COMBINED EFFECT OF SUN AND WIND ON SURFACE TEMPERATURE OF LITTER

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In forest fire research, the surface temperature of litter in the sun is important because of its effects on the drying rate of moist litter and the ensuing equilibrium moisture content (EMC). Temperature changes during drying are complicated by the cooling effect of evaporation, but surface temperature is easier to study after active drying has ceased. Because the absolute humidity is then about the same near the surface as it is some distance above, the relative humidity at the surface, and consequently the EMC, are both lower than in the shade. Wind also enters the picture, and must be considered in combination with sun. This article reports a laboratory attempt to measure the combined effects of sun and wind on surface temperature, and to test the form that a predictive equation should take. The general approach was suggested by some previous research on this question, which is first described below.

Byram and Jemison (1943), working with hardwood litter in North Carolina, deduced and tested this expression:

$$T_s - T_a = \frac{I}{aV + b} \qquad (1)$$

where T_s is surface temperature , °F

T_a is air temperature , °F

I is radiation intensity , cal cm^{-2} min^{-1}

V is wind speed , mph , and

a and b are constants for a given surface. In their work a was 0.015 and b was 0.026. The equation is based on the fact that for surface litter at thermal equilibrium rate of heat loss must equal rate of heat gain, and on the assumption that rate of loss is proportional to wind speed and to temperature difference between surface and air. The equation illustrates two features of the joint effect of sun and wind on surface temperature:

1) When $I = 0$, the $T_s = T_a$. Wind thus has no effect on surface temperature in the absence of radiation.

2) When $I > 0$, then T_s increases as V decreases. The surface temperature is thus highest when the surface is exposed to full sunlight in still air.

Samples of air-dry litter in plastic boxes ($4\frac{1}{2} \times 4\frac{1}{2} \times 1\frac{1}{4}$ inches) were exposed to an overhead bank of 150-watt floodlamps that could be raised or lowered to vary radiant intensity. Temperature was measured with 24-gauge copper-constantan thermocouples $\frac{1}{4}$ inch below the apparent litter surface. Wind was produced by a fan blowing across a smooth bench flush with the litter surface. By moving the fan wind speeds up to 6 mph were produced. Wind speed was measured 1 inch above the surface with an Alnor Velometer (Illinois Testing Laboratories, Chicago), an instrument using the principle of pressure difference. Radiant intensity was adjusted with the help of an actinograph.

The first tests were run with jack pine and trembling aspen litter at a radiant intensity of 1.5 cal cm^{-2} min^{-1}, about equal to full summer sunlight. Two runs with four samples and ten different wind speeds were carried out with each species. A further series of temperatures were taken in four jack pine samples for which the radiant intensity was set in turn at 0.5, 1.0, 1.5, and 2.0 cal cm^{-2} min^{-1}.

The results were plotted as temperature rise ($T_s - T_a$) against wind speed V for various levels of radiant intensity I. All temperature readings were grouped in classes of wind speed and only these averages are shown.

Figure 1 contains the separate results for jack pine and trembling aspen at 1.5 cal cm^{-2} min^{-1}, along with Byram and Jemison's curve. Similar curves were plotted for the set of tests at different values of I, and then replotted as temperature rise versus radiant intensity for four different wind speeds.

The effect of wind speed on temperature rise is illustrated in Figure 1. When these curves are replotted as the inverse of $T_s - T_a$ against V, Byram and Jemison's curve is a straight line, but the others are not. However, the jack pine and aspen data are remarkably straight on semi-log paper (Figure 2), suggesting a relation of the form:

$$T_s - T_a = R_o e^{-kV} \qquad (2)$$

where R_o is temperature rise at zero wind

e is base of natural logarithms, and

k is a constant.

The effect of radiation on temperature rise is illustrated in Figure 3. Over a wide range of wind speed, $T_s - T_a$ is apparently proportional to radiant intensity, and the lines converge fairly well at I = o. At constant wind, then

$$T_s - T_a = R_1 I , \qquad (3)$$

where R_1 is temperature rise at 1 cal cm^{-2} min^{-1}. To state the joint effects of sun and wind on surface litter temperature, expressions (2) and (3) can be combined to give

$$T_s - T_a = a\, I\, e^{-kV} , \qquad (4)$$

where a is a constant representing temperature rise at zero wind and 1 cal cm^{-2} min^{-1}. In this experiment the constants were as follows:

For jack pine, a = 44 , k = 0.10.

For trembling aspen, a = 35 , k = 0.10.

These results are open to question on several counts: small sample area, difference in spectrum between sun and lamps, and difficulty of maintaining steady wind speeds. Higher temperatures were observed in jack pine than in aspen, possibly because the thermocouple was not perfectly shielded from direct radiation; in the aspen tests it was simply placed under the uppermost leaf. Nevertheless the curves suggest a logical pattern similar to that obtained by Byram and Jemison, although of a slightly different mathematical form.

To apply these results to a specific outdoor situation, some field work would be required, especially to make use of wind speed at some standard height above ground rather than 1 inch. Either form of the general concept, Byram and Jemison's (expression 1) or the present result (expression 4), might be found to apply.

Reference

Byram, G.M., and G.M. Jemison - 1943. Solar radiation and forest fuel moisture. Journal of Agric. Research 67(4):149-176.

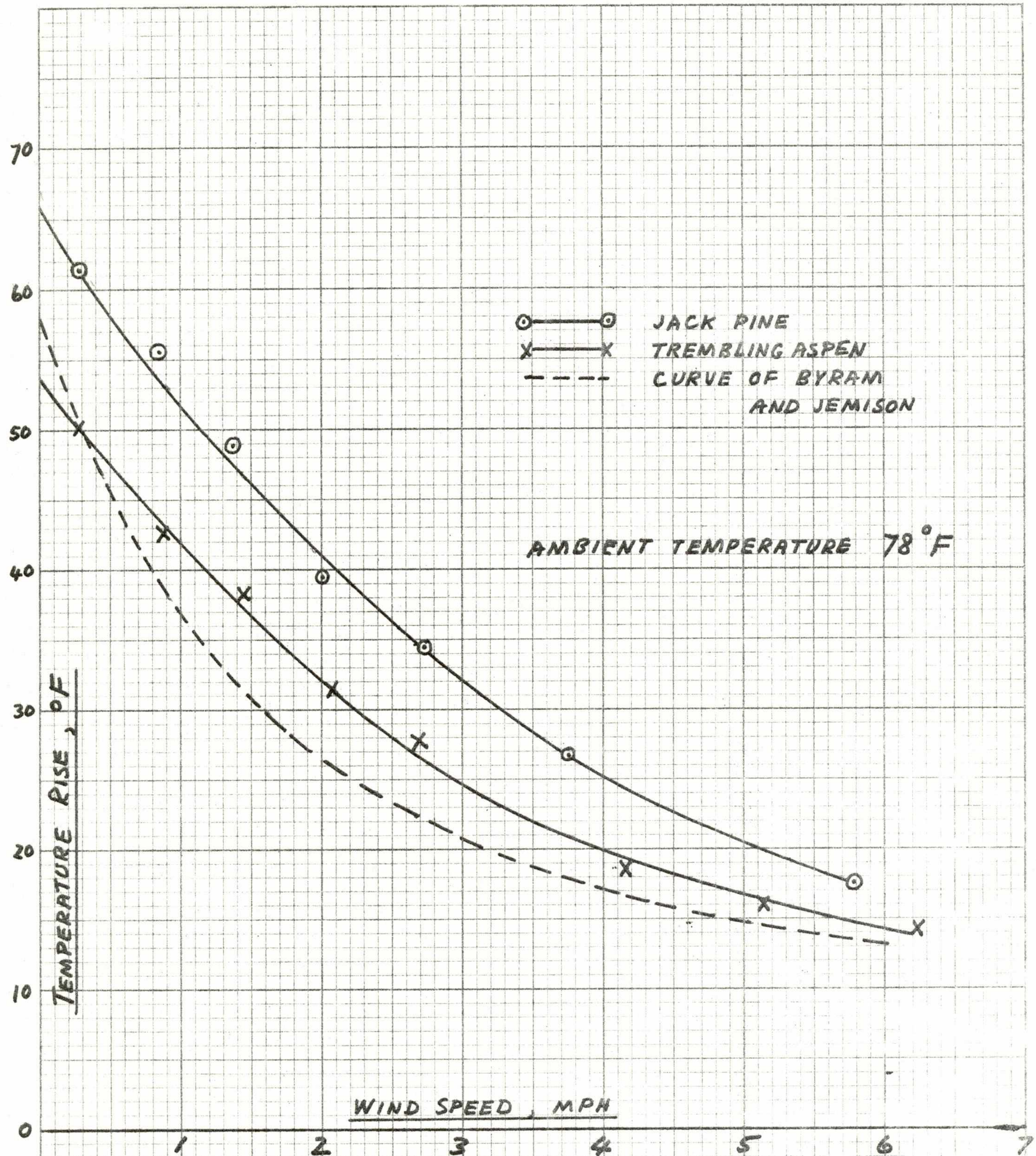

FIGURE 1. Effect of wind on the surface temperature of litter at constant radiation of 1.5 cal cm^{-2} min^{-1}.

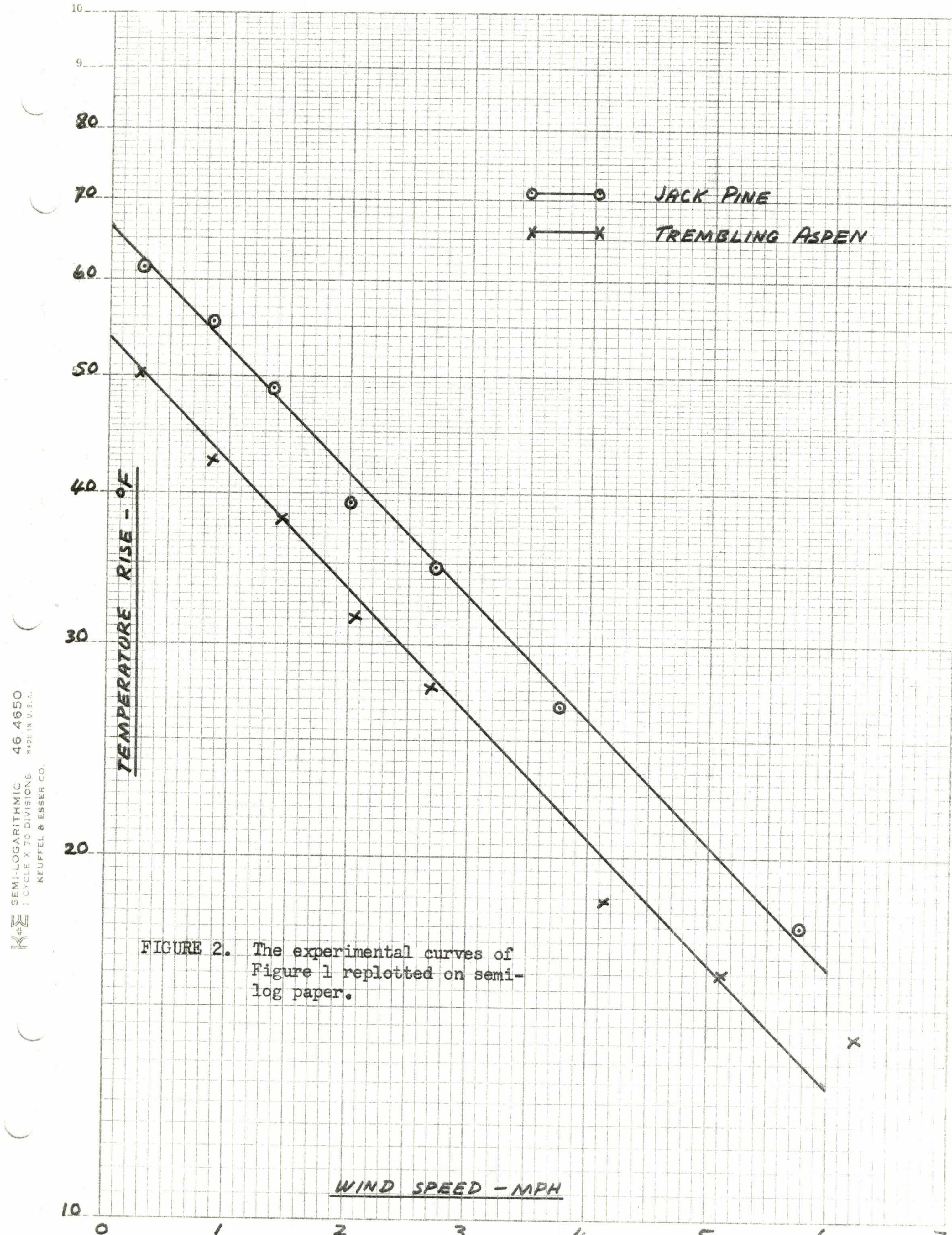

FIGURE 2. The experimental curves of Figure 1 replotted on semi-log paper.

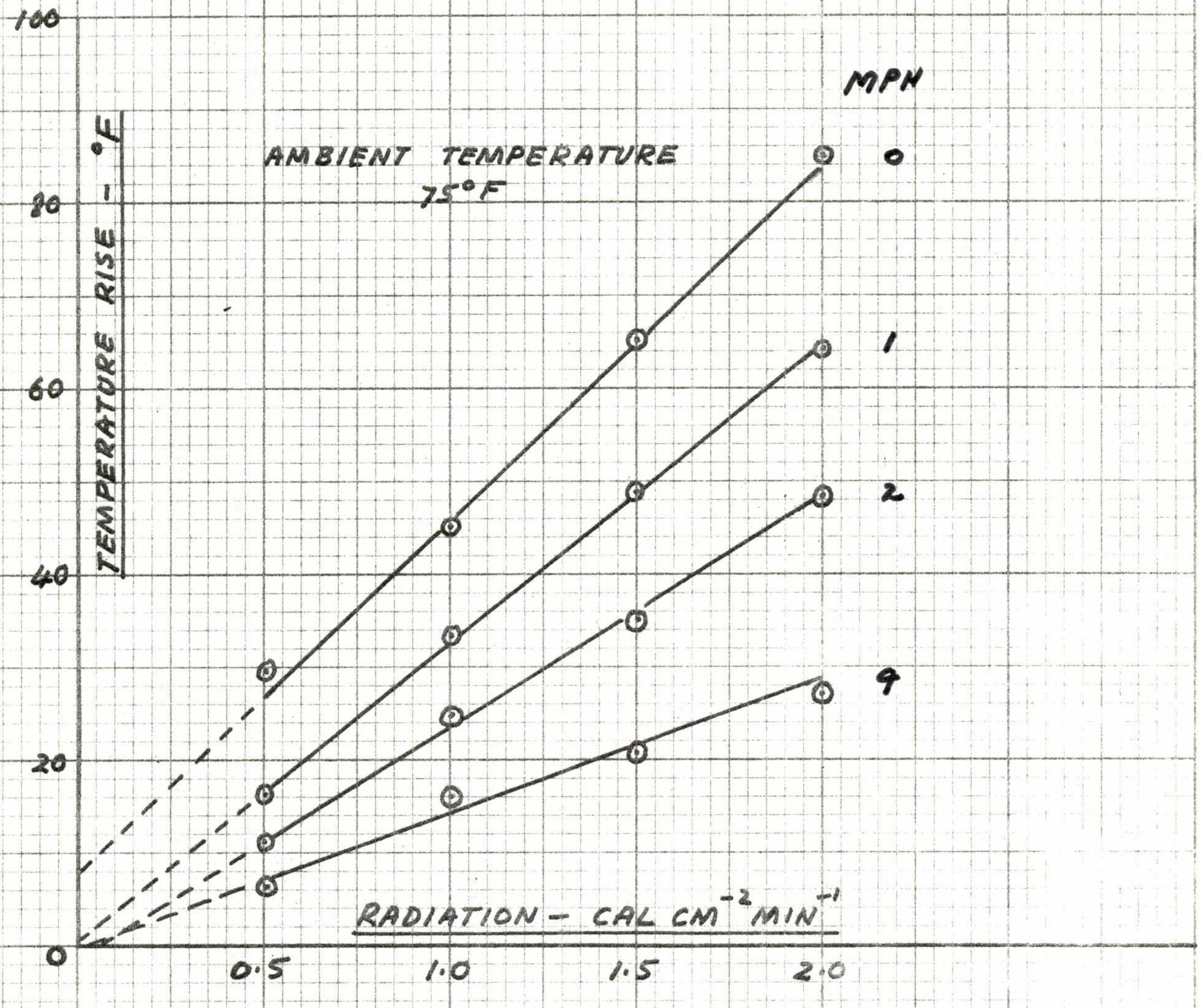

FIGURE 3. Effect of varying radiant intensity on the surface temperature of jack pine litter at four wind speeds. The plotted points are curve values from graphs of temperature rise against wind speed.