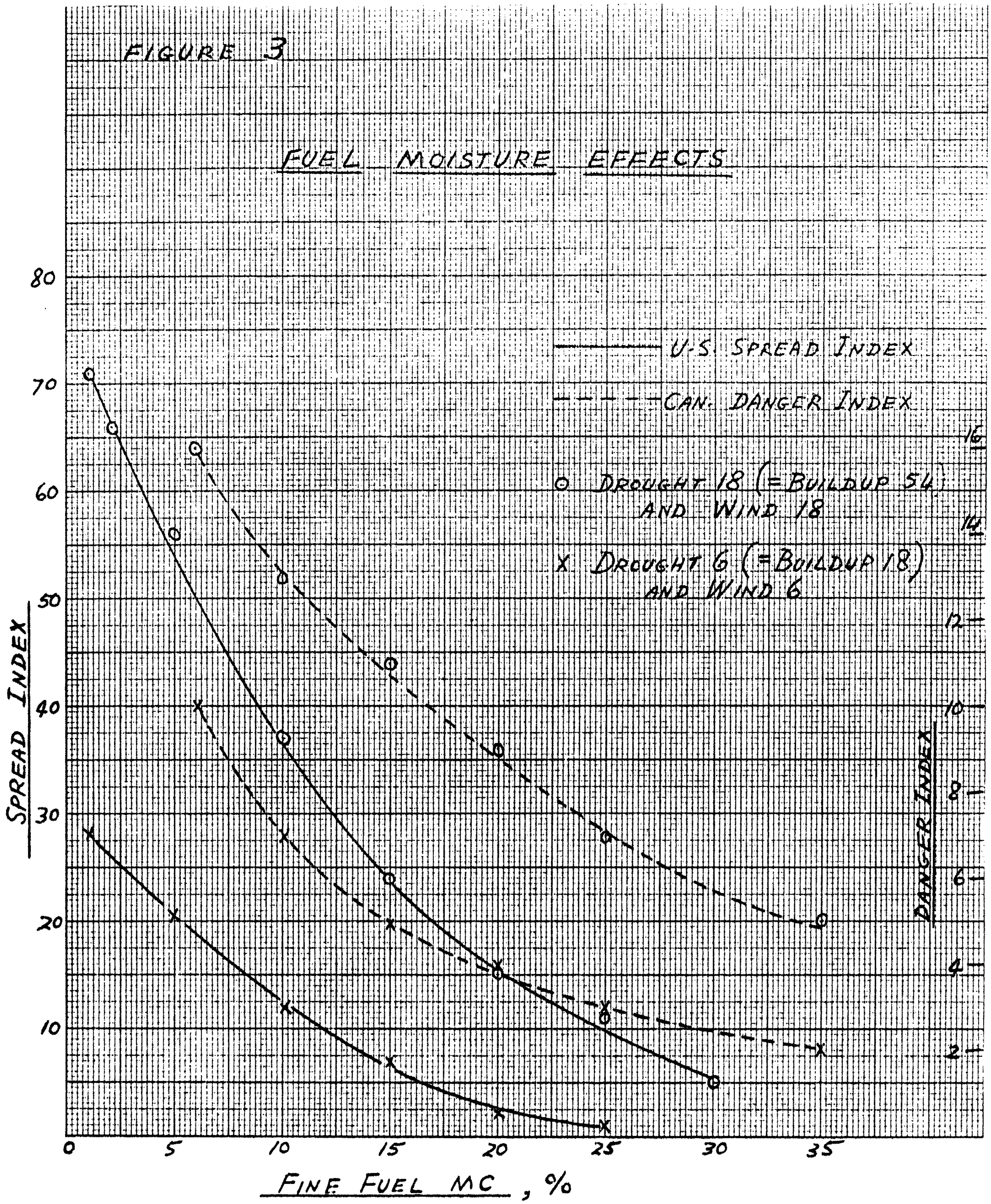

Figure 3. Effects of fine fuel MC on the U.S. spread index and the B.C. Coast wind-corrected danger index, for two combinations of drought (or buildup) and wind speed.

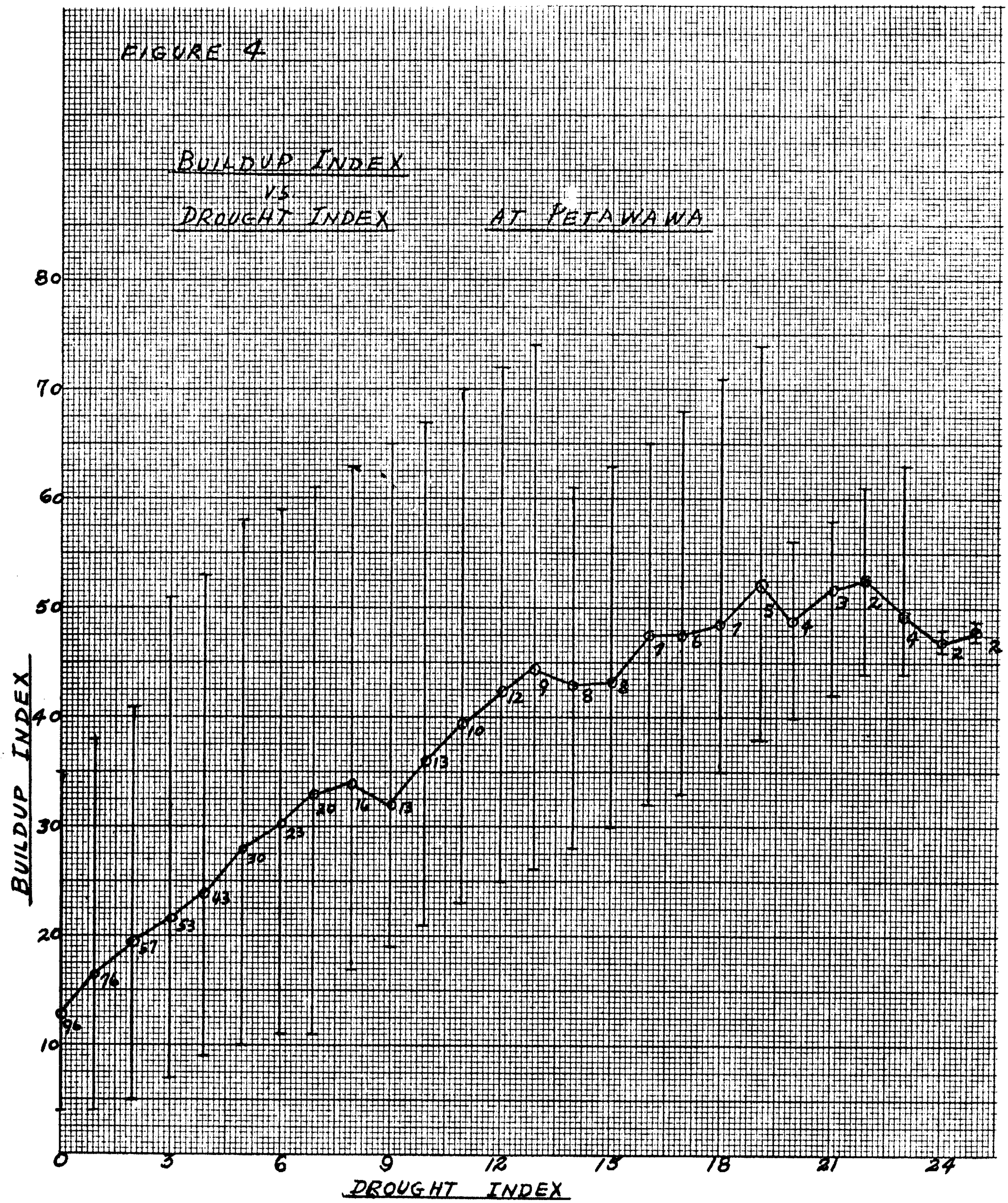

Figure 4. Three-year comparison of buildup and drought indexes showing the average value and range of the buildup index at each value of the drought index.

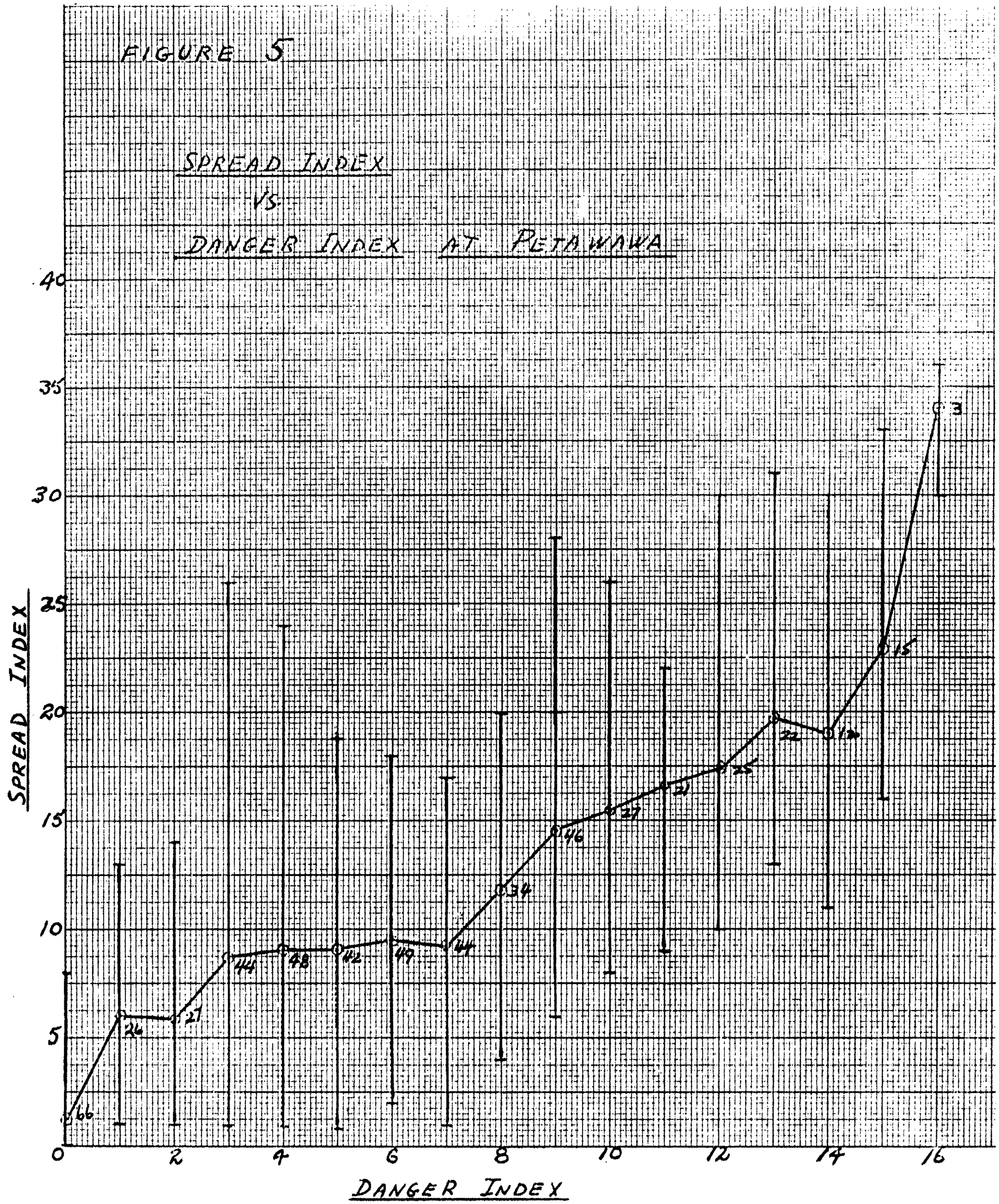

Figure 5. Three-year comparison of the U.S. spread index and the Ontario wind-corrected danger index, showing the average value and range of the spread index at each value of the danger index.

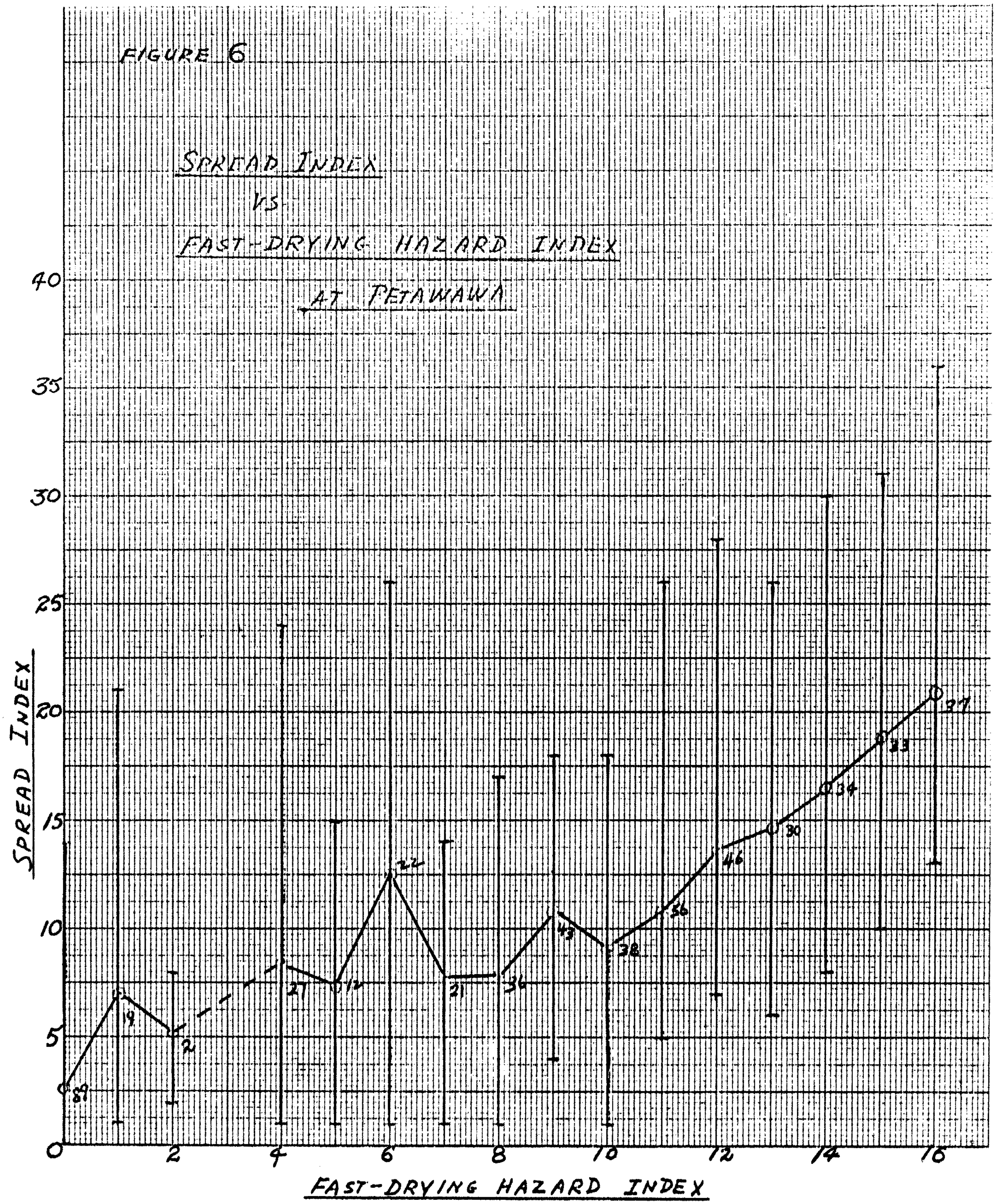

Figure 6. Three-year comparison of the U.S. spread index and the Ontario fast-drying hazard index, showing the average value and range of the spread index for each value of fast-drying hazard.