soils, as reported by Youngberg and Dyrness (1964), or it could be caused by the presence of the sand layer at about 2 feet.

The graph of precipitation across the bottom has been added to help explain the differences in soil-moisture use pattern from year to year.

A split plot analysis of the data was performed in which the "main plots" were the treatment versus control plots, and years were considered the subplots. This analysis showed a highly significant year-treatment interaction, indicating that the treatment that occurred between the 1964 and 1965 measurements did indeed significantly reduce soil-moisture deficits. We saw this in Figure 1, but the interaction effect is more clearly illustrated in Figure 2. The large decline in soil-moisture deficit the third year in both treated and control plots resulted from greater than normal summer precipitation.

This study has shown that significant potential savings of soil moisture are possible by cutting lodgepole pine in the conditions prevalent in the eastern Cascades. Further studies are necessary to determine the persistence of the treatment effect, the effect of thinning, and whether or not the water saved will show up as streamflow or will be utilized some place else on the watershed.

#### Literature Cited

Barrett, J. W., and C. T. Youngberg. 1965. Effect of tree spacing and understory vegetation on water use in a pumice soil. Soil Sci. Soc. Amer. Proc., 29: 472-475.

Dahms, W. G. 1967. Low stand density speeds lodgepole pine tree growth. Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service Research Note PNW-47. 11 pp.

Tarrant, R. F. 1957. Soil moisture conditions after chemically killing manzanita brush in central Oregon. Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service Research Note No. 156. 4 pp.

Wilm, H. G., and E. G. Dunford. 1948. Effect of timber cutting on water available for stream flow from a lodgepole pine forest. U.S. Dept. of Agric., Forest Service Tech. Bull. 968. 43 pp.

Youngberg, C. T., and C. T. Dyrness. 1964. Some physical and chemical properties of pumice soils in Oregon. Soil Sci., 97: 391-399.

Ziemer, R. R. 1964. Summer evapotranspiration trends as related to time after logging of forests in Sierra Nevada. Jour. Geophys. Res., 69: 615-620.

*Accepted for publication, October 14, 1967.*



**W. T. Hinds and W. H. Rickard**
Environmental and Radiological Sciences, and Biology Departments
Battelle Memorial Institute
Pacific Northwest Laboratory
Richland, Washington

# Soil Temperatures near a Desert Steppe Shrub[1]

The landscape of much of south-central Washington is dominated by natural vegetation of a fairly uniform appearance consisting of widely spaced shrubs about a meter tall with an "understory" of grasses and forbs growing beneath and between the shrubs. The shrubs are long lived, so any alteration in the environment which the shrubs induce is quasi-permanent. Although the total effect of the shrubs on the small herbaceous plants growing on the desert steppe floor must be rather small, the plants growing near the shrub will certainly be affected. One of the most pronounced effects of the shrubs is the pool of shade cast by the shrub, which provides a substantially cooler environment on the protected side of the shrub. Since observations showed a significant difference in phenology of cheatgrass, *Bromus tectorum,* when growing in the shady side compared with the sunny side of the same shrub, an investigation was begun to define more carefully the environmental differences between shady and sunny sides.

The purpose of the first phase of the investigation was to measure the pattern of soil temperature around a shrub. Although soil temperature in itself will not define an environment, it is closely tied to both insolation and ventilation, as well as soil characteristics. Thus, the pattern of soil temperatures may be used to illustrate differences between two environments in an integrated sense; to *define* the differences requires more versatile and specific measurements, especially the radiation balance.

The effect of shading on plant growth has been documented for some grasses; for example, Reid (Shaw, 1952: 381) showed that velvet bent grass grown in half-day shade produced only one-third the root weight of grass grown in full sun. More generally, the effect of vines on air temperatures near the surface (Geiger, 1965: 295) is pronounced, and one may also suppose a similar effect on soil temperature. Geiger's sketch indicates that the air temperature between rows of vines is higher than under the vines in vineyards planted with north-south rows. He ascribes the low temperatures to direct shading and the warm areas between the rows to protection from ventilation. Geiger also quotes (p. 290) some soil temperatures at 10 cm depths under various natural communities. The data show soil temperatures varying in space from 23 to 42 C under 90-cm tall evergreens whose canopies covered 75 per cent of the ground, with air temperatures at 2 meters of 22 to 28 C. One may surmise that steppe lands, sparsely

[1] Work performed under Contract No. AT(45-1)-1830 between the Atomic Energy Commission and Battelle-Northwest.

covered by shrub canopies, would show effects similar to those observed for both the vineyard and the evergreen data, *i.e.,* both localized increase and decrease of soil temperature.

**Methods Employed**

To investigate the pattern and intensity of a shrub's effect on the soil temperature immediately surrounding it, 18 thermohms (resistance thermometers) were placed around a single hopsage, *Grayia spinosa,* growing on the Hanford Reservation, Benton County, Washington. The plant was about 60 cm high and 120 cm in diameter; Figure 1 shows a photograph of the shrub. The thermohms, with a sensing element about 15 cm long and 1 cm in diameter, were buried horizontally at a depth of 3 cm (nominal) around the shrub in a pattern as shown in Figure 2. The signals from the thermohms were recorded by a multipoint strip chart recorder adjusted to record the soil temperature pattern at 30-minute intervals. Since a complete traverse of the 18 thermohms by the recorder took about 8 minutes, the temperatures were unmonitored for about 44 minutes each hour. Due to the slow change of soil temperatures, this was no handicap whatsoever.

The strip chart data were examined for irregularities in timing or calibration (the recorder showed a severe reaction to high ambient temperatures) then reduced to tabular form at two-hour intervals. More frequent readings were not necessary for the purpose of this study, since in general the temperature change with time was a very smooth, uninterrupted increase or decrease.

Figure 1. View of the hopsage from the north. Indicated heights are in decimeters.



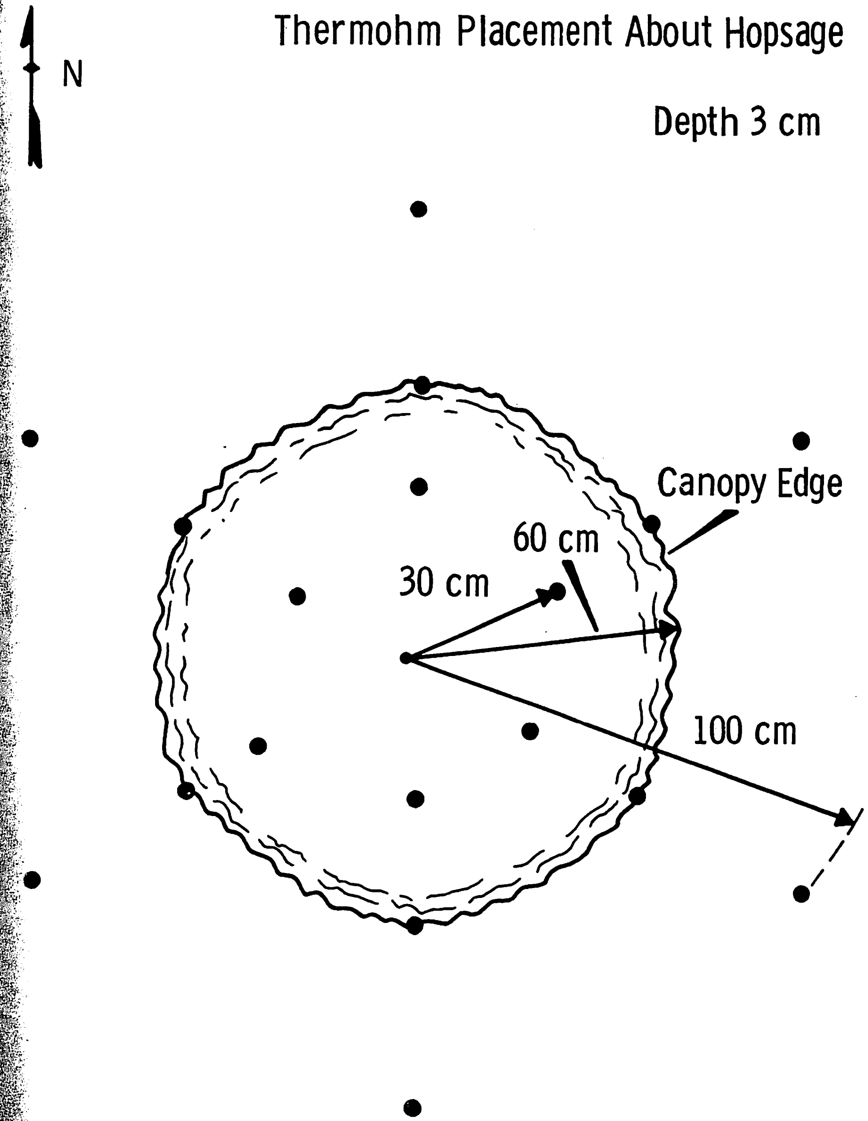


Figure 2. Pattern of thermohm placement around the hopsage. Sensors were 3 cm below surface.

The accuracy of the array of thermohms was within ± 2 F, a rather large error. However, the objectives of this investigation did not require greater precision, since the gradients concerned were on the order of 20 to 40 F between thermohms of interest.

**Results**

The temperature data from the edge of the canopy of the shrub on the north and south sides are shown in Figure 3. The data here are from three successive days which

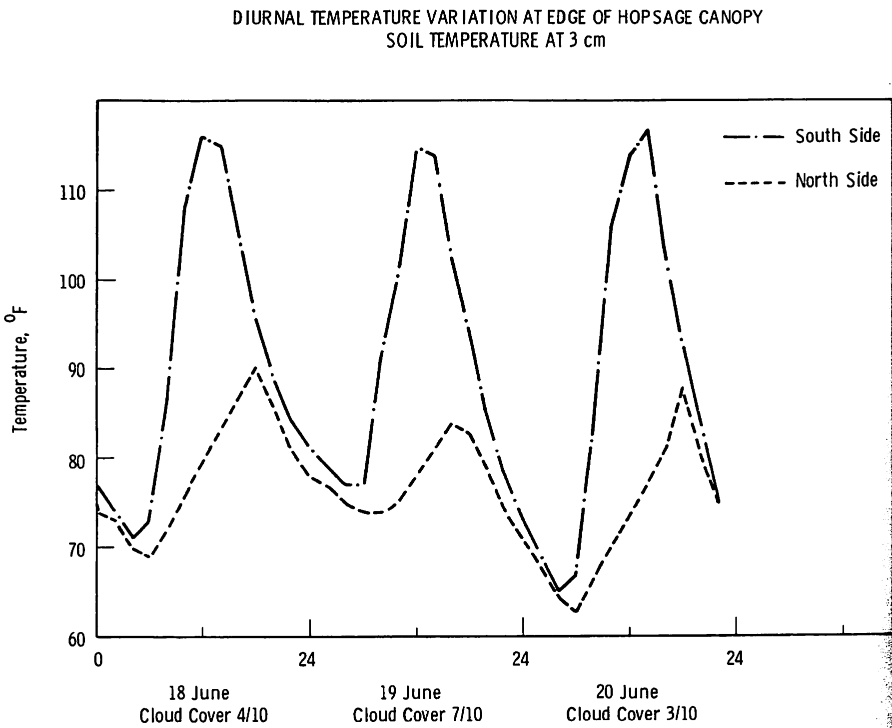


Figure 3.

were more or less typical of the time. The figure makes quite clear the extent of cooling due to shading, amounting to 25 or 30 degrees during the middle of the day. It is interesting to note, also, that the time of the maximum is some four hours later and the time of the minimum about one or two hours later, on the north side. Thus the north side acts as if it were at a virtual depth several cm deeper than the south side, especially during the day, when solar radiation is the dominant heating factor. At night, the two sides of the shrub are about equally cooled.

Field observations indicate that cheatgrass is more or less dependent upon accumulated temperature, that is, its growth and reproduction is a function of thermal exposure, the integral of the temperature vs. time curves in Figure 3. The rate of accumulation of temperature is shown in Figure 4 for sites under and outside the canopy on both the north and south sides of the shrub. The data in Figure 4 were corrected to allow for a lower limit of effective temperature for growth, presumed to be 35 F; although exposure to even lower temperatures (vernalization) is necessary for flowering, rapid shoot growth is associated with soil temperatures above about 35 F (Hulbert, 1955). It is interesting to note that the under-canopy positions are quite comparable. Since the sites were 30 cm from the center of a 60-cm radius shrub, the minimum extent of the shade pool must be at least 30 cm in radius. The outer positions, 40 cm beyond the canopy, are quite close in their behavior, as should be expected, being essentially beyond the reach of the canopy effect. The under-



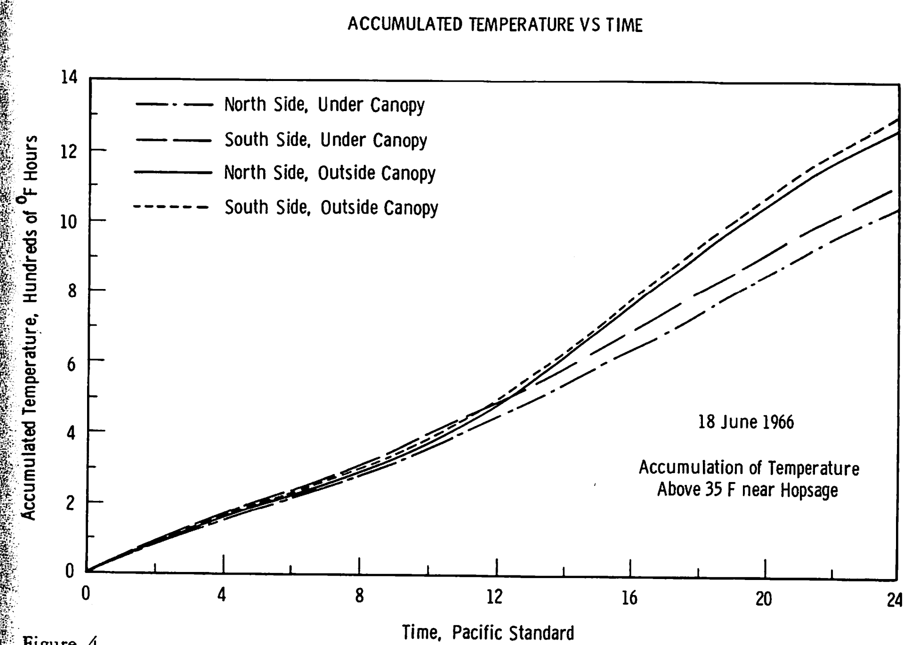


Figure 4.

canopy points accumulate temperature at a rate which is about 80 per cent that of unobstructed points, a significant reduction.

The total size of the shade pool at various times of the day can be found by drawing isotherms about the shrub using data from all thermohms. Figure 5 presents two isotherm patterns about the shrub drawn from three days' data, averaged at 0800 and 1400 PST. The isotherms were drawn according to the relative increase or decrease in temperature from the unobstructed temperature; a negative isotherm indicates an area cooler than unobstructed temperatures, a positive isotherm indicates an area warmer than the unobstructed temperature. At 0800, a definite warming is seen on the sunward side of the shrub, and a long shadow is obvious on the lee side. At 1400, the shadow is much smaller, but the shading is intense. A slight warming at the sunward edge of the canopy is also seen at this time. The intermediate times showed a fluctuating gradation between these two patterns. At night, all temperatures dropped to within a 6 F range, with the warmest area being directly beneath the shrub canopy, where shielding from radiation to the night sky was most effective.

## Discussion and Conclusions

Since the rate of accumulation of temperature is so different on the two sides of the shrub, some method of quantitative analysis of the effect of shading seems appropriate. To do this, consider the definition of accumulated temperature or, more precisely, the exposure of a point (or plant) to thermal energy: $E_T = \int T\,dt$. If $T_o$ represents the temperature of the unobstructed surface, the relative exposure of two points can be expressed as the ratio of two integrals to form a "shade factor" $f_s$:

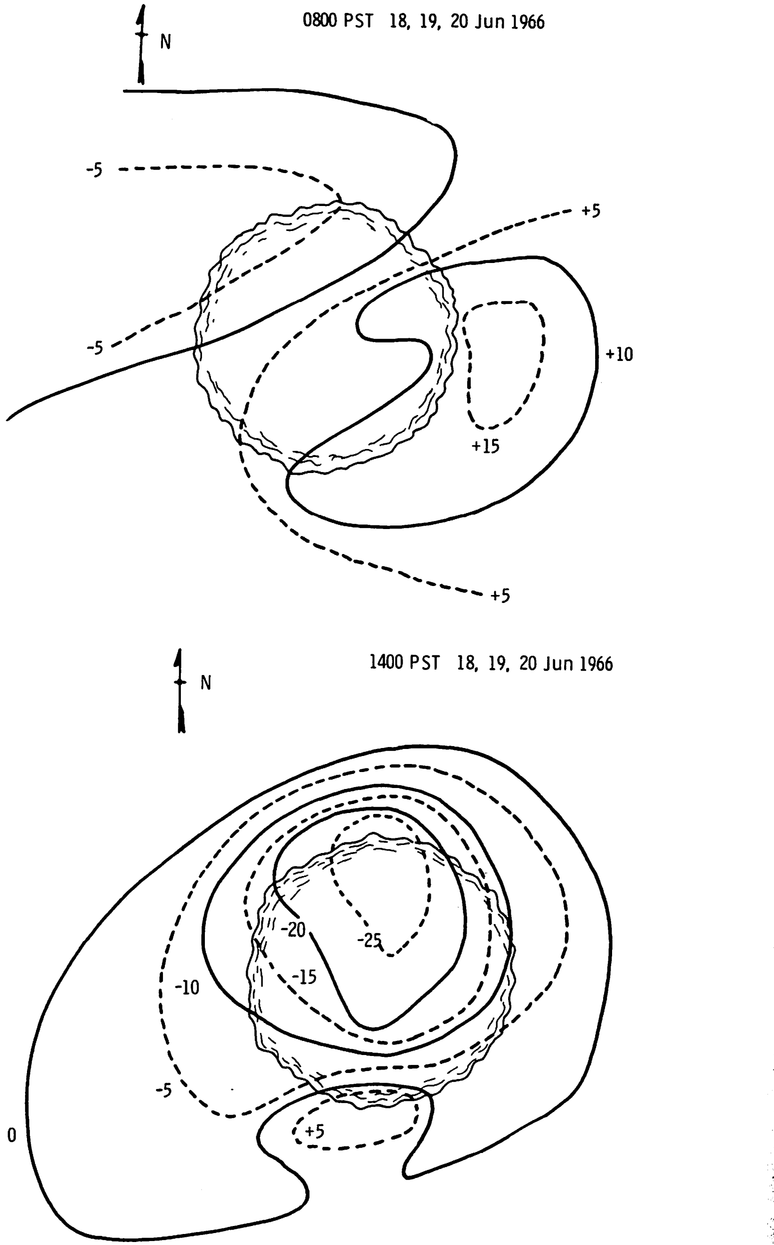


Figure 5. Isotherm patterns around the hopsage. Data are averages at the indicated hour over three days. Temperatures are relative to unobstructed surface temperature.



$$f_s = \frac{\int (T - T_c)\,dt}{\int (T_o - T_c)\,dt}$$

where $T_c$ is the lower bound of temperature effective for growth, in this case about 35 F. However, if $f_S$ is to be evaluated from the data, the integral must be replaced by a finite sum, over N hours, so:

$$f_s = \frac{\sum_{n=1}^{N} (T - T_c)}{\sum_{n=1}^{N} (T_o - T_c)} = \frac{\left(\sum_{n=1}^{N} T\right) - NT_c}{\left(\sum_{n=1}^{N} T_o\right) - NT_c}$$

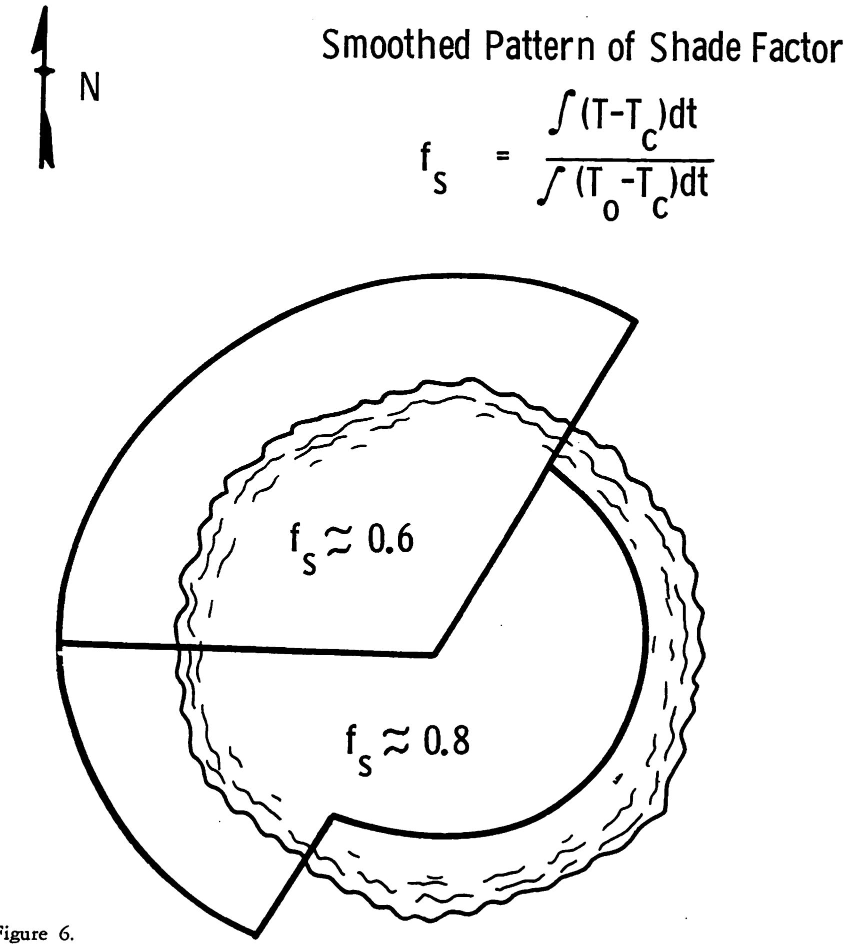


Figure 6.

The resulting pattern, in terms of $f_s$, is shown in Figure 6. The values of $f_s$ have been rounded off considerably to reflect the lack of confidence in detailed calculations from the temperature data; nevertheless, the pattern is clear and the shading effect is considerable, even in areas where one might expect little effect. The area covered by $f_s = 0.6$ is about half the area covered by the canopy; likewise, the area covered by $f_s = 0.8$ is also about half the canopy area.

It must be noted that $f_s = 0.6$ does not imply that $T = 0.6T_o$ over that area; the temperature is more nearly 0.75 $T_o$ and varies with $T_c$. The reduction in temperature for $f_s = 0.6$ is shown in Figure 7, for $T_c = 35$ F. Along the left side is the relative reduction in temperature, and along the right side the total reduction in temperature. It can be seen that although the total reduction in temperature increases linearly with $T_o$, the relative reduction increases more slowly and levels off at higher $T_o$. (The limit in relative reduction is in this instance 0.4.)

Some interesting points can be made considering the pattern of $f_s$ shown in Figure 6. The area of significant temperature reduction approximates half the canopy area of the shrub; if all shrubs show a similar pattern, then half of the total canopy cover over a desert steppe is associated with a significant reduction in soil temperature. A 20 per cent canopy cover is typical of arid shrub lands (Rickard and Beatley, 1965), so about 10 per cent of the total area is characterized by maximum soil temperatures which are about 30 per cent less than the temperatures reported for level, homogeneous soil surfaces. This occurs in spite of an insignificant reduction of the average surface temperature of the shrub land, since the average $f_s$ (for $T_c = 35$ F) over the entire area is about 0.93, implying an average temperature of about 0.97 $T_o$. The areas of the desert steppe characterized by cooler temperatures provide a more diverse environment for plant growth and development; this may be reflected by the appearance of otherwise unobserved species, and certainly will be reflected in any temperature-dependent life processes of affected plants.

FRACTIONAL AND TOTAL TEMPERATURE REDUCTION AS A FUNCTION OF UNOBSTRUCTED SURFACE TEMPERATURE FOR $f_s = 0.6$

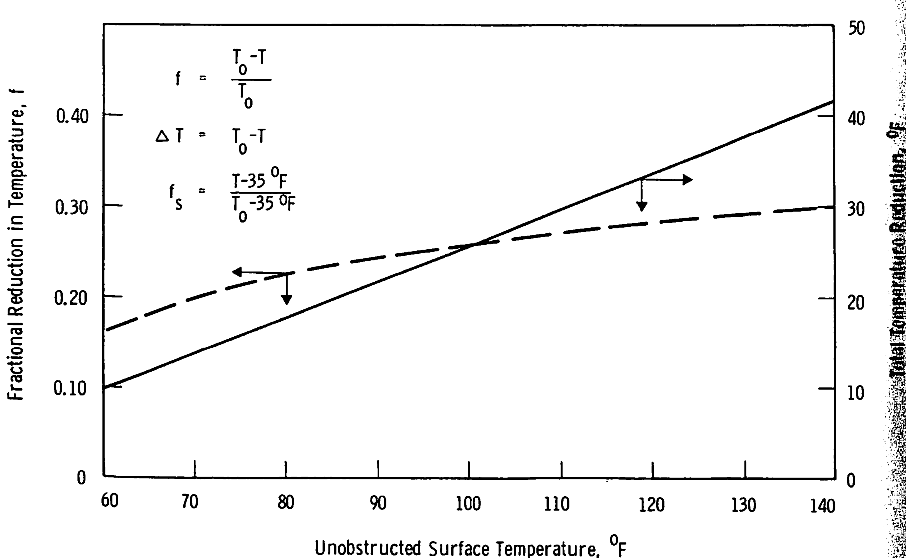


Figure 7.

## Literature Cited

Geiger, R. 1965. The climate near the ground. Harvard University Press, Cambridge, Massachusetts.

Hulbert, L. C. 1955. Ecological studies of *Bromus tectorum* and other annual bromegrasses. Ecol. Monogr., 25: 181-213.

Rickard, W. H., and J. C. Beatley. 1965. Canopy-coverage of the desert shrub vegetation mosaic of the Nevada test site. Ecology, 46: 524-529.

Shaw, B. T. (ed.) 1952. Soil physical conditions and plant growth. Academic Press Inc., New York, N.Y.

*Accepted for publication, September 26, 1967.*