SOLAR RADIATION AND RELATIVE HUMIDITY IN RELATION TO DUFF MOISTURE AND FOREST FIRE HAZARD

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The dependence of forest fire hazard on meteorological conditions is increasingly evident through the work of Plummer (*1*), Hoffman (*2*), Show (*3*), Gisborne (*4*), Stickel (*5*), and others. They have shown that among the various meteorological indices of increasing forest-fire danger a decreasing relative humidity is of large significance.

In all these studies stress is laid upon the gain and loss in the moisture of forest-fire fuels due to the equilibrium relations between them and the moisture in the atmosphere (4: p. 28–34). The source of the energy necessary to vaporize the water when it passes into the atmosphere has not been considered. Gisborne gave data for exposures to different totals of radiation (4: p. 22–35) and remarks that determination of variation in loss of moisture when only the amount of shielding from sunlight is varied would be valuable. But no clear-cut relation between radiant energy and duff moisture-content values was exhibited.

A relation discovered between solar radiation and relative humidity (7) led to a direct experimental investigation of the influence of radiation on the duff moisture of the very kind proposed by Gisborne.

An "open" station with a duff hygrometer was in continuous operation. Two additional plots of duff were covered with bobbinet cloth screens at a height of about 14 inches above the ground. The "2x" screen absorbed about 70 per cent, and passed an average of 30 per cent of the radiation; the "x" screen absorbed about 50 per cent and passed an average of 50 per cent of the radiation. Under each of the screens a duff hygrometer was placed to record the moisture content of the duff. Sets of thermopiles used with a recording galvanometer (6 and 7) integrated the radiation in the intervals between the readings at 8 a. m., 11 a. m., 2 p. m., and 5 p. m. At these hours the duff hygrometers were read, and the relative humidity of the air determined with a sling psychrometer. The height of the screens was sufficient to insure the same relative humidity and wind velocity of the air passing over the three duff sites.

These data for typical series of days are given in Table 1 and graphically in Figure 1. The series starts the third day after a rainfall of 0.96 inch on September 11, 1927. The previous 10 days, September 1 to 11, had been without rain so that the duff moisture in the open had averaged 5 per cent at 2 p. m.; at 2 p. m. on the 12th it was 7 per cent with a relative humidity of 41 per cent, and on the 13th, 10 per cent with a relative humidity of 66 per cent. On the 15th 0.14 inch of rain fell between 7 and 11 a. m.; the duff moisture in the open did not fall below 50 per cent. Between 5 p. m. on the 19th and 8 a. m. on the 20th, 1.27 inches of rain fell, so that under the "2x" cover the moisture content did not go below 50 per cent until 11 o'clock on the 22d. The graph therefore recommences with the 23d.

The data reveal the conditions found to be typical for the whole course of 60 days during which the experiment was continued; namely, that diminution in the radiation intensity incident upon the duff reduces the rate at which the duff moisture content decreases during the day.

By comparison of the relative-humidity values and the intensity in the "open" there is brought out here the relation between radiation intensity and relative humidity, which was discussed at length in a previous paper (7). A study of 313 three-hour records showed that the lower the relative humidity the greater the radiation intensity. It is believed that the screens used in this experiment and cloudiness of the sky produce the same result in slowing the drying out of the duff by a common effect of diminished radiation intensities.

Further analysis presents additional information on the importance of radiation intensity. The variations in the daily march of radiation intensity may be divided into three groups. The typical day is represented by September 14, 24, 25, and 26. On these days the 11 a. m. to 2 p. m. radiation intensity is the greatest, and the 8 a. m. to 11 a. m. and the 2 p. m. to 5 p. m. values of radiation intensity are smaller. The 27th of September was also characterized by a midday maximum, but the radiation intensities were of a different and lower order because of the higher relative humidity. A second group with radiation intensities diminishing through the day is represented by September 16, 18, and 23. The third group with radiation intensity increasing through the day is represented by September 17.

The first group of days with a midday maximum of radiation intensity shows a minimum duff moisture at 2 p. m. As the radiation intensity decreases in the afternoon, the duff moisture increases.

On the 16th, the gradually decreasing radiation started from an extraordinarily high 8 a. m. to 11 a. m. radiation intensity, with an 11 a. m. to 2 p. m. intensity almost as great. September 16 also shows minimum duff moisture at 2 p. m. On the other days there was either an increase of duff moisture as on the 18th, or a small decrease of duff moisture as on the 23d.

On the 17th there was a relative humidity march as on the typical day with a minimum relative humidity at noon. But because of an increasing radiation intensity, the duff moisture drops continuously until 5 p. m.

For the understanding of this phenomenon it will be necessary to consider not only the moisture outgo but the moisture income of the materials in the fuel horizons. Gisborne (4: p. 22) classified three sites as moist, medium, and dry. From the context it is evident that he was considering the conditions of exposure and evaporation rate, in addition to any differences in ground water movements and supply. For clarification of the research on forest fuel relationships, it will be important to classify sites solely on the rates at which they supply water to the fuel horizons.

In view of our experiments, and certain experiments cited by Stockbridge (8), a logical inference is to consider the duff as a level in which the water vapor is condensed from the upward-moving soil air. The small amount of energy thus liberated tends to raise the temperature of the duff but is radiated away into space. With an input of radiation at a given constant value, the duff moisture received from lower soil horizon is evaporated about as fast as it is condensed, and the equilibrium of duff moisture content maintained at a low value. If the radiation intensity is increased, and the duff moisture income is unchanged, the rate of evaporation is increased, with the result that a lower duff moisture equilibrium is reached. A decrease in radiation intensity diminishes the rates of evaporation, and a higher duff moisture equilibrium is maintained. In a like manner, any alteration in the rate of moisture supply from the lower soil horizons will, if the radiation intensity is unchanged, result in a new equilibrium for the duff moisture content. Evidence for this is obtained in a comparison of the duff moistures for three days, September 24, 25, and 26. No rain had fallen since the 20th, and since that time the soil had become progressively drier. The constant diminution in the rate of water supply to the duff horizon is reflected in the daily drying curve. The march of the relative humidity curves and the totals of radiations for the same hours of the three days are strikingly similar. Yet on each succeeding day the fuel material shows an earlier desiccation although the equilibrium values are about the same. The difference between the moisture contents of the duff in the open on the 25th and 26th, 30 as against 36 per cent respectively, is due to the smaller radiation intensity before 8 a. m. on the 26th. From dawn to 8 a. m. on the 25th the total radiation in the open was 61 gr.-cal per sq. cm., on the 26th it was 50 gr.-cal per sq. cm. for the same period. When compared with the three preceding days the march of the drying curve of the duff on the 27th is exceedingly instructive. Since there has been no rainfall the different values of radiation intensity alone must be responsible for the difference in moisture contents. The rate of water supply from the soil on the 27th is apparently about the same as on the 17th. With a radiation intensity in the open on the 27th very much like that under the "x" canopy on the 17th we find that the 2 p. m. readings of duff moisture are very much alike, 18 per cent and 21 per cent respectively. Under the canopies the radiation intensities were not sufficient to reduce the equilibrium moisture contents below 50 per cent.

TABLE I.—*September, 1927*

	11	12	13	14			15	16			17			18		
	Daily total	Daily total	Daily total	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	Daily total	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.
Radiation, gm.-cal. cm. 2 — 2x [1]				45	45	23		63	68	40	18	30	46	57	41	1
Radiation, gm.-cal. cm. 2 — X				63	88	75		100	93	75	26	37	49	82	52	2
No shade	248	727	240	124	175	150	347	200	187	151	53	75	98	164	104	4

	2 p. m.	2 p. m.	2 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	2 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.
Relative humidity, per cent	83	41	66	91	53	62	79	68	74	56	48	66	88	79	69	87	86	56	70	88
Duff moisture, per cent — 2x			24	50	31	21	25	50	50	26	17	22	50	50	35	29	50	26	25	36
Duff moisture, per cent — X			18	50	21	15	17	50	50	20	12	12	50	38	21	15	50	18	17	27
No shade	50	7	10	50	10	8	10	50	50	13	6	8	35	22	12	10	36	8	9	14
Duff temperature, °F — 2x			67	60	71	70	64	67	66	68	72	69	58	63	68	67	[2] 80	75	69	66
Duff temperature, °F — X			65	62	78	76	67	68	61	73	79	79	61	67	74	71	67	82	72	68
No shade	76	116	84	68	102	94	71	94	64	111	118	75	66	76	96	75	72	115	78	71
Vapor pressure inches hg	0.536	0.277	0.417	0.402	0.334	0.417	0.432	0.432	0.334	0.334	0.347	0.387	0.402	0.432	0.448	0.517	0.448	0.465	0.499	0.575
Rain, inches	0.96							0.14												

	19	20	21	22	23			24			25			26			27		
	Daily total	Daily total	Daily total	Daily total	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.	8–11 a. m.	11 a. m.–2 p. m.	2–5 p. m.
Radiation, gm. cal.-cm. 2 — 2x [1]					45	40	10	46	58	20	48	55	20	47	56	19	13	12	8
Radiation, gm. cal.-cm. 2 — X					75	56	20	78	90	72	72	85	52	72	84	52	16	20	10
No shade	58	536	448	423	151	113	40	154	180	145	145	171	109	143	169	105	32	41	11

	2 p. m.	2 p. m.	2 p. m.	2 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.	8 a. m.	11 a. m.	2 p. m.	5 p. m.
Relative humidity, per cent	99	45	53	54	79	55	51	79	73	55	43	76	76	53	53	66	78	51	42	79	94	85	79	81
Duff moisture, per cent — 2x	50	50	50	37	50	50	33	41	50	50	26	28	50	36	25	29	50	33	24	29	50	50	50	50
Duff moisture, per cent — X	50	50	31	17	50	23	18	25	50	25	15	16	50	23	16	18	50	18	14	17	50	50	50	50
No shade	50	23	7	6	34	9	8	11	34	9	5	7	30	8	6	8	36	6	6	8	35	29	18	18
Duff temperature, °F. — 2x	58	66	66	62	55	64	60	56	54	63	64	58	54	66	69	61	58	71	72	62	53	54	56	54
Duff temperature, °F. — X	59	70	71	67	58	76	63	58	58	74	75	66	58	78	78	65	63	82	81	68	56	58	61	56
No shade	58	103	102	84	59	105	83	59	62	104	107	71	61	108	110	66	60	116	114	66	58	67	73	57
Vapor pressure, inches hg	0.417	0.310	0.360	0.322	0.334	0.310	0.298	0.347	0.310	0.310	0.277	0.334	0.322	0.360	0.417	0.373	0.387	0.417	0.373	0.432	0.387	0.347	0.347	0.310
Rain, inches	0.93	0.34																						

[1] The solar radiation intensities under the X canopy are taken to be equal to 50 per cent of the intensity in the open and are therefore only approximate figures. This transmission value of 50 per cent was determined by discontinuous observations during the period given here, and by continuous observations made before and after the dates cited.
[2] Low altitude sun underneath canopy on thermometer.

These experiments, by direct evidence, support the assertion of Lamb (9) that quick regrowth is an important factor in reducing fire hazard on cut-over areas. The importance of such growth is shown to be in its shading effect. Any interference with wind must be of secondary importance.

The complementary effects of leaves and relative humidity are also significant in studying the seasonal change in fire hazard. In southern New England there is a period of average low relative humidity before the leaves develop on the broad-leaf trees. High radiation intensities are observed, and the fire hazard is the greatest of any time in the year. After the appearance of the green leaves the fire hazard diminishes; with the summer rise in relative humidity a further decrease in forest fire hazard results.

For the prediction of fire hazard the relations discovered between relative humidity, solar radiation intensity, cloudiness, and forest-fire hazard suggest the importance of a cloud "weather eye" to patrolmen. By estimation of the cloudiness, the probable hazard can be estimated. By summation of the average cloudiness since the last rainfall a better estimate of its effect on reducing the fire hazard is probable. The mean cloudiness of a given region will aid in relating the hazard in that region as compared with other regions. Similarly, the amount of given cover on a cut-over area will be an important criterion of the hazard it presents.

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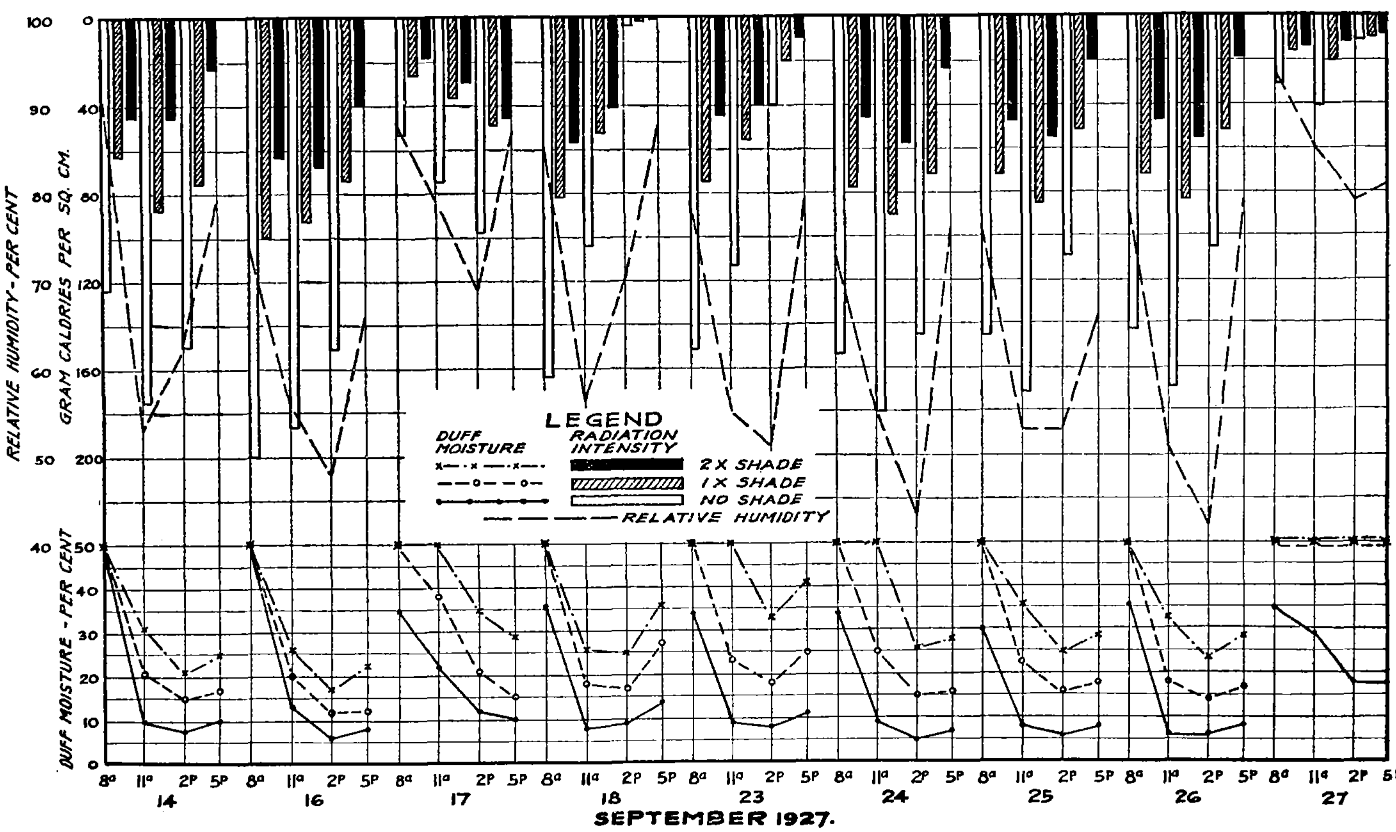
FIGURE I.



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DURATION OF RAINFALL AT HAVRE, MONTANA

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[Weather Bureau Office, Havre, Mont., October 23, 1929]

As the duration of precipitation in various parts of the United States is of much interest to forecasters, aviators, farmers, and business men in general, and as information of the kind so far published is for stations in the Atlantic States, it seemed desirable to prepare the data for a station in the semiarid plains region of the far Northwest.

The duration of precipitation for each hour during the 10-year period 1919–1928 was compiled for Havre, Mont., and entered on suitable forms. One form holds a month's record. All beginnings and endings of precipitation were considered and all intervals between rains were eliminated. The total for each day in hours and tenths were counted. Then the monthly totals were computed. Two compilations were made. The first, Table No. 1, includes every occurrence of precipitation recorded on Form 1014; the second, Table No. 2, includes only the hours in which 0.01 inch or more was recorded.

During the winter season in this section from November 1 to April 1, practically all of the precipitation occurs in the form of snow, and automatic registration is impracticable. Since the winter 1926–27 the observer has estimated the hourly amounts of snow as it fell during the awake hours. Previous to that time the hourly amounts, for this paper, were estimated as well as possible from the beginnings and endings and the 12-hour amounts. There are many times during zero weather in winter