Forest Research Branch

SOME EFFECTS OF SLOPE ON FIRE CLIMATE

by

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Sommaire et conclusions en français

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ABSTRACT

Variations of fuel moisture and related parameters attributable to degree of slope were studied by establishing fire weather stations on six land surfaces of the same elevation and aspect but varying from 0 to 62 per cent in steepness.

Mean maximum daily temperature was found to be directly related to degree of slope while mean minimum temperature was inversely related to degree of slope on all classes of days. The maximum difference was approximately 4°F for the former and about 5° for the latter.

Afternoon fuel moisture content tended to be from 1 to 2 percentage points less on the steeper slopes.

The conclusion is drawn that degree of slope is a minor factor in microclimate compared to the location of the slope in respect to the surrounding topography.

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by

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INTRODUCTION

Variations of the macroclimate induced by the exposure (aspect and slope) of land surfaces within climatic regimes have been measured in various parts of the world (Geiger 1959). Microclimates attributable to exposure are the result of variations in duration and angle of exposure to direct insolation, and an interaction of the effects of aspect and slope may be present. In mid-latitude arid areas, the effect of aspect is often strikingly portrayed by contrasting vegetation on north and south aspects.

PURPOSE

This study was conducted to determine the climatic effects of variations in slope and the significance of these effects on fuel moisture and on the locating of fire weather recording and research stations. The results will be used to establish guides to determine the degree of slope which can be tolerated when locating fire weather stations for more detailed study of climatic variations resulting from the topography in mountainous terrain.

DESCRIPTION OF AREA

During the summer of 1961, field work was conducted approximately 12 miles northeast of Kamloops near Paul Lake at a latitude of 50° 45′ N and a longitude of 120° 12′ W. The study area is at an altitude of approximately 2200 feet in the transition zone between the grassland and montane vegetational zones, (Rowe 1959) (Figure 1).

The ground cover is predominantly cheat grass, *Bromus* spp., and other annual grasses and forbs with scattered bunch grass, *Agropyron* spp. remnants. The soils of the area are gravelly loams of glacial origin. The climate is classically dry continental, temperature extremes being common throughout the year. Mean annual precipitation at Kamloops is 10.16 inches (Anon. 1959). Approximately 30 per cent of the total annual precipitation occurs during the months of June, July and August as localized thunderstorms.

INSTRUMENTATION AND MEASUREMENTS

To test the hypothesis that degree of slope influences the macroclimate and the subsequent drying of fuels, five slopes having a common aspect and elevation, and a level area were instrumented (Figure 2). The instrumented area on each slope was termed a station, designated by the steepness of the slope in per cent. All stations, including the level station (Station 0) were located at an elevation of about 2200 feet, at the same elevation above the valley floor and on slopes with a general south-westerly aspect (Figure 1).

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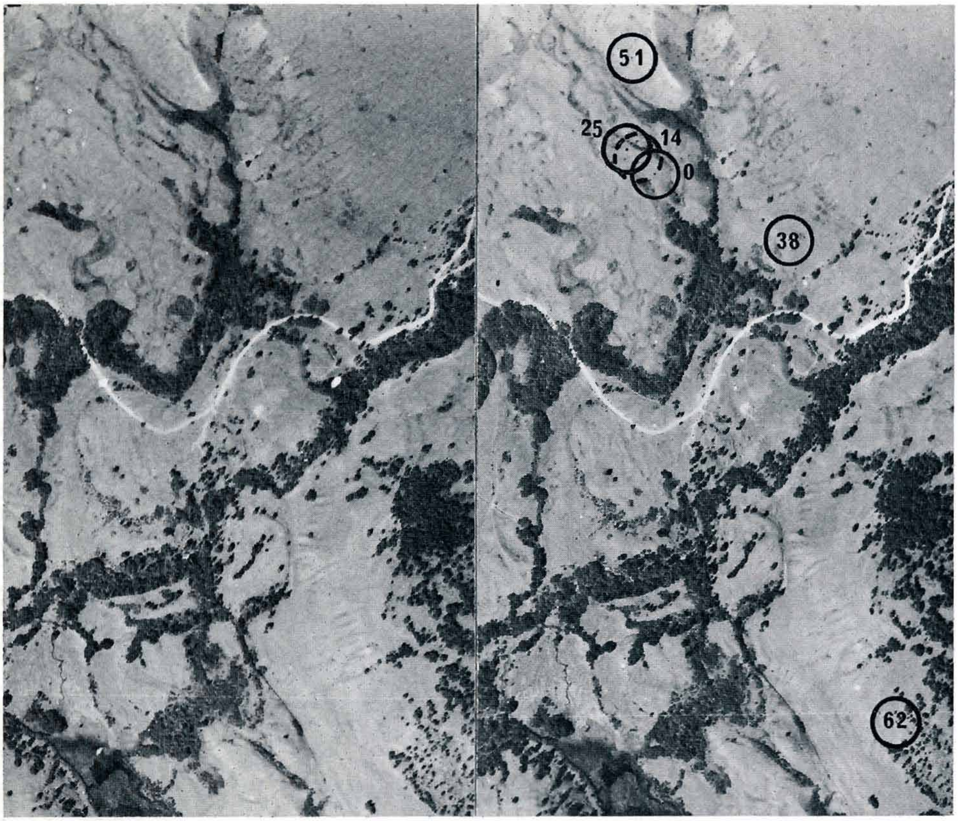

FIGURE 1. Stereogram of study area showing station locations. North is towards the top of the page.

At each station, daily measurements were made of the moisture content of two sizes of fuel moisture indicators at ground level and at one foot above ground; average moisture content of the upper two inches of soil; and temperature and relative humidity at four feet and one foot above ground level. Standard B.C. Forest Service fuel moisture indicator sticks were used to obtain a measure of fuel moisture at the ground surface and at 12 inches above the ground. The sticks were supported by wire racks, the long axes parallel to the contour. Four hundred grams (O.D. weight) of match splints in nylon lined ¼-inch mesh metal baskets, measuring 12 x 12 x 2 inches, were used as indicators of fine fuel moisture content. The effect of wind during weighing was minimized by the use of shelters at each station. To eliminate variations in ground cover, a 1-inch bed of pine needles was distributed under each fuel moisture indicator. A summary of the type of measurements made is given in Table 1.

The moisture content of the top two-inch layer of soil was determined daily following rain. Sampling was discontinued when the day-to-day change in moisture content at Station 0 was less than two percentage points. Tins were used for transporting and processing the soil samples, each being oven-dried for a twenty-four hour period at 212°F to determine its moisture content.

Temperature and relative humidity were recorded at a height of four feet, normal to the slope, by hygrothermographs in single-louvred shelters. A hygro-

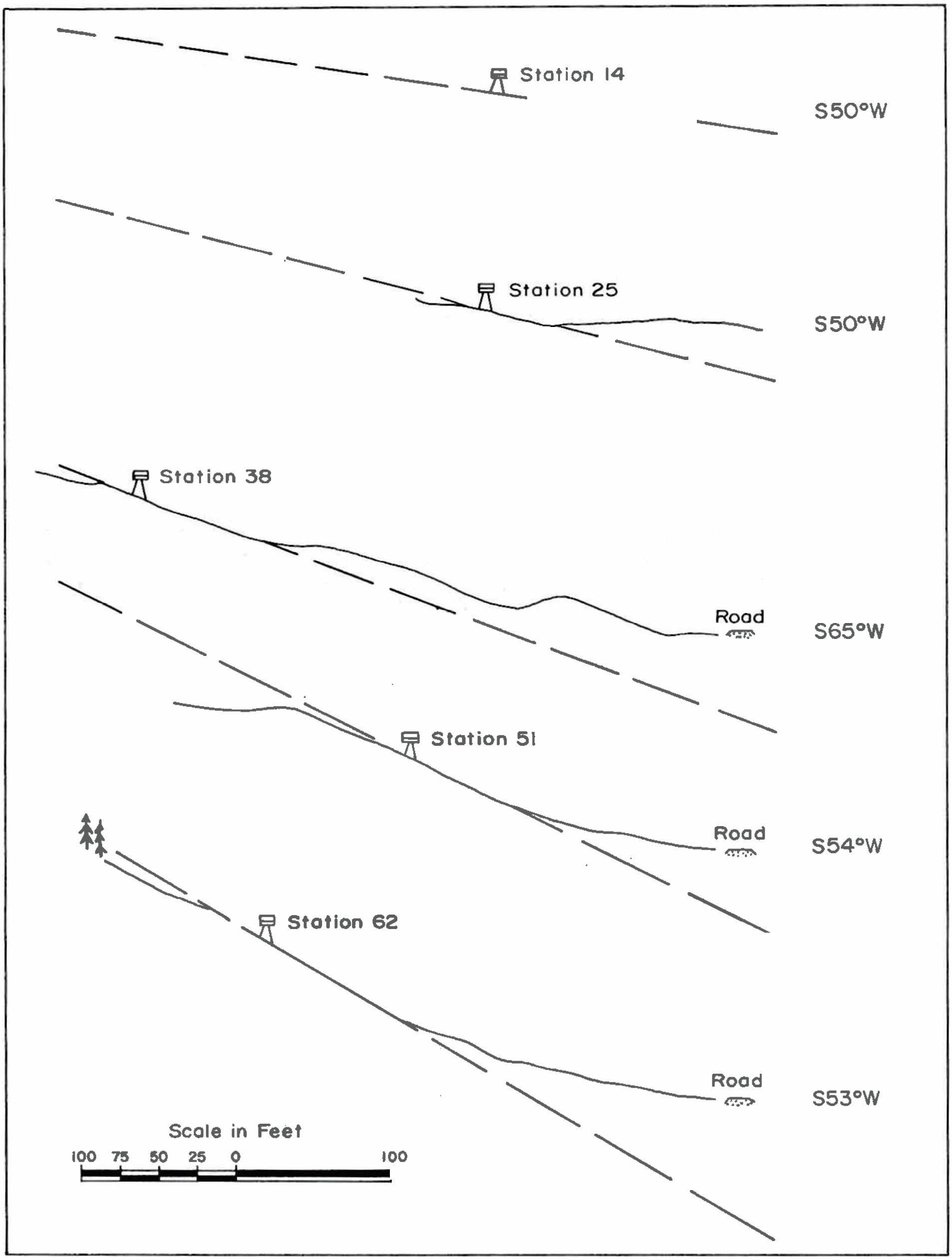

FIGURE 2. Profiles of slopes on which stations were located. The aspect of each slope is indicated to the right of each profile.

thermograph was not available for Station 25. Relative humidity at the four-foot level outside the shelter and at the one-foot level was also measured using a psychrometer.

TABLE 1. FACTORS MEASURED AT FIELD SITES

Measurement	Method	Station					
		0	14	25	38	51	62
Wind at 10 feet (1 mile recording)	Anemovane	x					
Sunshine duration	Campbell-Stokes recorder	x					
Daily precipitation	Rain gauge	x					x
Relative humidity at 4 feet (continuous)	Hygrograph in shelter	x	x		x	x	x
Relative humidity at 4 feet, daily	Psychrometer	x	x	x	x	x	x
Relative humidity at 1 foot, daily	Psychrometer	x	x	x	x	x	x
Temperature at 4 feet, (continuous)	Thermograph in shelter	x	x		x	x	x
Temperature at 4 feet, daily	Psychrometer	x	x	x	x	x	x
Temperature at 1 foot, daily	Psychrometer	x	x	x	x	x	x
Fuel Moisture at 1 foot, daily	B.C.F.S. ½-inch indicator sticks	x	x	x	x	x	x
Fuel moisture at surface	B.C.F.S. ½-inch indicator sticks	x	x	x	x	x	x
Fine fuel moisture at 1 foot, daily	Match splints, 400 gr.	x	x	x	x	x	x
Fine fuel moisture at surface, daily	Match splints, 400 gr.	x	x	x	x	x	x
Soil moisture, top 2″, daily	Oven drying	x	x	x	x	x	x

The instrumentation at Station 0 was similar to that of the slope stations with the addition of measurement of wind direction and velocity at a height of ten feet, duration of bright sun, and precipitation. Wind direction and speed was measured with a Meteorological Service Type B anemograph, duration of bright sunlight by a Campbell-Stokes sunshine recorder and precipitation by standard Meteorological Service rain gauges. Measurements were made at each station at least once a day commencing about the first of July and ending about the middle of September. Although there was some variation, most readings were made between 1400 and 1600 P.S.T.; occasionally readings were taken in both morning and afternoon of the same day.

ANALYSIS OF DATA

Two methods of classifying the type of day were used:

(a) Days were separated into three classes according to the total number of hours of bright sunshine. Class I days were those having more than 9 hours of bright sunshine; class II days with 6 to 9 hours; and class III days with less than six hours. This classification was used for the purpose of comparing daily station temperatures from hygrothermograph records.

(b) In the second classification, days on which the moisture content of the sticks at one foot at Station 0 decreased by at least one percentage point per 24 hours were classed as drying days. The remaining days were classed according to hours of bright sunshine prior to the mean time of afternoon observations. Days having more than six hours of bright sunshine were classed as clear; those with less than six were classed as cloudy. This classification was used in comparing fuel and soil moistures at the various stations.

Tables or graphs were prepared for the following measurements by class of day:

(1) Minimum temperatures
(2) Noon temperatures
(3) Maximum temperatures

(4) Moisture content of half-inch indicator sticks at ground level and at 12″
(5) Moisture content of match splints at ground level and at 12″
(6) Soil moisture
(7) Comparison between morning and afternoon fuel moisture and soil moisture.

Mean Minimum Temperatures

Mean daily minimum temperature for the various stations and classes of days are shown in Figure 3. Values for Stations 0 and 14 are significantly lower than those of the other stations indicating the effect of some influence other than slope. A curve extrapolated from the minimum temperature for Stations 38, 51 and 62, assuming that these stations were unaffected by the same influence, indicates a mean temperature depression of approximately 5°F at Stations 0 and 14. A difference in mean minimum temperature of 2°F between Stations 38 and 62 was found on nights preceding Class I days.

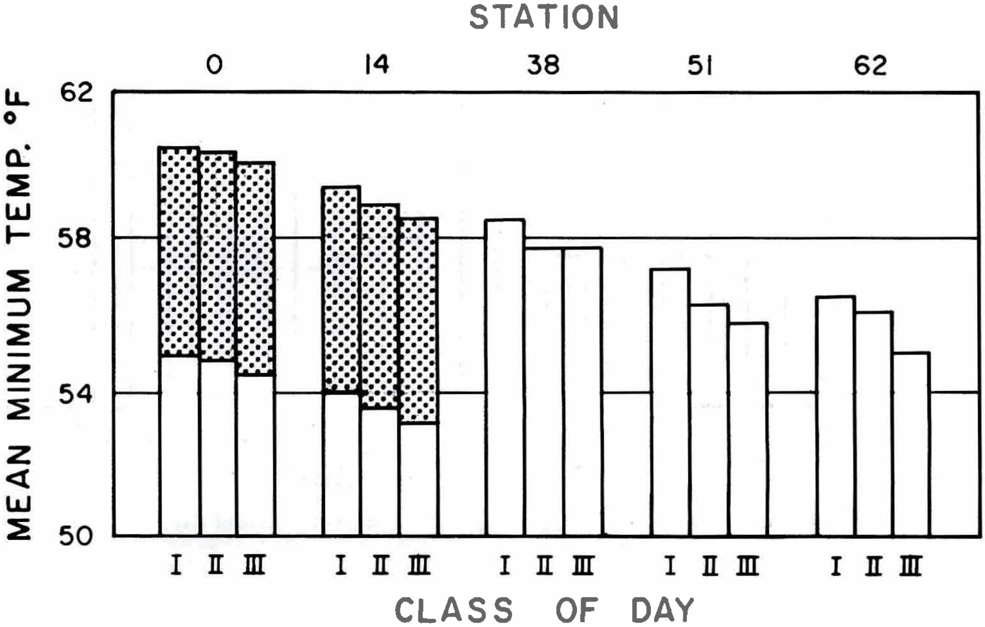

FIGURE 3. Mean minimum temperatures at 5 stations by class of day. (Extrapolated temperatures are shown by the dotted areas.)

Thus, although differences of minimum temperature were found to exist between level and sloped areas, the values obtained here indicate that the location of the area relative to the surrounding topography probably has a much greater effect than degree of slope. It seems probable that these differences are a result of the flow patterns of cold air drainage rather than a difference in radiational emissivity of the land surface.

Mean Noon Temperatures

Figure 4 shows a histogram of the mean noon temperatures on the three classes of days for five stations. Except for Station 62, a general temperature increase occurred as the degree of slope increased on Class I and Class II days. On Class III days a general trend is not evident. The lower temperature on the

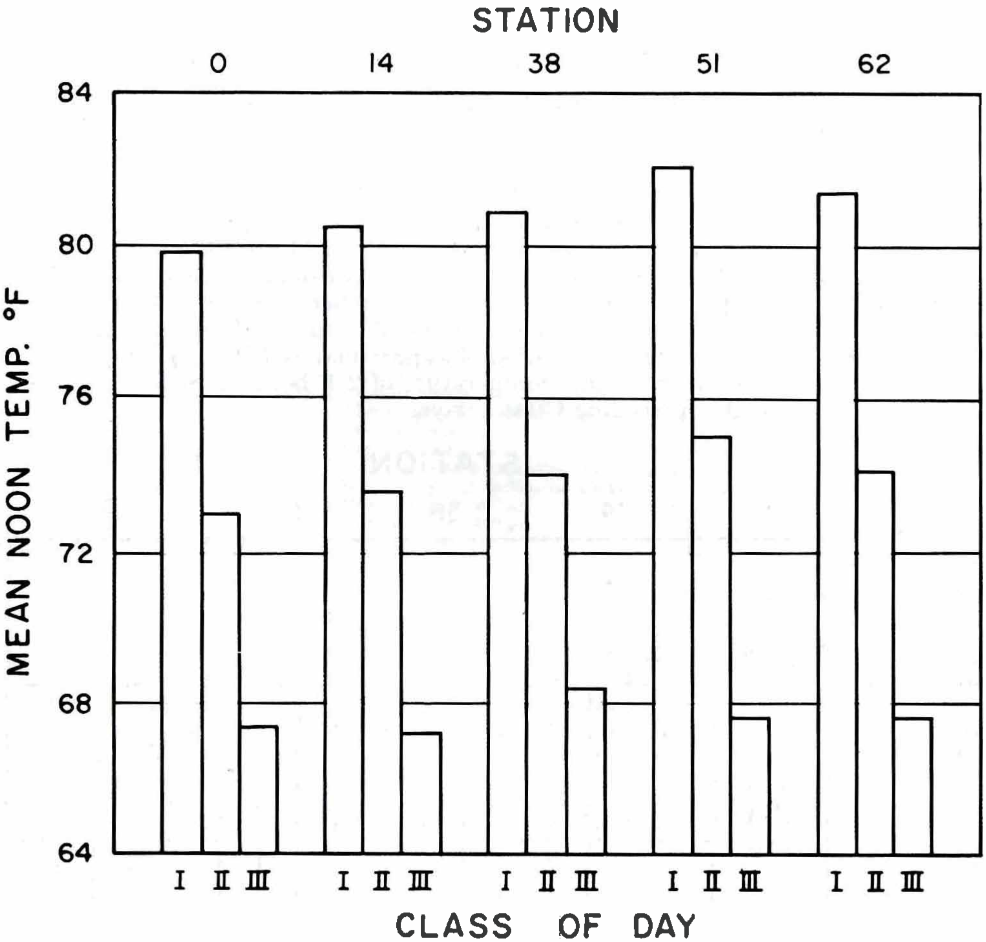

FIGURE 4. Mean noon temperatures at 5 stations by class of day.

steepest slope is likely a result of its being at the least favourable exposure for morning insolation as well as being the coldest slope at the start of the day (Figure 3). According to work done by Kaemfert, and cited by Geiger (1959), at nearly the same latitude, southerly slopes of approximately 60 per cent are subject to the greatest amount of insolation at noon during the summer period. In the morning during the summer, the steeper the southern slope the more time is required for the sun to "move" from its northeastern azimuth to a position high enough to strike the slope. This time delay is increased as the aspect becomes more westerly. Temperature measured at noon showed the least difference with slope of the three daily temperatures.

Mean Maximum Temperatures and Humidity Effect

Mean maximum temperatures were directly related to steepness of slope except for Class II and III days at Station 14 (Figure 5). As would be expected, the mean maximum temperatures showed a greater variation between stations than did the noon temperatures and only slightly less variation than the mean minimum temperatures. Mean differences of less than 4°F were found for Class

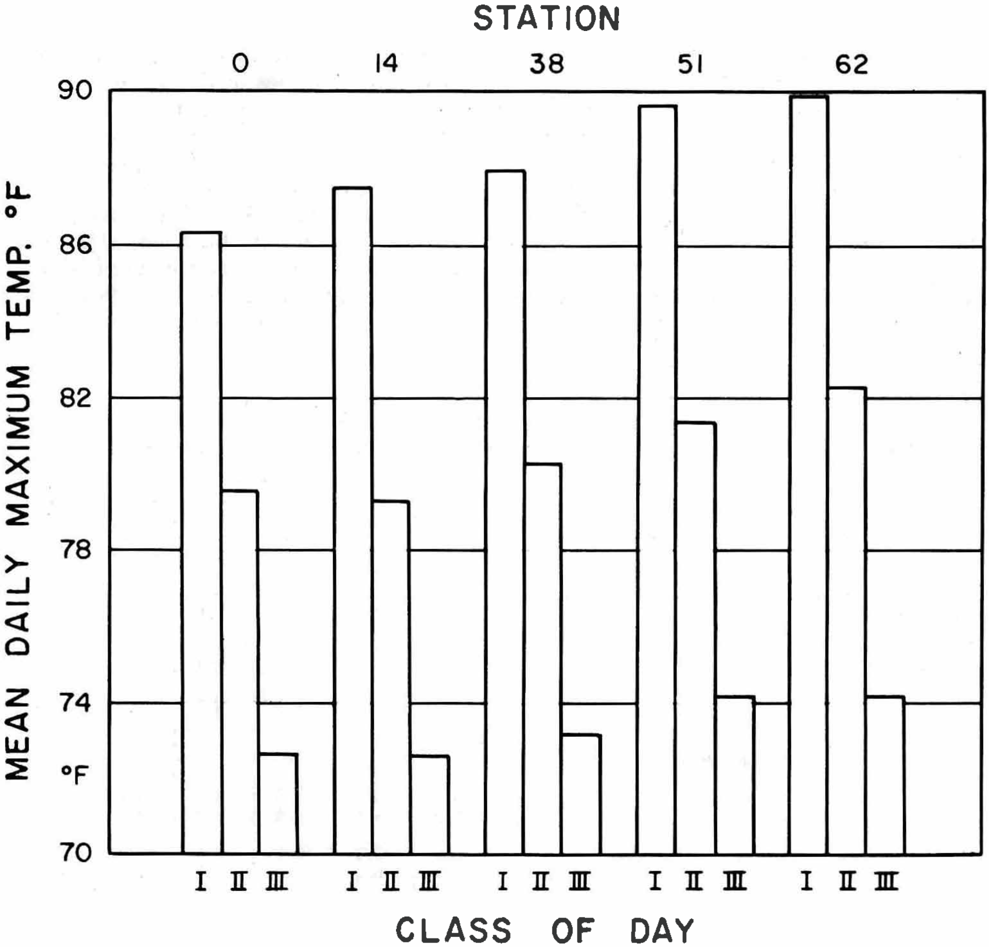

FIGURE 5. Mean daily maximum temperatures from 5 stations according to class of day. Compiled from a total of 54 days as follows: 27 class I, 13 class II, and 14 class III days.

I days, less than 3°F for Class II days and less than 2°F for Class III days. Although these temperature differences may seem significant, a change in relative humidity caused by a change in temperature varies directly as the relative humid- of the air mass. Thus, at very low humidities, when fire conditions are most serious, the differences in relative humidity on varying slopes will be relatively small. To illustrate, assume that an air mass having a temperature of 86°F and a relative humidity of 25 per cent, measured at Station 0, is lying over the study area. The relative humidity at Station 62, where the modified temperature is 90°F, would be 21 per cent, a difference of 4 percentage points. However, if the air mass had a temperature of 86°F and a relative humidity of 10 per cent, the relative humidity at Station 62, where the temperature is 90°F, would be 8.5 per cent, a difference of only 1.5 percentage points. According to equilibrium moisture content tables these differences in relative humidity result in approximately the same amount of change in moisture content of wood. In the first example the moisture content would be reduced from 4.9 to 4.4 per cent and the second from 2.7 to 2.3 per cent. Test fires in standardized fuels have shown that differences of .5 per cent moisture content would have a negligible effect on rate-of-spread (Fons 1946).

Fuel and Soil Moisture Content

The mean moisture content of the sticks and splints at two levels and of the upper two inches of soil were compared for the three classes of days. Data from 20 days were used for clear, 8 for cloudy, and 16 for drying days in the analysis (Table 2). Generally, the differences in moisture content were small. Although the moisture content values were usually lowest on the steepest slopes for all classes of days, differences between the six stations were only one to two percentage points. The extremely low moisture content of the ground level sticks at Station 51 shows that their exposure differed from those at the other stations. Because of moisture on the bottom of the splint trays due to lack of ventilation (it was so pronounced that grass germinated and grew under the baskets in the middle of August) the ground level splints had a higher moisture content than those at 12 inches.

TABLE 2. MOISTURE CONTENT % OF FUEL AND SOIL ON SIX DEGREES OF SLOPE BY THREE TYPES OF DAYS

	Station					
	0	14	25	38	51	62
Clear Days						
Splints at Ground	6.1	5.6	5.5	6.1	5.4	4.7
Splints at 12″	3.8	3.8	3.5	3.6	3.7	3.7
Sticks at Ground	5.1	4.7	4.7	4.6	3.5	5.0
Sticks at 12″	5.7	6.1	6.0	6.4	5.7	6.2
Soil	3.1	2.6	1.9	2.7	1.7	1.8
n = 20						
Cloudy Days						
Splints at Ground	6.0	5.5	5.5	5.6	5.6	6.2
Splints at 12″	6.0	5.4	5.3	5.3	5.2	4.8
Sticks at Ground	5.9	5.2	5.7	5.2	4.3	5.2
Sticks at 12″	6.5	6.1	6.8	6.6	5.9	6.3
Soil	4.0	2.8	2.7	2.9	2.6	3.8
n = 8						
Drying Days						
Splints at Ground	26.9	23.3	23.6	24.7	21.6	17.1
Splints at 12″	12.3	12.4	11.5	12.1	12.6	12.4
Sticks at Ground	10.4	9.8	10.1	9.6	8.6	10.2
Sticks at 12″	10.0	9.9	9.9	10.2	9.7	10.6
Soil	12.2	9.3	8.9	11.0	7.4	11.6
n = 16						

Morning and Afternoon Differences in Fuel and Soil Moisture

A comparison of the difference between morning and afternoon fuel moisture and soil moisture was made for 11 days (Table 3). Generally, afternoon readings were the same at all stations, although slightly drier conditions were indicated on the steeper slopes. The morning reading at Station 0 usually indicated lower levels of fuel and soil moisture than the slope stations. This lower morning reading accounts for the abrupt change in the magnitude of differences between Station 0 and the slope stations (Table 3). The smaller changes between morning and afternoon readings at Station 0 indicate that level areas tend to maintain a moderated drying regime; stronger than that of the slopes in the morning and slightly weaker in the afternoon.

TABLE 3. MORNING AND AFTERNOON MEAN DIFFERENCES IN PER CENT FUEL MOISTURE AND SOIL MOISTURE COMPUTED FROM 11 DAYS' DATA

Moisture Indicator	Station					
	0	14	25	38	51	62
	Per cent					
½" Sticks at 12"	1.6	2.1	2.2	2.4	2.2	2.4
½" Sticks at ground level	2.4	3.4	3.4	4.5	4.8	3.8
Splints at 12"	9.2	9.6	8.8	12.4	9.6	12.2
Splints at ground level	11.8	13.6	13.2	14.3	15.1	14.0
Soil Moisture	1.1	2.6	2.0	2.3	2.2	2.0

SUMMARY AND CONCLUSIONS

Data obtained from six stations located on slopes varying from 0 to 62 per cent on a generally southwest aspect indicate that:

(a) Lower minimum temperatures can be expected as the steepness of the slope increases. A mean temperature decrease of 2°F was obtained on three slopes from 38 to 62 per cent while a difference of 4°F was extrapolated on five slopes from 0 to 62 per cent. Minimum temperatures on nights preceding cloudy days were found to be lower than on nights preceding clear days.

(b) Noon temperatures increased as the degree of slope increased, up to 51 per cent; at 62 per cent they decreased. Differences on cloudy days were negligible.

(c) Daily maximum temperatures varied directly as degree of slope. Maximum temperature on the steepest slope was slightly less than 4°F higher than on the level during sunny days; temperature differences between stations varied inversely with cloudiness.

(d) Although there were indications that a relationship did exist between fuel moisture content and degree of slope, it was not substantiated.

(e) Soil moisture content showed an inverse relationship with degree of slope on clear days.

(f) Morning to afternoon differences of fuel and soil moisture showed little variation between slopes. Those of the level station were somewhat lower, indicating that extremes may occur on slopes but elevated level areas remain comparatively moderate.

Differences in fuel moisture content attributable to degree of slope are small, at least on southern exposures. Differences in temperature with slope found in this study were small and their significance is dependent on the type of measurements to be taken and the accuracy of the instruments used. If temperatures are to be measured with thermometers which are to be read to the nearest degree, only a minimum slope variation should be tolerated. If thermographs are to be used, a slope variation of plus or minus 15 per cent should not result in errors larger than the tolerance of the instrument, although extreme variations in slope should be avoided.

Degree of slope alone has little influence on either fuel moisture or the parameters of this measure selected for study. It seems likely that the location of the slope in respect to surrounding topographic features is of much greater importance. It would seem that topography below slopes would influence daytime variations, while that above slopes would influence nighttime variations.

SOMMAIRE ET CONCLUSIONS

Les données recueillies dans six stations situées sur des pentes dont la déclivité variait de 0 à 62 p. 100, et faisant en général face au sud-ouest, révèlent que:

a) La température minimum tend à baisser en proportion directe de la déclivité de la pente. Une baisse moyenne de 2°F a été observée sur trois pentes dont la déclivité variait de 38 à 62 p. 100, tandis que sur cinq pentes variant de 0 à 62 p. 100, la baisse moyenne de température s'établissait à 4°F. Les températures minima étaient moins élevées durant les nuits qui précédaient des journées nuageuses que durant les nuits qui précédaient des journées claires.

b) La température à midi augmentait selon le degré de déclivité, et ce jusqu'à 51 p. 100; à partir de 62 p. 100 de déclivité, la température commençait à baisser. Par temps nuageux, les différences étaient presque nulles.

c) La température maximum de la journée variait en proportion directe de la déclivité. Par temps ensoleillé, la température maximum sur la pente la plus abrupte était d'un peu moins de 4°F plus élevée qu'en terrain plat; les différences de température d'une station à l'autre variaient en proportion inverse de la concentration de nuages.

d) Bien qu'il doive exister un certain rapport entre la teneur en humidité des matières combustibles et le degré de déclivité, la chose n'a pu être démontrée.

e) Par temps clair, la teneur en humidité du sol était en rapport inverse de la déclivité.

f) Les variations de teneur en humidité des combustibles et du sol, du matin à l'après-midi, étaient presque sans rapport avec la déclivité. En terrain plat, la teneur en humidité était un peu moins élevée, ce qui indique que de fortes variations peuvent se produire sur les pentes, tandis qu'en terrain plat les variations demeurent relativement modérées.

Les variations de teneur en humidité attribuables à la déclivité sont minimes, tout au moins sur les pentes faisant face au sud-ouest. Les variations de température attribuables à la déclivité constatées au cours de la présente étude sont minimes et leur importance varie selon la façon d'enregistrer la température et la précision des instruments utilisés. Si la température est enregistrée à l'aide de thermomètres gradués en degrés, il faut restreindre la tolérance pour les variations de déclivité. Si l'on se sert de thermographes, une variation de la déclivité de l'ordre de quelque 15 p. 100 ne cause pas plus d'erreurs que celles qui seraient attribuables au manque de précision de l'instrument; toutefois, il vaut mieux éviter les cas de forte variation de la déclivité.

La déclivité seule n'a que peu d'effet sur la teneur en humidité des matières combustibles ou sur les paramètres du coefficient d'humidité choisi pour une étude donnée. Il semble probable que l'emplacement de la pente par rapport à la topographie des environs ait beaucoup plus d'importance. Il semble donc que la topographie du terrain situé au bas de la pente influe sur les variations qui se produisent durant la journée, tandis que celle du terrain situé au haut de la pente influe sur les variations qui se produisent durant la nuit.

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