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A STATISTICAL ANALYSIS OF SOME RATES OF SPREAD OF FOREST FIRES

by

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SUMMARY

Data on the rates of spread of forest and heathland fires have been examined using elementary statistics to see whether any useful conclusions can be drawn. Fires appear to be divisible into two main categories according to the statistical distribution of their rates of spread. This could have some justification in theory. Upper limits of rate of spread have been calculated for the categories of fire described.

KEYWORDS: Statistics, ~~Fire~~, Fire spread, ~~Rate~~, Forests, Wildland.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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1. INTRODUCTION

The Fire Research Station has for some time been carrying out research on the nature and physical processes of the spread of forest and heathland fires and is now attempting to apply the laboratory and theoretical work to field conditions employing data collected by the Joint Fire Research Organization and by officers of the Forestry Commission who carry out controlled burnings. It has been possible to interpret data obtained in the laboratory largely in terms of a physical theory since these data are fairly detailed and the methods of measurement used were relatively precise. The data collected by the Forestry Commission using methods more suited to routine observations have a greater scatter and as yet there are insufficient data to outweigh the scatter and make it possible to apply physical theories. It was thought however that it might be possible to make some use of the data in a purely statistical manner following the example of Abell[1]. At the same time data on wildfires and experimental fires in the open have been collected by the author from publications, reports, etc. The purpose of this report is to try to examine these data statistically.

2. THE DATA

Data for controlled burnings have been extracted from cards filled in by Forestry Commission officers carrying out controlled burnings in the United Kingdom in heather, heath, gorse and bracken and mixtures of these fuels.

The data for wild fires and experimental fires used in the analysis are shown in Table 1. These constitute fires in the open in reports to which the author had ready access. Data from some books on forest fires were also included. Neither the controlled fire nor the wildfire data are of course random samples of fires occurring in these fuels.

Table 1

Wild and experimental fire data+

Place and date of fire	Rate of spread ft/min
Nethy Bridge Scotland 1960[3]	7.5
Trensaq France[4]	87
Three experimental fires in Jack Pine Slash[5]	
:- head fires	16, 25, 55
:- backing fires	2, 4
Eastern Seaboard Fires U.S.A. 1963[6]	6, 8, 5, 60, 48
Fires in Southern France 1960[7]	120, 80, 83
Basin Fire U.S.A. 1961[8]	90
The Clare Fire South Australia[9]	120
California[10]	22
The Drain River Fire Michigan[11]	88
Ontario "Season 1955 on the Cochrane District"[11]	88
Story of an Intense Crown Fire at Petawawa[12]	80
History of a small Crown Fire[13]	5, 35
The Loop Fire, Los Angeles 1967[16]	4
Tasmania 1967*[15]	176

+Where more than one estimate is available the maximum has been taken or when a fire front map is given the maximum rate has been measured

*This is an upper estimate, the fire spread from the point of origin 4 miles from the town to an outer suburb in 2 hours.

However the wildfire data are valuable because fires which are reported in the fire journals etc, are presumably the more serious and faster spreading ones. The data from controlled burns are also biased but in the other direction as foresters would not carry out controlled burns under hazardous conditions, e.g. in high winds. They would be representative of the slower rather than the faster fires.

3. CLASSIFICATION OF THE DATA

3.1. Controlled fires

First the controlled fire data have been plotted on arithmetical probability paper Fig.1. For fires in fine grass and fine grass mixtures it is the maximum rate of spread which is plotted in Fig.1 since an analysis of the data, not yet reported, has shown that the maximum rates have a more normal distribution than the average. The data fit well on two straight lines indicating that there are at least two populations. Fires spreading at rates up to 11 ft/min have been separated and replotted on their own (Fig.2). No physical reason could be found for differentiating between these two groups of data except that backing and still air fires are all in the slow category. The slow data shown in Fig.2. show relatively little scatter about a straight line, indicating a normal population.

Then, all the rates of spread of 12 ft/min and above were plotted in Fig.3. These showed something of a tail at the lower end of the spread range. As the lower end contains nearly all heather fires, whereas the faster spreading fires are fine grass/fine grass mixtures, they can be separated on this basis. The straightness of the lines obtained both for fine grass/fine grass mixtures (Fig.4) and heather (Fig.5) suggests that Fig.3 is a combination of two populations, the heather fires burning more slowly.

3.2. Wildfires and experimental fires

All the wildfire data are plotted on arithmetic probability paper in Fig.6 and show two populations. These have also been split up and replotted on arithmetic probability paper, "Wildfire Data Fast" on Fig.7 and "Wildire Data Slow" on Fig.8.

3.3. The categories of fire spread data

From the above it can be seen that the data have been divided into the following categories:

A. Slow controlled (Fig.2)

B. Fast controlled fine grass and fine grass mixtures (Fig.4)

C. Fast controlled heather (Fig.5)

D. Fast wildfire (Fig.7)

E. Slow wildfire (Fig.8)

Later some of these will be combined but a statistical justification will be given for any such combination.

4. UPPER LIMIT FOR RATE OF SPREAD

The purpose of the statistical analysis is to try to determine an upper limit for rate of spread of fire in each category. The upper limit is taken as the 99% point, the rate of spread such that only one per cent of fires spread at a faster rate. The calculation has been made using the upper 99% confidence limits of the sample mean and standard deviation.

The procedure followed has been to find the sample mean $\bar{x}$ and variance and obtain from the latter an estimate S^2 of population variance using Bessel's correction. Then the upper 99% confidence limit of the mean $\bar{x}_{99\%}$ is calculated using Student's t distribution (one tail)

$$\bar{x}_{99\%} = \bar{x} + \frac{tS}{\sqrt{n}}$$

where n is the number in the sample.

The upper 99% confidence limit of the standard deviation $S_{99\%}$ has been determined using the chi-squared distribution (one tail) for (n - 1) degrees of freedom

$$S^2_{99\%} = \frac{nS^2}{\chi^2_{99\%}}$$

The 99% point lies at 2.33 standard deviations from the mean, so that to obtain the 99% confidence limit of the 99% point in the rate of spread population 2.33 $S_{99\%}$ has been added to $\bar{x}_{99\%}$, the upper 99% confidence limit of the mean. This is not a statistically rigorous treatment but it represents a conservative estimate and the extra contribution to the upper limits which results from taking the 99% confidence limit of the mean rate of spread is small.

The results are given in Table 2 for the categories given in Section 3.3.

Table 2

Statistical comparison of categories

Category	Sample mean ft/min	Upper 99% confidence limit of mean ft/min	Sample standard deviation ft/min	Population standard deviation ft/min	No. of fires	Upper 99% confidence limit of 99% point ft/min
A Slow controlled	6.6	8.1	2.6	2.66	20	17.9
B Fast fine grass and fine grass mixture	73	94	35.7	36.6	19	230
C Fast controlled heather	29	62	25.6	27.6	7	158
D Fast wildfire	68	91	38.6	39.7	18	246
E Slow wildfire	5.2	7.3	1.87	2.0	8	18.3

It can be shown from the above calculations that the "slow controlled" data (A) and the "slow wildfire" (E) are not significantly different from one another and can be combined. Similarly the "fast controlled fine grasses and fine grass mixtures" data (B) and the "fast wildfire" data (D) can be combined. The details of these comparisons are given in Table 3 below and the statistics derived by combining A and E and B and D in Table 4.

Table 3

Results of comparisons of various categories

	F	Required F at 5% level for significance	t	Required t at 5% level for significance
Comparison of A and E "slow data"	1.77	3.5	1.35	2.06
Comparison of B and D "fast data"	1.17	2.2	0.4	2.03

Table 4

Statistics of combined data

	Sample mean ft/min	Upper 99% confidence limit of mean ft/min	Upper 99% confidence limit of 99% point ft/min
A and E "slow data"	6.2	7.4	16.1
B and D "fast data"	71	88	207

Although the selection of the data was not random it has been shown that the data can be pooled - the differences between them being in the rates of spread - fast and slow not the source of the data.

5. DISCUSSION

In the case of wildfires, unlike the controlled fires, all the rates of spread are average over long distances, in many cases miles, and these average rates of spread should be of importance in fire fighting strategy, especially large scale strategy. Fires may, of course, spread locally much faster or slower than the average due to uneven terrain or vegetation or the shape of the fire front.

Various theoretical expressions have been derived for the rates of spread of fire in terms of quantities such as fuel bed height, bulk density of fuel etc, but as yet no attempt has been made to examine what kind of statistical distribution of spread rates one should expect a priori.

The discovery of two distinct orders of magnitude of rate of spread, however, is in accord with the theory put forward by Thomas[14] which predicts two stable equilibrium one fast and one slow with an unstable equilibrium between.

There are so few of the fast heather fires that it is not possible to say much about them with any certainty, although their central tendency is perhaps less pronounced than that of the other categories.

It is interesting that the mean spread rate 16 miles in 9 hours (1.75 mph) of a recent very large and fast fire in the U.S.A., the Sundance fire[17], is within the upper confidence limit of fast spread (approx. 2.4 mph). In general it seems fires spread slower than is sometimes implied by phrases like "as fast as a man can run". Van Wagner[2] suggests an even lower limit than that given above.

6. CONCLUSIONS

From the data employed two distinct populations of spreading fires, both at least approximately normal, have emerged, the faster spreading one having rates of spread an order of magnitude larger than those of the slower.

Only 1 in 100 fires are likely to spread at more than 1.05 m/s (3.46 ft/s) except locally.

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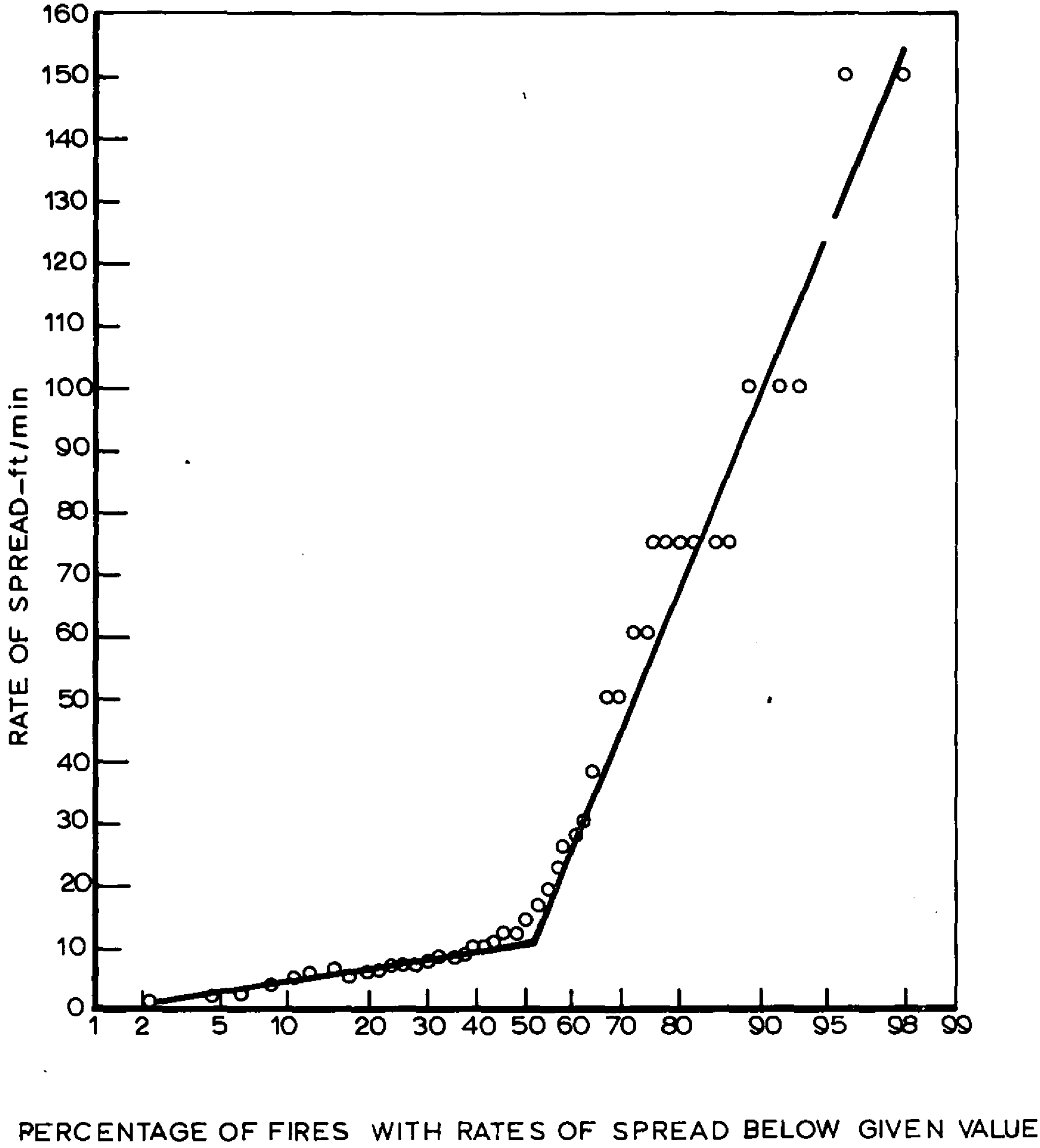

FIG. 1. ALL CONTROLLED FIRE DATA

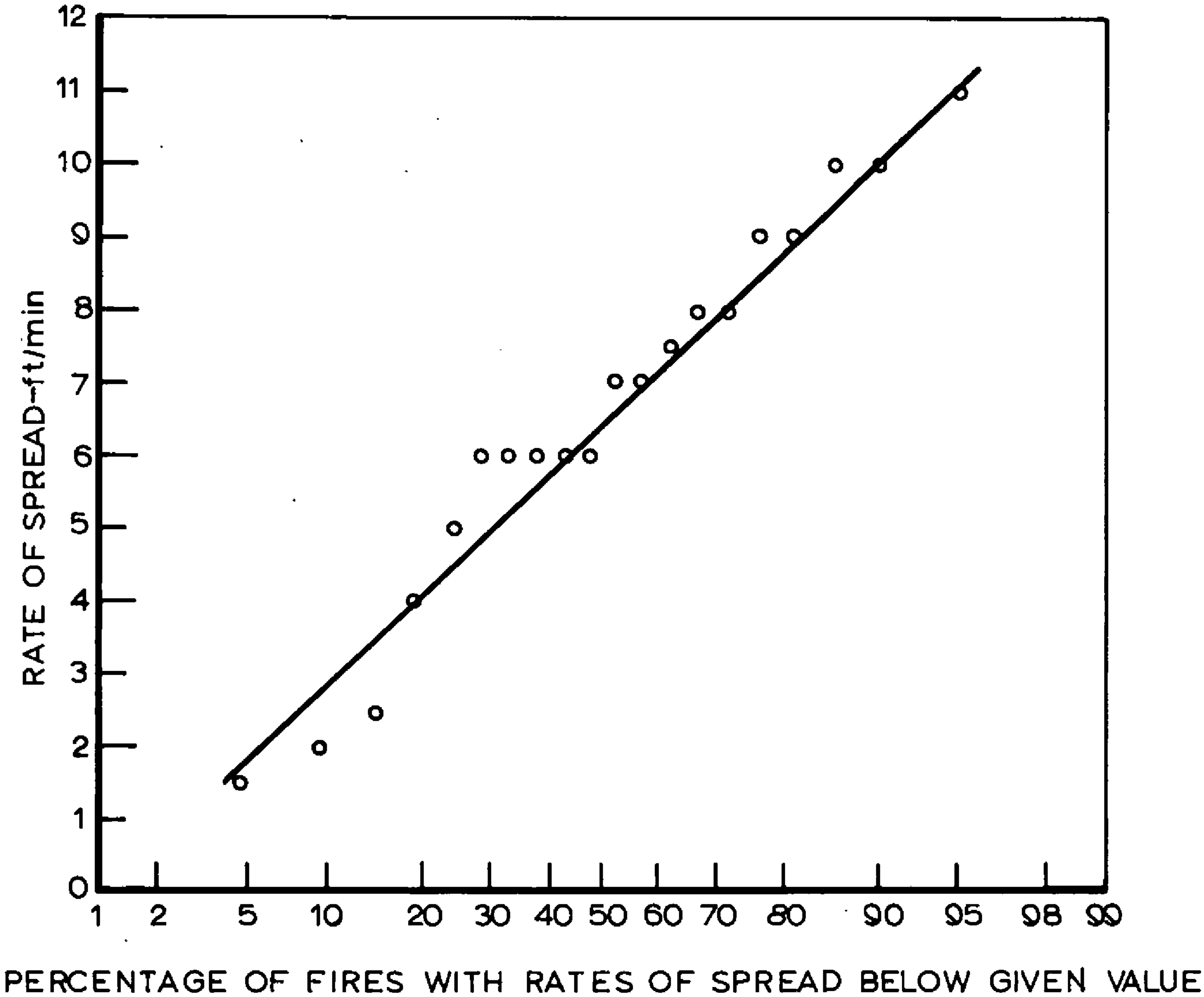

FIG. 2. CONTROLLED FIRE DATA BELOW 11ft/min

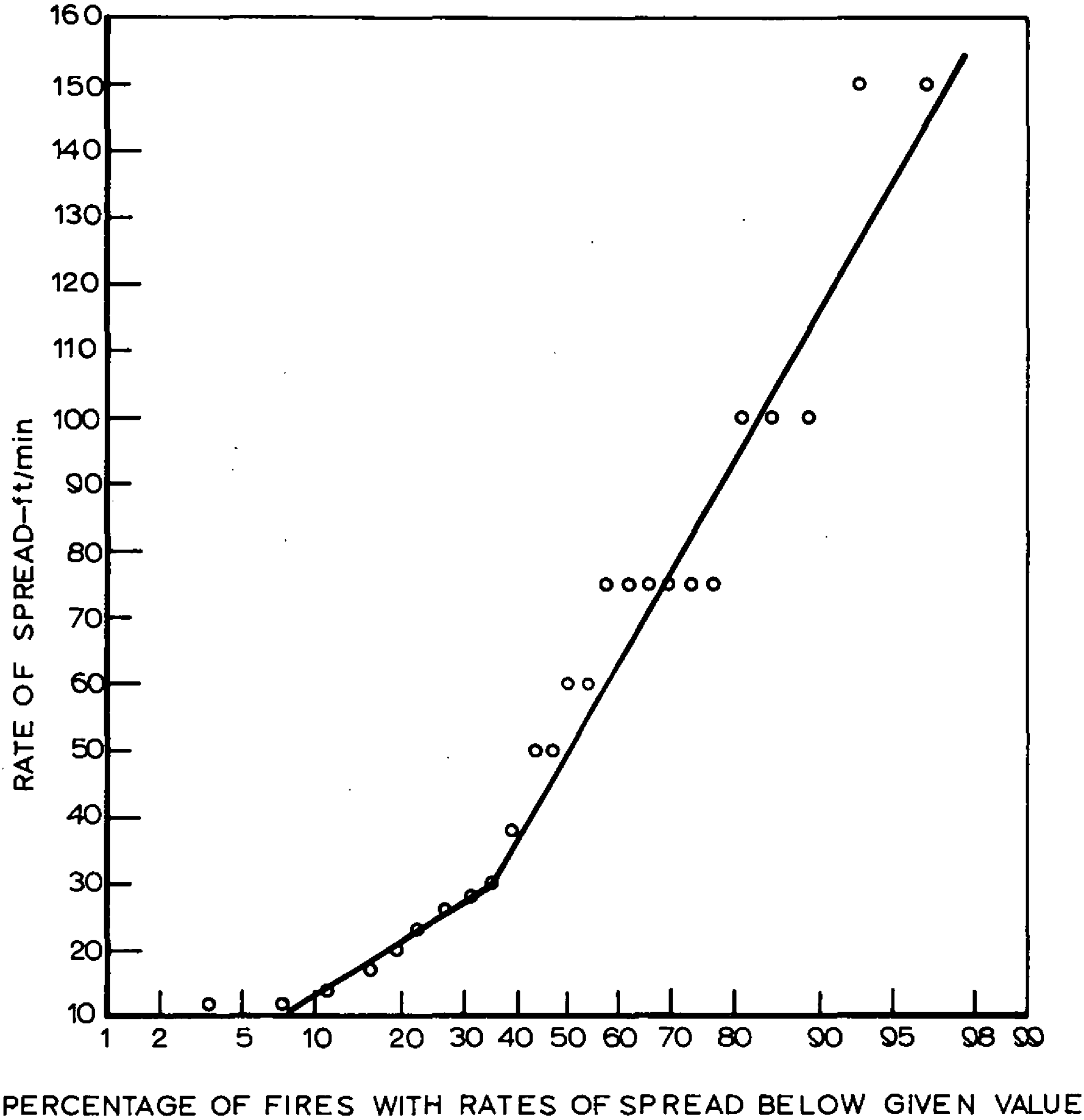

FIG. 3. CONTROLLED FIRE DATA ABOVE 11 ft/min

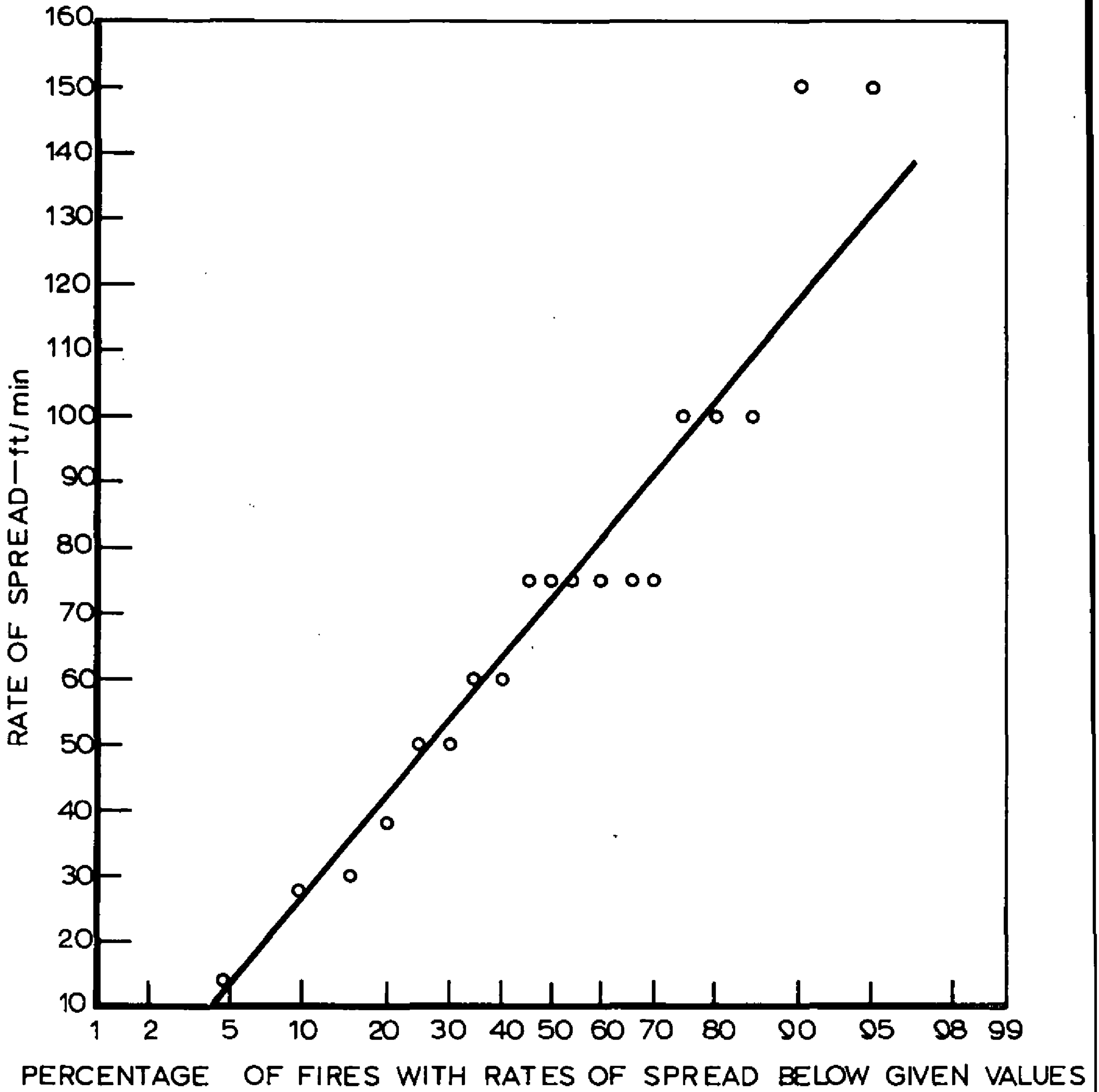

FIG. 4. CONTROLLED FIRE DATA
FINE GRASS / FINE GRASS MIXTURES

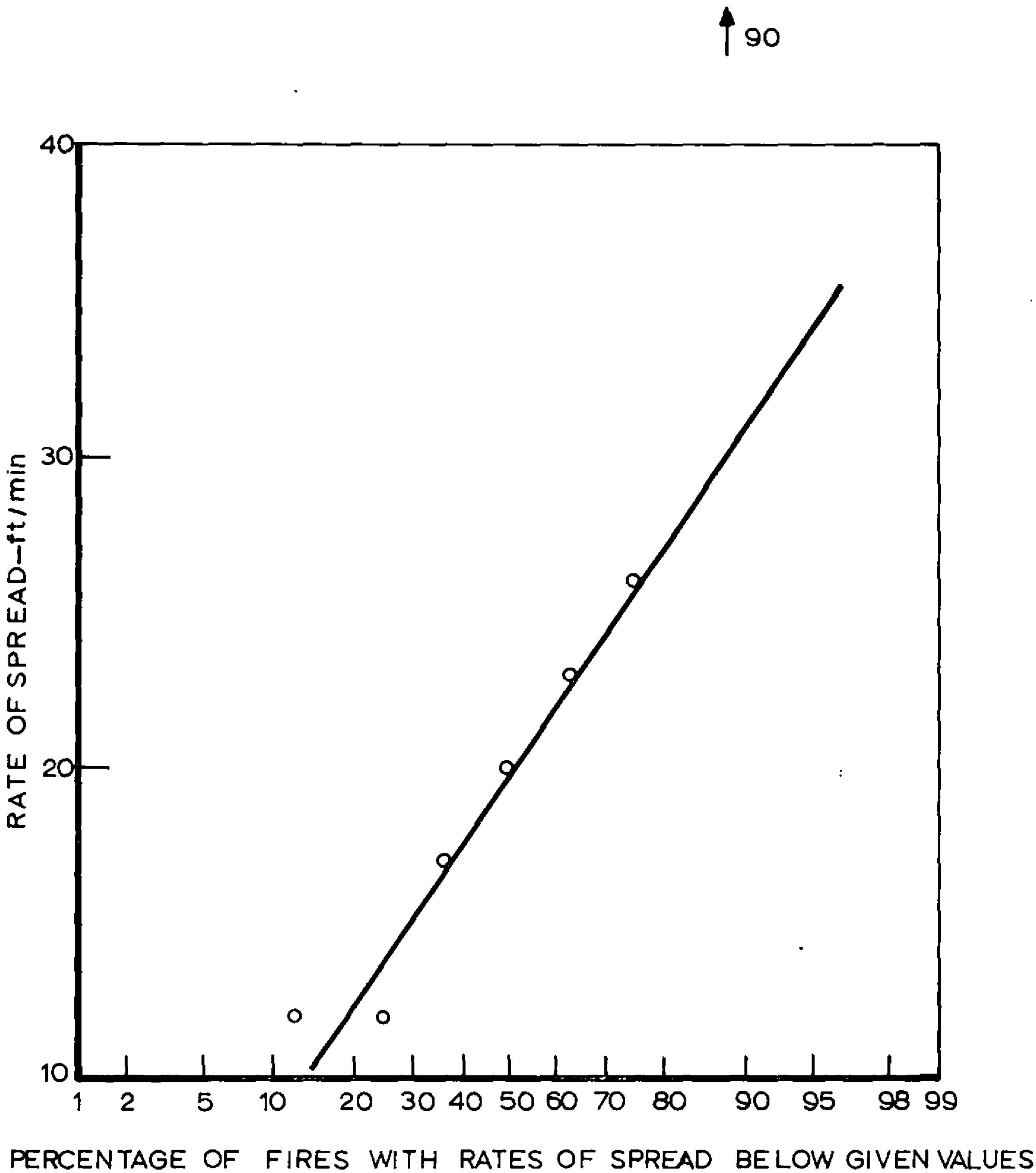

FIG. 5. CONTROLLED FIRE DATA HEATHER

12ft/min AND ABOVE

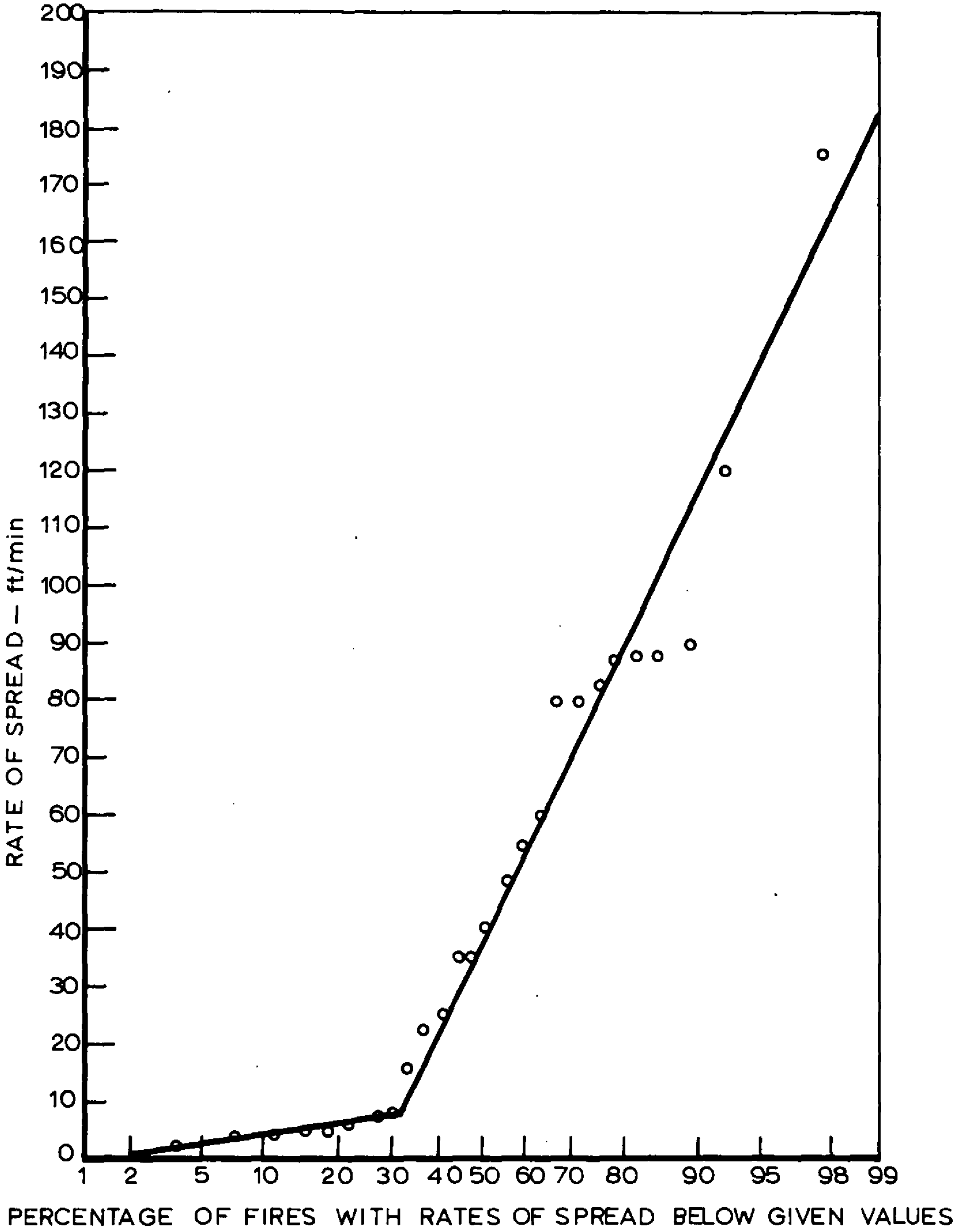

FIG. 6. ALL WILDFIRE DATA

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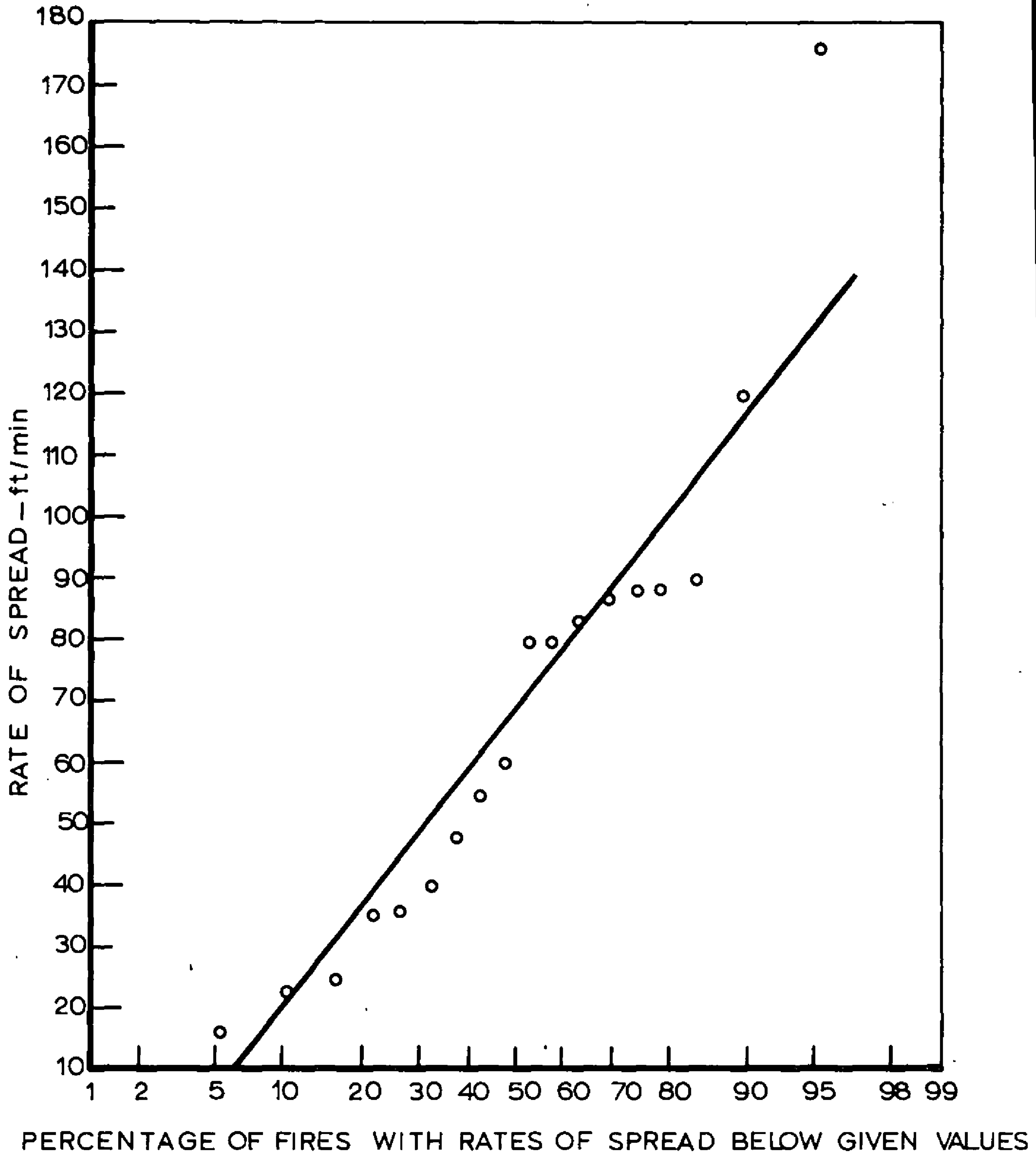

FIG. 7. FAST WILDFIRE DATA

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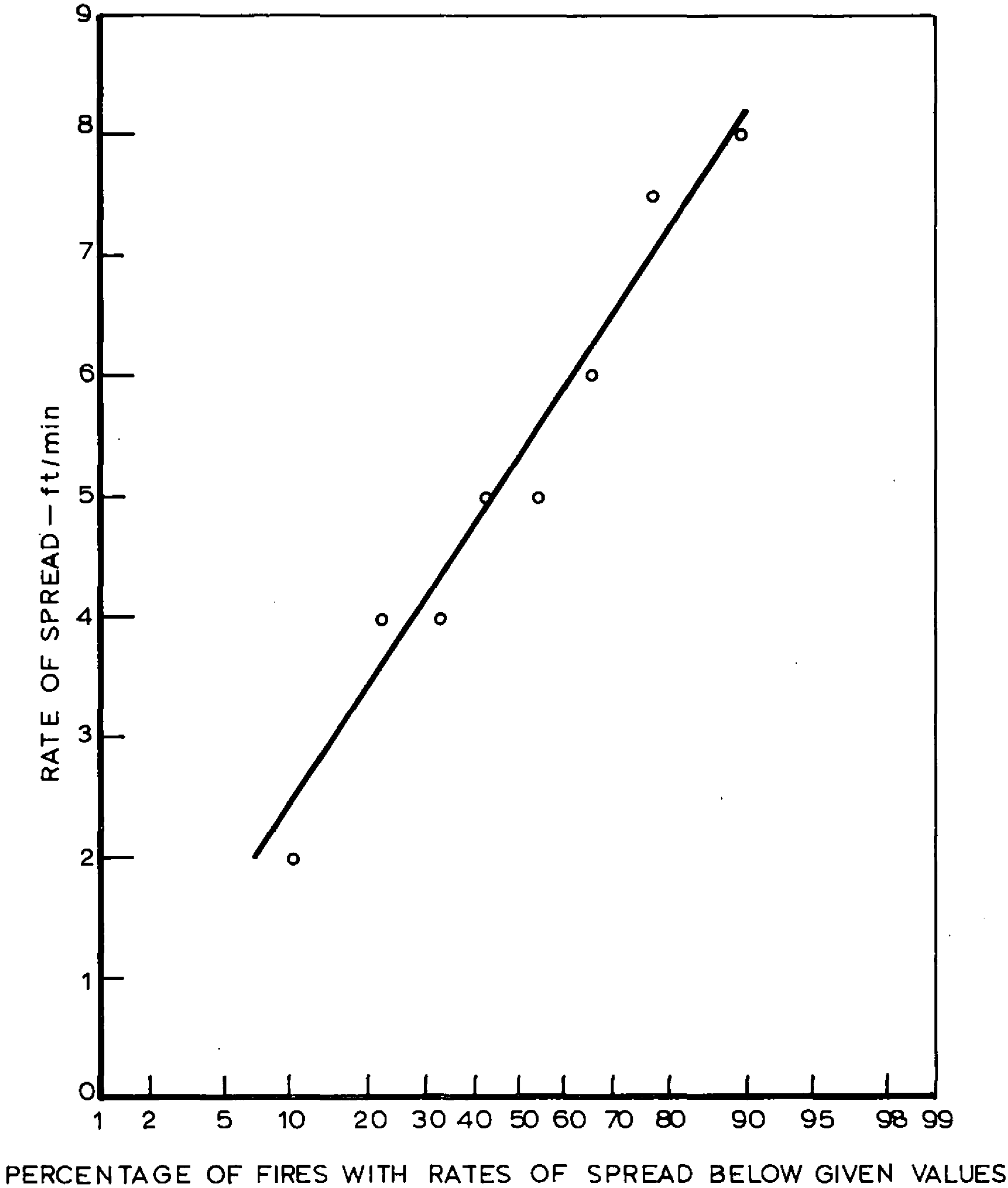

FIG. 8. SLOW WILDFIRE DATA