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Air Temperature and Vapor Pressure Changes Caused by Sprinkler Irrigation[1]

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ABSTRACT

The downwind effect of evaporation from sprinkler spray was studied in the field to determine if air temperature and vapor pressure were changed enough to influence plant growth and water use. Wet-bulb and dry-bulb temperature profiles were measured upwind and at three distances downwind from a sprinkler lateral before and during sprinkling. Wind-speed and direction were also measured. Air temperature generally was reduced less than 1 C, and vapor pressure in the air was increased less than 0.8 mb. This amount of change in the air temperature and humidity is not likely to be sufficient to cause any significant change in plant growth or evaporative loss of water.

Additional index words: **Evaporation loss, Evaporative cooling, Spray evaporation.**

SPRINKLER irrigation exposes the applied water to the atmosphere in a manner which enhances evaporation. The evaporation process cools the droplets, enabling heat to be drawn from the air through which the droplets pass, and adds water vapor to the atmosphere. The increase in atmospheric vapor pressure and decrease in air temperature caused by sprinkler irrigation are of interest in crop production because significant changes in these microclimatic variables could either benefit or retard plant growth depending on existing conditions and plant requirements. Cool-season plants growing under warm weather conditions might experience improved growth, while a warm-season crop might be retarded.

In this paper, changes in vapor pressure and air temperature just above the crop surface are compared under field conditions with and without the operating sprinklers. Changes in these two parameters are directly dependent on the amount of water evaporated, a quantity often termed "evaporation loss." Generally, evaporation loss includes the evaporation from the spray plus that from the wetted foliage. Wetted-foliage evaporation under sprinkler irrigation has been studied with full-cover crops of alfalfa (*Medicago sativa* L.), oats (*Avena sativa* L.), sudangrass [*Sorghum sudanense* (Piper) Stapf], and ryegrass (*Lolium multiflorum* Lam.) under arid conditions with the findings that evapotranspiration from the wetted foliage was approximately equal to that from nonwetted, actively growing foliage with adequate soil moisture (1, 6, 10). Therefore, we concluded that the influence of sprinklers on air temperature and vapor pressure over a well-watered crop is mainly from spray evaporation.

THEORY

Evaporation of spray is difficult to measure because errors are additive in catch methods and salt concentration or electrical conductivity methods and exaggerate the estimate of evaporation. In catch methods the procedure is to measure the volume of water reaching the soil surface, subtract it from the volume applied, and call the difference "evaporation loss." However, the difference not only includes the evaporation loss from the spray, but also that from the catch device (catch cans or plastic covered area) and the mist carried beyond the measurement site, and other possible incomplete catch errors (7, 13). The portion actually lost by spray evaporation could be less than 30% of the total difference. The time of flight of the droplets is usually less than 2 seconds. However, the droplets may be exposed on metal or plastic surfaces of the catch container, which are often heated by solar radiation, for much longer times, resulting in continued evaporation and appreciable errors (8). If exaggerated evaporation losses were used to estimate temperature and vapor pressure change, large temperature and vapor pressure changes would be indicated.

George[3] avoided the errors of incomplete catch and mist drifts by measuring the electrical conductivity of water caught in funnels. However, clinging droplets and travel down the funnels allowed evaporation and salt concentration. George estimated that half of his measured "evaporation loss" occurred in the funnels, resulting in corrected evaporation losses of 5% or less depending on climatic conditions and application rates. Till (14), using a similar method, obtained an evaporation loss of about 2% for the larger drops at the outer edge of the spray.

Seginer (11) estimated the combined loss from spray and droplets on corn (*Zea mays* L.) on the coastal plain of Israel to be about 5% based on seasonal water use data. More recently, he developed a resistance model to predict evaporation during sprinkling (12). Under similar arid conditions, the model predicts only a few percent evaporation loss from the spray.

If an evaporation loss of 5% is accepted as reasonable for sprinkler-irrigated areas in the western United States, the approximate reduction in air temperature and increase in vapor pressure can be estimated for a sprinkler lateral perpendicular to the wind. To give an idea of the change to be expected, it is assumed that the evaporation occurs uniformally in the first 2 m (h) above the crop; that the mean windspeed (u) for the 2-m height is either 2 or 3 m/s; that the air temperature is 30 C and the relative humidity (RH) is 20% (for an air density (ρ_a) of 1 kg/m³ and a heat capacity (c_p) of 0.24 cal/g-degree); and that the sprinkler discharge (Q) is 0.032 liters/second per meter of line with a 5% evaporation (E). The decrease in air temperature (ΔT) can be approximated by:

$$\Delta T = E\ Q\ L_v \rho_w / u\ h\ \rho_a\ c_p \qquad [1]$$

where L_v = latent heat of vaporization of water (580 cal/g)

ρ_w = density of water (1000 g/liter)

and other symbols are as previously defined. The estimated temperature changes calculated for the above conditions assuming block flow are listed in Table 1.

The corresponding increases in vapor pressure (Δe) can be approximated by:

$$\Delta e = e_{w2}\,[\,(m_{v1}\,RH_1/100 + E\ Q\ \rho_w/u\ h)/m_{v2}] - e_{w1}\,RH_1/100 \qquad [2]$$

where m_v = saturation vapor density (g/m³)

e_w = saturation vapor pressure (mb)

and the subscripts represent conditions at temperatures T_1 or T_2. The estimated vapor pressure changes are also listed in Table 1.

These changes in air temperature and vapor pressure are small compared to the noticeable change in air temperature that one experiences when driving into an irrigated area from arid surroundings. Some studies (7, 13) suggest a threefold increase in the "evaporation loss" than is assumed in the above

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[3] T. J. George, 1955. Evaporation from irrigation sprinkler sprays as determined by an electrical conductivity method. M.S. Thesis. University of California, Davis.

Table 1. Calculated reduction in air temperature and increase in vapor pressure due to spray evaporation for a flow of air past an operating sprinkler line.

Windspeed	Temperature Reduction	Vapor Pressure Increase
m/s	°C	mb
2	1.0	0.6
3	0.7	0.4

calculations and a corresponding threefold change in air temperature and vapor pressure.

To gain more information on the magnitude of the effects of operating sprinklers on these parameters, data were collected around an ordinary sprinkler lateral.

METHODS

Wet- and dry-bulb temperature profiles were measured upwind and at three distances downwind from an operating sprinkler lateral. The site was an irrigated field with about 0.3 m of top growth. The upwind mast was located 10 m west of a north-south lateral 99 m long. The lateral was placed 95 m east from the western boundary of the alfalfa. The three downwind masts were 10, 22, and 44 m east of the lateral. During observations winds were westerly. Distances from the lateral were corrected for wind deviation from true west. A 30-m wide barley (*Hordeum vulgare* L.) field separated the alfalfa from a 400-m wide bean (*Phaseolus* sp.) field on the west. Although longer fetch would have been preferred, the field was similar in size to many farmers' fields and the data were analyzed in such a manner as to account for any fluctuations that may have occurred due to the shorter than desirable fetch.

Wet- and dry-bulb temperatures were measured with copper-constantan thermocouples in aspirated shields on a mast at 1, 2, 4, and 6-m elevations. A diagram of an individual sensing unit is shown in Fig. 1. The dry-bulb sensor was one pair of 26-gauge, copper-constantan thermocouple wires twisted and soldered with stainless steel solder. The thermocouple junction was potted with silicone rubber in a 12-mm length of 2.5-mm outer diameter (OD) nylon tube. The wet-bulb sensor was a modification of one developed by Collins (2) similar to one of Lourence and Pruitt (9). It was made of 36-gauge, copper-constantan thermocouple wire inserted in 100-mm of 1.9-mm OD ceramic tubing sealed with silicone rubber on the end. The thermocouple was 15 to 20 mm from the sealed end. The ceramic tube was connected to a formed nylon tube that led to a water supply. The lead passed through the bottle, was joined to 26-gauge wire, and passed to a multipoint recorder with a thermocouple reference unit. Both the wet- and dry-bulb thermocouples had time constants of approximately 20 seconds.

The shielding consisted of an outer PVC pipe (1 inch size—30 mm ID) 260 mm long coated on the inside with aluminum foil and on the outside with aluminized mylar, and of an inner PVC pipe (½ inch size—17.5 mm ID) 200 mm long coated inside and outside with aluminum foil. This was centered in the outer pipe with small styrofoam blocks. The innertube was recessed 60 mm to prevent direct solar radiation from reaching the sensor. A butterfly valve was placed between the sensing unit and mast to regulate airflow. Although airflow velocity was difficult to measure accurately, the flow was maintained between 4 and 8 m/s through the unit. A vacuum cleaner was used to draw air through the four sensors on each tower.

The assembly produced relatively trouble-free measurements equal to those of an Assmann Psychrometer.

One multipoint recorder with an accuracy of ± 0.13 C was placed near the base of each tower in a small enclosure. Thermocouples were scanned on the average of two times per minute. The windspeed profile was measured with a Thornthwaite wind profile register system with matched cups at heights of 20, 40, 80, 160, 240, and 320 cm above the soil surface. The counters were read every 5 to 10 minutes, permitting average windspeeds for that interval. Wind direction was monitored with a wind vane attached to a recorder giving a continuous record with a 10° resolution.

A 76 mm (3-inch) sprinkler lateral was used with 3.2 mm (⅛-inch) single nozzles in sprinkler heads on 700-mm risers at 6.2-m intervals. The sprinkler heads were held stationary and ejected the water at 30° above the horizontal along the lateral. A flow of 0.2 liters/second at a pressure of 3.5 bars (3.2 gpm at 50 psi) produced a spray reaching a height of 3 m and a distance of about 13 m, thus providing good overlap. Except for some wind distortion, this arrangement provided a line source.

During each run, meteorological data were collected for 1 hour prior to operating the sprinklers and then for 15 to 30 minutes while sprinkling. The data for the upwind tower were used as a reference for comparison with the other towers and as a basis for selecting the most stable 5-minute intervals for averaging. Runs were made when conditions were fairly stable so that the boundary conditions could be expected to hold prior to and during the time the sprinkler lateral was operated. The sprinkler-induced temperature changes were calculated assuming the same relationship would have held between upwind and downwind masts during sprinkling as before.

RESULTS AND DISCUSSION

The irrigated tracts in southern Idaho are surrounded by large arid areas. Noncropped fields are also interspersed within each tract. During the growing season there is typically an advection of sensible heat from the dry areas to fields of well-watered, actively growing crops where evaporative cooling occurs. Daytime temperature inversions frequently exist in the first few meters above the well-watered crops. Lapse temperature profiles are typical above this inversion layer and over drier fields that are either harvested, mature, or fallow.

The varied nature of the surroundings produced wide variations in the temperature measured at a given point above the crop. The dry-bulb temperature record exhibited amplitudes of up to 1 C while the wet-bulb trace fluctuated over a 2 C range, both having periods of about 1 minute. Averaging temperature measurements over 5-minute intervals produced an accuracy of about ±0.2 C for the dry-bulb temperature and about ±0.4 C for the wet-bulb.

The depression in dry-bulb temperature caused by sprinker operation is listed in Table 2 as a function of height above the soil and distance downwind from the lateral. Also presented are the average dry-bulb temperature, relative humidity, and windspeed for each run. For August 12 the data for the two lower levels at 16.7m downwind may be questionable, as mist

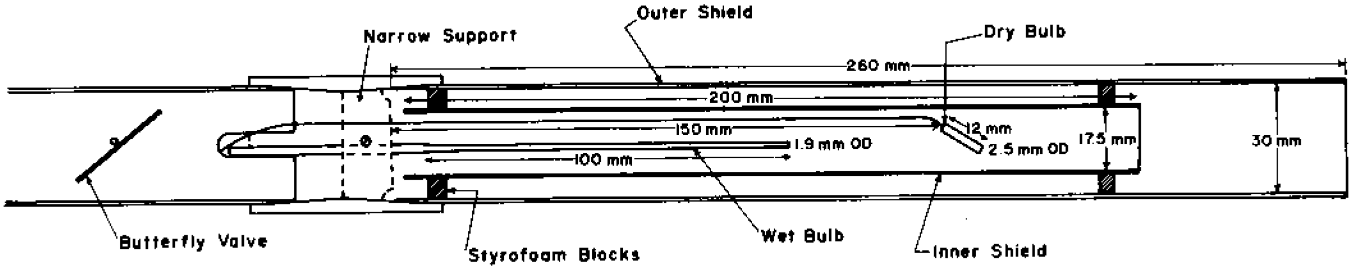

Fig. 1. Cross section of dry-bulb and wet-bulb temperature sensing unit.

Table 2. Temperature depressions observed downwind from an operating sprinkler lateral, 1970.

	Temperature Depression, C														
	12 Aug, 1500-1600			13 Aug, 1500-1600			14 Aug, 1100-1200			14 Aug, 1300-1600			14 Aug, 1500-1600		
	Distance downwind from lateral, m														
	16.7	36.6	67	10	22.8	45	10	22.8	45	14.7	30.5	61	10	22.8	45
Height															
6m	0.1	0.1	0	0.1	0.1	0.2	0	0.2	0.1	0.1	0	0.2	0.1	0.1	0.2
4m	0.5	0.2	-0.1	0.3	0.2	0.2	0	0.3	0.1	0.2	0.2	0.2	0.2	0.1	0.1
2m	1.4	0.6	0	0.5	0.1	0.2	-0.2	0.4	0.2	0.4	0.3	0.2	0.4	0.3	0
Air Temp, C		31			27			22			23			26	
R.H., %		23			20			39			35			30	
Windspeed, m/s		2.9			3.7			3.1			3.3			3.2	

could have entered the sensors and evaporated from the dry-bulb thermocouple. Shields to protect against mist drift were installed on August 13 and were used for succeeding runs. The profile from the 10m mast of the 1100 run on August 14 appears inconsistent with the other data. No explanation is evident. Summary curves of the data are given in Fig. 2. Even though the curves could have been shifted somewhat Fig. 2 does show the magnitude in temperature depression experienced under the conditions of the study. These measured values are in close agreement with the estimates in Table 1.

The reduction in atmospheric cooling with elevation and distance downwind is the result of rapid vertical mixing by eddy diffusion. The magnitude of the changes in the horizontal direction is not expected to increase much with reduced windspeed, as strong vertical mixing exists under such conditions during the summer daylight hours.

For the most part, the addition of evaporated water vapor to the air passing through the spray is an adiabatic process. This reduces the dry-bulb temperature, increases vapor pressure, and does not change the wet-bulb temperature. Consistent with this, the wet-bulb temperature did not change significantly although the oscillations in wet-bulb temperature could have masked a half-degree change. Assuming a constant wet-bulb temperature and neglecting the August 12 run, with possible mist drift errors, vapor pressure increases due to spray evaporation were less than 0.8 mb.

A rotating sprinkler applies water from a jet, the droplets of which actually occupy a very small portion of the air volume above the crop at a given instant. Therefore, one cannot expect a large change in temperature and vapor pressure from a single operating lateral.

The magnitude of these changes can be compared with the modification in temperature and vapor pressure near the ground resulting from dry air passing over an actively growing crop. DeVries and Birch (3), comparing irrigated with dryland pastures in Australia, found a temperature decrease of 1 to 2 C, and a vapor pressure increase of 0.7 to 2.0 mb at the 1.25-m height with a 1 to 5-km irrigated fetch. Dyer and Crawford (4), studying the conditions at the lysimeter site at Davis, California, found that at the 1-m height, the air was cooled from 1 to 1.5 C after passing over 200 m of actively growing fetch. A transect of the San Joaquin Valley (5) revealed that air temperature was 1 to 2 C cooler in the irrigated areas. Vapor pressures appeared more variable ranging from 13 mb in the desert to over 20 mb in irrigated areas. The variation in vapor pressure appeared to represent cross sections of vapor pressure boundary layers generated over recently irrigated fields adjacent to the traverse.

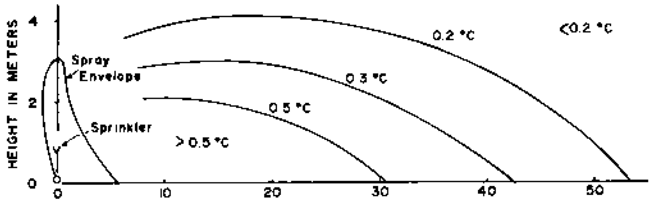

Fig. 2. Dry-bulb temperature depression downwind from an operating sprinkler lateral.

CONCLUSIONS

Although the evaporation of sprinkler spray from an operating sprinkler lateral does modify the temperature and vapor pressure downwind, the effects are small when considered against the background of the actively transpiring crop. Compared with diurnal and cyclonic temperature fluctuations, sprinkler effects are very small.

Even though evaporation of water from wetted plants may significantly influence the temperature and water balance of these plants, the change in air temperature and absolute humidity downwind from the sprinklers is not likely to cause a major change in plant growth or in consumptive use of water.

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