

CROP COOLING WITH SPRINKLERS

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INTRODUCTION

The use of sprinkler irrigation equipment to cool the aerial environment of crops is a recent innovation in agricultural production. The benefits to be gained include increased yield and quality of the crop and the extension through climatic modification of the normal geographic limits of specific crop production.

Plant water potential is influenced more by evaporative demand of the atmosphere than by soil water availability, particularly when soil water is maintained within the tensiometer range (1, 4, 9). The significance of changes in plant water potential is not well defined (1) but there is evidence (7) that the changes can be controlled by mist irrigation with resultant beneficial yield response.

Plant growth is restricted by water deficits caused by excessive transpiration during the heat of midday (10). Simultaneous plant and air temperatures may differ widely and plants may respond to air temperature changes of only a few degrees Celsius (13). A change of a few degrees in leaf temperature can make a major difference in the biological functions of plants (6).

Beans, peas, potatoes, tomatoes, strawberries, and tree fruits are among the crops reported to have critical maximum temperatures from which they can be profitably protected (5, 7, 9, 11, 15). Little has been recorded about critical temperatures but 90°F (32.2°C) has arbitrarily been assumed to be the upper threshold temperature for most temperate zone crops (2, 7).

Reductions in air and soil temperature produced by sprinkling with conventional and low-rate irrigation equipment have been documented (2, 9, 11, 12, 14, 15). Improved crop growth has often been associated with these environmental modifications, but in many instances the degree of modification has not been

interpreted on a climatic basis. None of the studies reported has been conducted in a climate similar to that of southern Alberta, which features hot dry summers but which has few extreme maximum temperatures (8). The sprinkler method of irrigation has been increasing in popularity to the extent that it predominates in some localities and many systems currently in use have a crop-cooling capability. This paper describes crop-cooling experimental techniques used in southern Alberta and relates the results to prevailing meteorological conditions.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

Most crop cooling described in the literature has been done when air temperature exceeded 90°F (32.2°C). At Lethbridge, on the average, air temperature has exceeded 90°F (32.2°C) on only five occasions for a total of 16 h annually. It was considered impractical to assess cooling on the basis of so few extreme temperatures. But, on the average, air temperatures exceed 80°F (26.7°C) 6, 16, 14, and 5 d in June, July, August, and September, respectively, or a total of nearly 150 h. Consequently, this lower temperature was used as a base.

The experimental design consisted of 12 plots, each 40 ft (12.2 m) square, arranged in three replications. Each four-plot replication contained two irrigation treatments on which cooling was superimposed and two on which cooling was not superimposed. Irrigation and cooling treatments were randomized within each replication. The replicated design was provided for the physiological assessment of the crops being studied under the cooling regime. Equipment availability limited the instrumentation for cooling assessment to one complete replication.

Sprinklers for both irrigation and cooling were of full-circle, single-nozzle, conventional design and were located at the corners of the plots. Sprinkler nozzles of two sizes, 13/64 inch (5.2 mm) and 7/64 inch (2.8 mm), were used for the two irrigation treatments but for cooling

4/64-inch (1.6-mm) nozzles were used.

For cooling, a temperature controller located near the pump actuated an electric pumping unit as long as the ambient temperature exceeded 80°F (26.7°C). Cooling was arbitrarily cycled 16 min on and 14 min off by a time clock. The purpose of the on-off cycling and the use of small-sized nozzles was to reduce the amount of water applied to the plots. The cooling treatment was intended only to cool the crop environment and not to supply water for crop use.

Catch cans were placed on a 10-ft (3.0-m) grid over the plot area to determine the actual amount of water applied to the soil and plant surfaces during irrigation and cooling and to provide data for calculating distribution uniformity coefficients by the Christiansen (3) method. Coefficients for 25 consecutive irrigations averaged .75 and ranged from .70 to .83.

The cooling sprinklers, operating at 55 psi pressure, applied water at the rate of 0.050 inch (1.27 mm) per h on the 40-ft² (12.2-m²) plot area. Operational cycling produced a net application rate of 0.026 inch (0.66 mm) per h, a rate similar to that of evaporation from a free water surface during midsummer. Distribution uniformity coefficients for cooling applications were similar in magnitude to those for irrigation. During highly evaporative conditions, however, many of the catch cans were dry immediately after a cooling application.

Water for cooling and irrigation was pumped from a small reservoir supplied from the Irrigation District canal. Water temperature was as high as 80°F (16.7°C) during the hottest part of the day. The pump intake was equipped with a 4/64-inch (1.6-mm) screen. This screen, the settling reservoir, and a thorough flushing of the cooling system after installation effectively prevented nozzle-plugging problems.

During 1969 and 1970, data were recorded for potatoes, cult Netted Gem, and in 1971 for green bush beans, cult

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Executive. Tensiometers and neutron-scattering techniques were used to schedule irrigations and monitor soil moisture. The effects of cooling and irrigation were separated by insuring that irrigations were applied only on those days or during periods of the day that cooling was not required.

Hourly maximum air temperature and wind data were obtained from the Canada Department of Environment meteorological station located about 4 miles (6.4 km) south of the test plots. Relative humidity was determined daily with a psychrometer at about the time that ambient temperature was greatest. Additional humidity measurements occasionally were made in the immediate plot area. Air temperature within the plant canopy in all four plots of one replication was recorded on thermographs. The sensing elements were located in the crop row 4 inches (10.2 cm) above the soil surface and were shielded from the sun and from direct contact with the sprinkler spray. Soil temperature at a depth of 4 inches (10.2 cm) under the crop row also was recorded. The maximum daily temperature reduction due to cooling was determined from the thermograph charts for each of 88 cooling days during the 3 yr of the tests. These data were related by simple and multiple correlation to relative humidity, maximum ambient air temperature, and wind velocity at the time of maximum temperature reduction. Regression equations relating these indices to temperature reduction were also calculated.

RESULTS AND DISCUSSION

Sprinkling reduced the canopy air temperature by a maximum of 16°F (8.9°C), but the average reduction, under a wide range of weather conditions and over an extended period of time, was 6°F (3.3°C). As a rule the cooling effect was greatest in midafternoon (Figure 1) and decreased as the day progressed. There was usually some residual effect in the evening that occasionally was still apparent the next morning. Air temperature in the plot canopy was not always the same as that at the controller. Consequently, towards evening the cooling equipment did not necessarily shut off precisely when the canopy temperature of the noncooled plots fell to 80°F (26.7°C). On the cooled plots the canopy temperature at the time the cooling sprinklers were shut off was below ambient temperature by the amount that the treatment was influencing temperature at that time. In the highly vegetative potato crop, cooling always maintained the plant canopy air temperature below 80°F

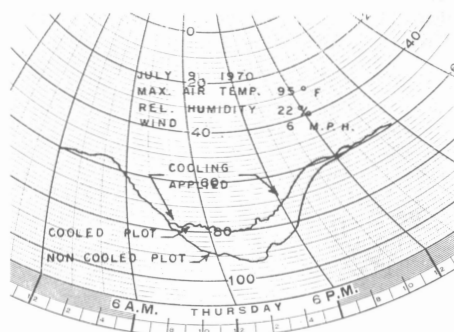


Figure 1. Typical effects of cooling on canopy air temperature.

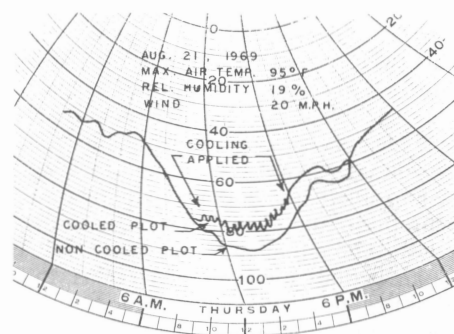


Figure 2. Temperature changes resulting from cycling of the cooling system under highly evaporative conditions.

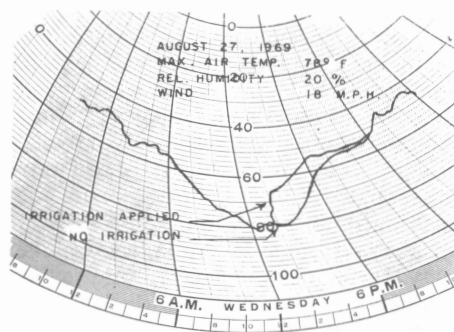


Figure 3. Temperature changes resulting from a normal field-type irrigation.

(26.7°C), but with beans the canopy temperature occasionally was higher than this.

The temperature recovery during the 14-min off period varied, depending upon the prevailing weather, from practically nothing to about 4°F (2.2°C). Figure 2 depicts the well-defined cycling pattern that occurred under high evaporative conditions. Chesness and Braud (2), in a similar study in Louisiana, applied water at rates of 0.08 inch (2.03 mm) per h on strawberries and reported a recovery of 40% during a 15-min cycling period. Generally, though, as in Figure 1, the

cycling pattern was much less sharply defined and the temperature recovery was in the order of 10-20% of the maximum temperature reduction.

Air temperature in the plant canopy was also influenced during sprinkling for irrigation (Figure 3). The residual temperature reduction was more pronounced after irrigation than after low-rate cooling because of the greater wetting of the soil surface. The effect was quite apparent the following day but was dissipated completely within 48 h.

Soil temperature was also influenced by sprinkler cooling but to a much lesser extent than air temperature, the reduction usually being between 1 and 2°F (0.6 and 1.1°C).

Although the rate of application of cooling water approximated the evaporation rate, the soil became slightly moister in the cooled plots. The occasional residual effect of cooling evidenced on the morning after cooling also indicated some moisture carryover. This increase in soil moisture can be attributed directly to a contribution from the cooling water and indirectly to a reduction in transpiration during cooling. Reduced transpiration due to lowered temperature and increased humidity is indicated. The magnitude of the reduction is the basis for continuing studies. On a seasonal basis, however, both water application to and evapotranspiration from the cooled plots were greater than from the noncooled plots. Thus the reduction in transpiration was outweighed by the amount of cooling water applied, and the cooling treatment actually decreased the overall efficiency of water use. It does not seem practical to further reduce the size of the cooling nozzles but the duration of the cooling treatment might be reduced.

During the 88 d on which cooling took place, the maximum air temperature recorded was 97°F (36.1°C), but on 67 of the days the temperature did not exceed 90°F (32.2°C). Relative humidity ranged between 10 and 50% but two-thirds of the time was between 20 and 35%. Wind velocity varied from 2 to 25 mph (3.2 to 40.2 km/h) but exceeded 15 mph (24.1 km/h) only 25% of the time. Thus the range of weather conditions prevailing during the study was not extreme.

When the three meteorological indices — humidity, maximum air temperature, and wind — were simply correlated to temperature depression by cooling, humidity had the greatest influence, the relationship being negative ($r = .794$). Maximum air temperature ($r = .602$) and wind ($r = .513$) were less well related.

TABLE I REGRESSION EQUATIONS, MULTIPLE CORRELATION COEFFICIENTS, AND STANDARD DEVIATIONS FOR TEMPERATURE REDUCTION (Δt) VS. HUMIDITY (x_1), MAXIMUM AIR TEMPERATURE (x_2), AND WIND (x_3)

Temp reduction (F)	Constant	Relative humidity (%)	Max air temp (F)	Wind velocity (mph)	Multiple correl. coef.	SD
$\Delta t =$	15.62	$-.267x_1$.794	1.92
$\Delta t =$	13.48	$-.236x_1$	$+.111x_2$.819	1.83
$\Delta t =$	-.29	$-.192x_1$	$+.114x_2$	$+.145x_3$.840	1.74

The low correlation with wind is not surprising. Under the weather that prevailed during the cooling process (air temperature above 80°F (26.7°C)) wind velocities were usually neither extreme nor widely variable. Consequently they would not have contributed large or fluctuating amounts of convective heat. But there was usually sufficient wind to remove the moist air from the plant canopy and thus effect the cooling process. The correlation between wind and air temperature reduction was slightly higher for the potato crop in 1969 and 1970 than for the bean crop in 1971 (.552 vs. .385), probably because of the effect of the differences in foliage density of the two crops.

The three indices were related in multiple regression to temperature depression (Table I). As indices were successively introduced into the equation, the multiple correlation coefficient increased and the standard deviation decreased, but the changes were not large. The introduction of wind caused a greater reduction in residual variance than did the introduction of temperature. Thus wind assumed a higher level of importance when considered in multiple correlation than when considered in simple correlation. The equations indicate the relative contribution of each of the indices used and provide a means of estimating broadly, within the limits of the meteorological variations encountered, the effect on the crop environment of sprinkler cooling.

SUMMARY

Irrigated plots of potatoes and bush beans were sprinkled intermittently with water whenever the ambient air temperature exceeded 80 degrees Fahrenheit (26.7 degrees Celsius). Conventional but low-volume irrigation equipment was used to apply the cooling water at a net theoretical application rate of 0.026 inches (0.66 millimeters) per hour. Over a 3-year period and 88 applications this sprinkling rate effectively reduced plant canopy air temperature. The average temperature reduction was 6 Fahrenheit degrees (3.3 Celsius degrees) but reductions as large as 16 Fahrenheit degrees (8.9 Celsius degrees) occurred. The amount of cooling achieved was dependent upon the weather prevailing during cooling. Humidity exerted the greatest single influence, maximum air temperature was next in importance, and wind was less well related. When all three meteorological indices were considered together, their combined influence was greater than that of any single index. The multiple regression equations indicate, within the range of weather conditions prevailing during the study, the amount of temperature reduction likely to be achieved with field-type sprinkler irrigation equipment.

REFERENCES

1. Cary, J.W. and J.L. Wright. 1971. Response of plant water potential to the irrigated environment of southern Idaho. *Agron. J.* 63: 691-695.

2. Chesness, J.L. and H.J. Braud. 1970. Sprinkling to reduce heat stressing of strawberry plants. *Agr. Eng.* 51: 140-141.
3. Christiansen, J.E. 1942. Irrigation by sprinkling. *Univ. Calif. Bull.* 670. 124 pp.
4. Denmead, O.T. and R.H. Shaw. 1962. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. *Agron. J.* 54: 385-390.
5. Dolan, M.W. 1963. Solid-set sprinkler systems. R.M. Wade and Co., Portland, Oregon. 8 pp.
6. Gates, D.M. 1964. Leaf temperature and transpiration. *Agron. J.* 56: 273-277.
7. Gilbert, D.E., J.L. Meyer and J.J. Kissler. 1971. Evaporation cooling of vineyards. *Trans. Amer. Soc. Agr. Eng.* 14: 841-843, 859.
8. Hobbs, E.H. 1970. The agricultural climate of the Lethbridge area, 1902-1969. *Agrometeorol. Publ. 1. Res. Sta., Can. Dept. Agr., Lethbridge, Alberta.* 13 pp.
9. Howell, T.A., E.A. Hiler and C.M.H. van Bavel. 1971. Crop response to mist irrigation. *Trans. Amer. Soc. Agr. Eng.* 14: 906-910.
10. Kramer, P.J. 1963. Water stress and plant growth. *Agron. J.* 55: 31-35.
11. Peterson, L.E. and J.L. Weigle. 1970. Varietal response of potatoes to air conditioning irrigation. *Amer. Potato J.* 47: 94-98.
12. Robinson, F.E. 1970. Modifying an arid microclimate with sprinklers. *Agr. Eng.* 51: 465.
13. Tanner, C.B. 1963. Plant temperatures. *Agron. J.* 55: 210-211.
14. Van den Brink, C and R.L. Carolus. 1965. Removal of atmospheric stresses from plants by overhead sprinkler irrigation. *Mich. Agr. Exp. Sta. Quart. Bull.* 47: 358-363.
15. Wheaton, R.Z. and E.H. Kidder. 1966. To control heat stress in plants. *Agr. Eng.* 47: 325.