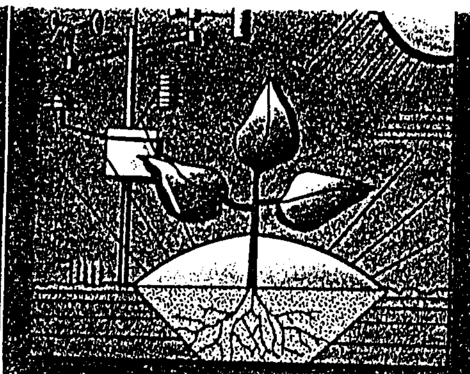

EVAPOTRANSPIRATION AND IRRIGATION SCHEDULING

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Scheduling Effects on Evapotranspiration with Overhead and Below Canopy Application

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ABSTRACT

The method of water application can influence water loss distribution when irrigating a crop canopy. The Cupid-DPE model was used to evaluate water loss during irrigation with a moving lateral system above a corn canopy. Comparisons were made based on total water loss and loss distribution between overhead sprinklers (impact and spray) and below canopy (LEPA device) water application, as well as irrigation timing (daytime versus nighttime). Model results indicate that application methods, such as LEPA, which apply irrigation water below much of the canopy can potentially reduce water loss compared to overhead sprinkler systems. For daytime irrigation this reduction was up to 18%. This same advantage was also found for nighttime irrigation, although the differences in water loss were reduced. There was essentially no difference in water loss for the day after irrigation, regardless of the application method.

Keywords. Sprinkler, LEPA, Evaporation, Transpiration, Canopy

INTRODUCTION

Water applied to crops is used most effectively when it enters directly into the transpiration stream or is held in storage to meet plant water demands. However, depending on the irrigation application method, irrigated water can be subject to direct evaporation of droplets, wind drift, and evaporation from the wetted canopy and soil. Evaporation rate is influenced by the total available incoming energy, and the energy exchange between the irrigation water based on its relative difference in temperature compared to the air, canopy, and soil.

The mode of sprinkler application can influence water loss distribution and total loss. For example, systems such as LEPA reduce canopy evaporation by applying water below much of the plant leaf area. Because of the lowered resistance of direct evaporation from wetted leaves compared to transpiration through stomata, net water loss can decrease compared to sprinkler systems that wet the entire plant (Norman and Campbell, 1983). A management option that has also been suggested to reduce net water loss is to irrigate at night when evaporative demands are lower. The effectiveness of this practice depends on soil water availability to meet evapotranspiration (ET) demands prior to irrigation, and how the shift in water demand continues throughout the day. Environmental conditions during the night, including wind speed, temperature, and humidity, can also influence this net effect.

The objective of this study was to evaluate the effect of above and below canopy irrigation, and timing on water loss distribution and efficiency. Comparisons were made based on model estimates of transpiration, evaporation from the wetted canopy and soil, droplet evaporation, and total ET. The Cupid-DPE energy balance, droplet evaporation model (Thompson et al., 1993, 1994) was used to determine the distribution of water loss.

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PROCEDURE

A 5-day period of weather data for modeling was selected from available measurements taken at the USDA-ARS research laboratory located near Bushland, TX (35.2 deg. N. Lat.; 102.1 deg. W long.; 1,170 m elev.). The Cupid-DPE model has previously been validated for sprinkler irrigation using field lysimeters at the Bushland site (Thompson et al., 1994; Martin, 1991). Each simulation was based on five consecutive days; three prior to the irrigation to establish the required environmental profiles, the day of irrigation, and the day following irrigation. Conditions considered included above and below canopy water application, and two different times of irrigation application. Depth of application was 25 mm for each test.

The sprinklers simulated included an impact, spray, and LEPA device. The impact sprinklers modeled were positioned 4.3 m above the soil surface. Body angle was 6 degrees, nozzle diameter was 6.7 mm, water pressure was 215 kPa, and average flow rate was 6.0 L min^{-1} m^{-1}. Spray sprinklers modeled were located 1.5 m above the ground, having a flat deflection plate, a nozzle diameter of 3.2 mm, water pressure of 232 kPa, and average flow rate of 6.4 L min^{-1} m^{-1}. The LEPA devices were modeled for the following conditions: water discharge below the canopy (typical with sock attachments), all water impounded using small reservoirs to facilitate infiltration, infiltration completed within 5 minutes of application, and every furrow irrigated. In practice, depending on the crop and row spacing, irrigators may water alternate furrows and increase the application depth per furrow. This normally increases the time required for infiltration and reduces the surface area wetted. Because less surface is wetted, soil evaporation tends to decrease, but the rate per wetted area increases due to increased duration of standing water on the surface. Less wetted surface would also increase the soil surface sensible heat load, which in turn would increase the potential evaporation rate. The net result of alternate furrow application would probably be to decrease net soil evaporation, the exact amount depending on leaf area (LAI), initial soil water content, and the time needed to infiltrate all standing water (normally less than 30 minutes). Assuming that water was quickly absorbed into the plant, the effect of alternate row irrigation on transpiration should be minimal. The approach taken in this study is the simpler case of wetting the entire surface.

Irrigation durations simulated were 115, 45, and 25 min., with peak application rates of 18, 68, and 120 mm h^{-1}, respectively for the impact, spray, and LEPA application devices. Irrigation water temperature was 22.1°C, supplied from a surface reservoir. All irrigations were scheduled on the fourth day of simulation. Irrigation began at approximately 00:30 a.m. for nighttime application, and approximately 12:30 p.m. for daytime irrigation. Initial soil water tensions were between 0.5 to 1.5 MPa, with the soil drier near the surface.

The upper boundary layer was assumed to be unaffected by irrigation, and was fixed at a height of 6 m above the ground. Crop height was 1.2 m with a maximum LAI of 3.0. Although the model is one dimensional, advection can be approximated by varying the height of this boundary layer; the closer to the soil surface the greater this affect. Based on Bushland conditions, the 6-m height was determined to be appropriate (Thompson et al., 1994). The wind speed was measured at a 10-m height and was extrapolated down to a 6-m height.

RESULTS AND DISCUSSION

Environmental conditions for the day of irrigation are listed in Table 1. Nighttime air temperatures were near 21°C from midnight to 2:00 a.m., with wind speeds between 5 to 8 m s^{-1} until sunrise. Humidities were near 35%, resulting in moderate ET demands. Conditions near the time of daytime irrigation were for temperatures near 31°C, wind speeds near 7 m s^{-1}, and humidities near 15%. A summary of the predicted water loss distributions are listed in Table 2 for the day of irrigation application, and in Table 3 for the day after application.

Table 1. Summary of diurnal environmental parameters for the day of irrigation.

Hour of Day	Wind Speed ($m\ s^{-1}$)	Solar Radiation ($W\ m^{-2}$)	Dry Bulb Temp (°C)	Vapor Pres (kPa)
0.25	5.7	0.0	21.5	1.42
1.25	6.8	0.0	21.0	1.42
2.25	7.6	0.0	20.7	1.48
3.25	6.9	0.0	20.1	1.51
4.25	5.9	0.0	19.8	1.50
5.25	5.2	0.0	19.3	1.50
6.25	5.3	41.2	19.2	1.53
7.25	5.5	138.8	20.0	1.61
8.25	8.7	427.5	23.3	1.68
9.25	8.5	610.4	25.3	1.75
10.25	7.6	785.7	27.6	1.77
11.25	7.0	911.8	28.9	1.73
12.25	7.1	976.8	30.3	1.70
13.25	7.5	792.0	31.0	1.56
14.25	7.8	606.4	31.0	1.60
15.25	7.1	521.1	31.0	1.59
16.25	7.6	649.5	31.5	1.59
17.25	8.4	466.5	31.8	1.56
18.25	8.0	277.8	31.6	1.55
19.25	6.8	76.4	30.6	1.43
20.25	3.8	0.0	27.5	1.37
21.25	4.1	0.0	25.7	1.34
22.25	4.3	0.0	24.7	1.41
23.25	4.2	0.0	24.1	1.38

Table 2. Predicted water loss distribution for day of irrigation, daytime or nighttime application, and soil moisture between 0.5 and 1.5 MPa tension.

	Transpiration	Canopy Evaporation	Soil Evaporation	Droplet Evaporation	Total
Daytime Appl.			(mm)		
Impact Sprinkler	4.57	2.75	2.43	0.050	9.80
Spray Sprinkler	5.00	1.75	2.47	0.044	9.26
LEPA Device	5.76	0	2.55	0	8.31
No Irrigation	5.31	0	2.36	0	7.67
Nighttime Appl.					
Impact Sprinkler	5.84	1.42	2.40	0.048	9.71
Spray Sprinkler	5.84	1.21	2.43	0.052	9.53
LEPA Device	6.04	0	2.47	0	8.51
No Irrigation	5.31	0	2.36	0	7.67

Table 3. Predicted water loss distribution for day after irrigation, daytime or nighttime application.

	Transpiration	Canopy Evaporation	Soil Evaporation	Droplet Evaporation	Total
Daytime Appl.			(mm)		
Impact Sprinkler	5.89	0	1.84	0	7.73
Spray Sprinkler	5.88	0	1.84	0	7.72
LEPA Device	5.87	0	1.85	0	7.72
No Irrigation	5.38	0	1.94	0	7.32
Nighttime Appl.					
Impact Sprinkler	5.87	0	1.83	0	7.70
Spray Sprinkler	5.89	0	1.84	0	7.73
LEPA Device	5.88	0	1.84	0	7.72
No Irrigation	5.38	0	1.94	0	7.32

From Table 2, total predicted ET for the day of irrigation assuming no irrigation was applied, was 7.67 mm. This was distributed between nearly 70% transpiration and 30% soil evaporation. This is shown graphically in Fig. 1, where transpiration rate reached a maximum of about 0.53 mm h^{-1} just after noontime. For daytime impact irrigation (Fig. 2), the predicted transpiration rate dropped sharply with the onset of irrigation (about 67% decrease), with a subsequent increase in canopy evaporation, decrease in

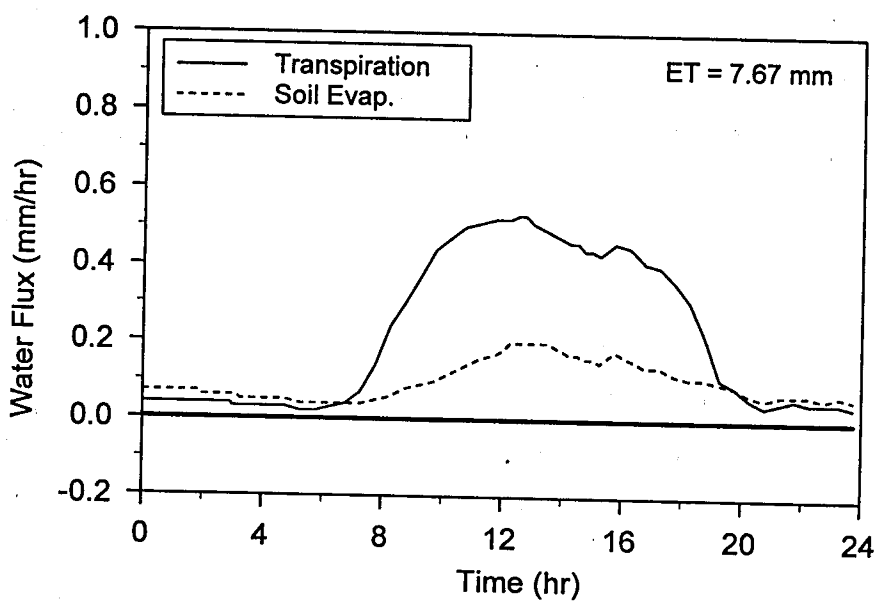

Figure 1. Predicted diurnal water budget for the day of irrigation assuming no irrigation was applied.

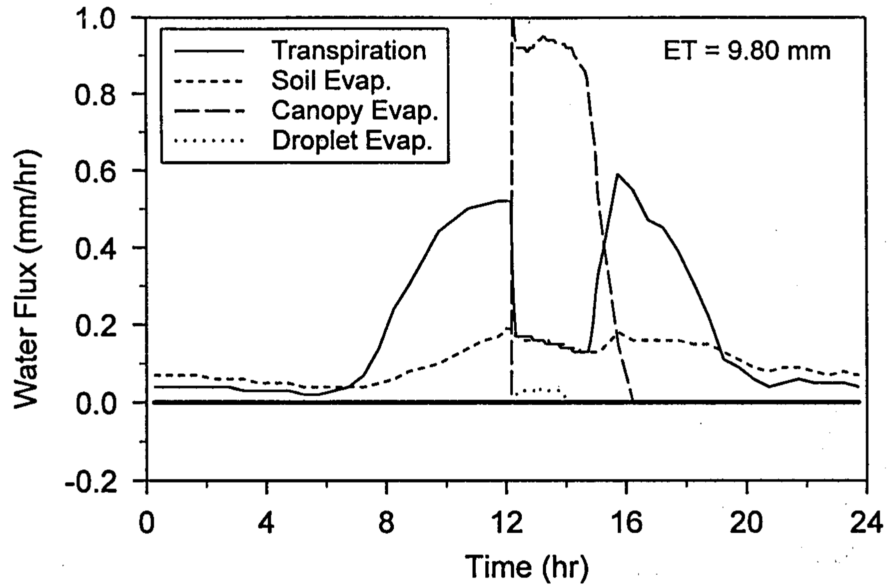

Figure 2. Predicted diurnal water budget for the day of irrigation; impact sprinkler, daytime application from 12:15 to 14:10.

soil evaporation, and a slight amount of droplet evaporation. The predicted canopy evaporation remained high until the end of irrigation, becoming negligible within an hour and a half after irrigation ended. Transpiration recovered during this time, the maximum rate exceeding the rate prior to irrigation by nearly 14%, indicating that transpiration was somewhat water limiting prior to irrigation. Total predicted ET for the day was 9.80 mm, an increase of about 28% compared to the no-irrigation condition.

Comparing daytime irrigation water loss distribution between impact and spray sprinklers, the overall effect was much the same, the biggest difference being that because spray irrigation duration was nearly 70 minutes less, the shift from transpiration to canopy evaporation was not as significant. As shown in Table 2, total predicted canopy evaporation was 1 mm less than predicted for the impact sprinkler but transpiration was more than 0.4 mm greater. Total predicted water loss for the day was 9.26 mm compared to 9.80 mm for impact irrigation.

The results for LEPA irrigation are shown in Fig. 3. Because LEPA irrigation has the potential to not wet the canopy, the shift from transpiration to canopy evaporation does not occur. Note that the predicted transpiration rate now increases nearly 25% with the beginning of irrigation (again indicating that transpiration was water limiting prior to irrigation), with the predicted rate after 16:00 being nearly identical to that of impact and spray sprinkler irrigation. (The drop in transpiration rate at 15:30 was due to intermittent cloud cover.) Also, because water droplets were not being discharged into the air, there was no droplet evaporation. This is a minor advantage since total water loss for the day caused by direct evaporation of droplets was less than 1%. However, a greater advantage for windy climates, such as found in the High Plains region, is elimination of offsite drift and an increase in application uniformity. Total predicted water loss for the day was 8.31 mm, 8% greater than the no-irrigation case, but 11% and 18% less than for the spray and impact sprinkler application methods, respectively. This reduction was primarily caused by the elimination of canopy wetting.

Comparisons were next made assuming nighttime irrigation. All other factors, including application depth, were the same as for daytime irrigation. Water loss distribution for impact sprinkler irrigation is shown in Fig. 4. The trends for spray irrigation are similar and are not shown. For both overhead sprinkler methods compared to daytime irrigation, canopy evaporation was reduced because the canopy was wetted during the night when evaporative demands were lower, with the canopy drying just

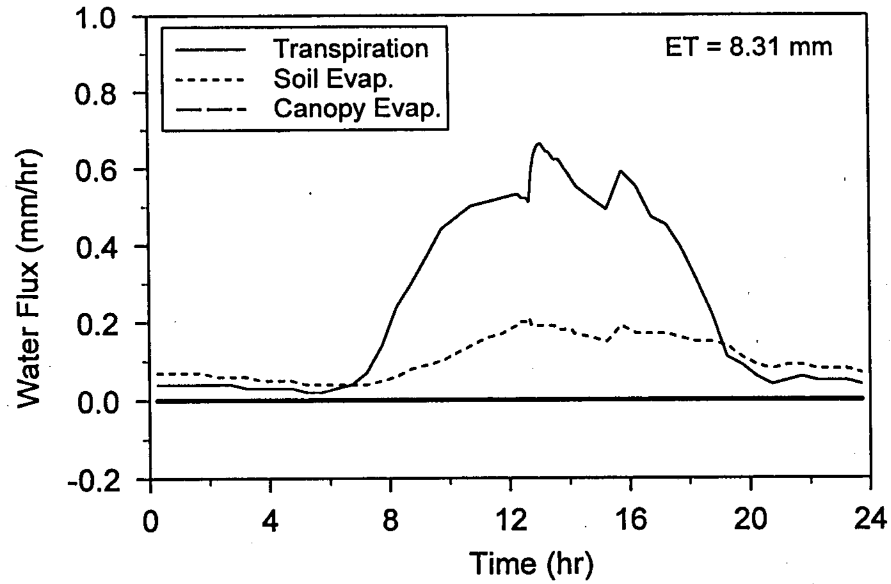

Figure 3. Predicted diurnal water budget for the day of irrigation; LEPA device, daytime application from 12:40 to 13:05.

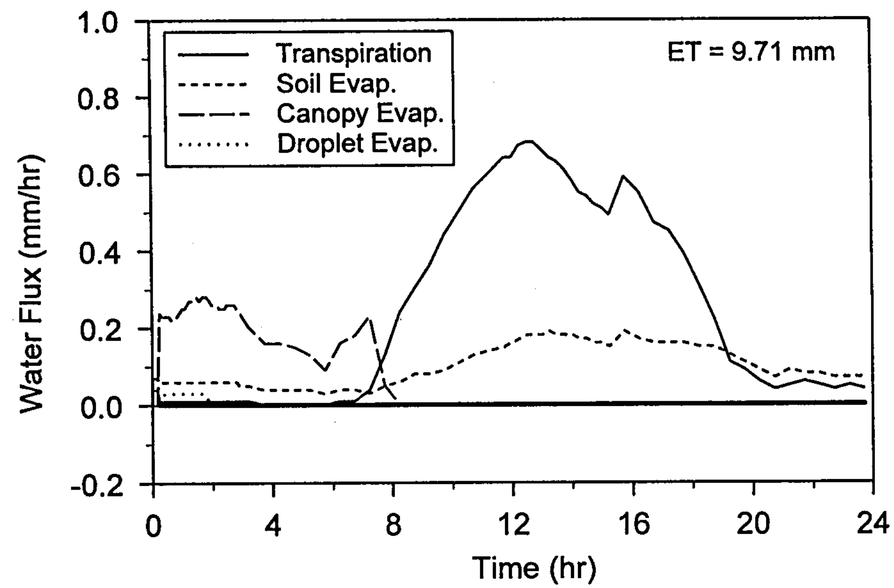

Figure 4. Predicted diurnal water budget for the day of irrigation; impact sprinkler, nighttime application from 00:15 to 02:10.

after sunrise. Predicted canopy evaporation for the impact sprinkler irrigation was reduced nearly half compared to daytime application, as noted in Table 2. This is because the canopy is limited in the amount of water that can be held on the leaves before it begins to drip off. Therefore, even though the leaves remain wet for a longer duration with nighttime irrigation, the evaporation rate is much lower (nearly one-fourth the daytime rate). Once the sun rises, water remaining on the canopy evaporates at a greater rate, but because it is not replenished by additional irrigation, total canopy evaporation is reduced. Total predicted transpiration for the day, assuming nighttime irrigation, was essentially the same for both types of overhead irrigation, but less than for LEPA application. The net effect of nighttime irrigation compared to daytime irrigation was a slight increase in predicted daily ET for LEPA and spray irrigation, and a slight decrease in predicted ET for irrigation with impact sprinklers. As previously noted, the drop in transpiration rate at 15:30 and subsequent recovery by 16:00 was due to intermittent cloud cover. Its effect is more pronounced here and in Fig. 3 for daytime LEPA irrigation than in Fig. 1 for the no-irrigation case because prior to irrigation, transpiration rate was somewhat water limiting. This response is not evident in Fig. 2 for daytime impact sprinkler irrigation because timing of cloud cover coincided with the end of irrigation and recovery of transpiration and drying of the canopy.

For the day after irrigation (Table 3), total predicted ET was nearly identical for the three methods of irrigation, regardless of the time that water had been applied the previous day. This would be expected because sufficient water had been applied the previous day with each of the methods so that water was not limiting. Compared to the no-irrigation case, daily ET increased about 8%.

CONCLUSIONS

Application methods, such as LEPA, which apply irrigation water below much of the canopy, can potentially reduce total water loss compared to overhead sprinkler systems. Based on model results from this study, water loss was reduced by up to 18% for the day of irrigation compared to overhead application methods. Actual reductions will depend on LAI, application duration, sprinkler package, and environmental conditions during application. Although not examined here, frequency of irrigation may also influence this, depending on how wet the soil surface remains. Typically the wetter the soil, the less difference between daily water loss for different application methods and timing (Thompson et al., 1995). Other factors that may contribute to differences include row spacing, maintenance of furrow reservoirs, the use of alternate furrow application, and the care taken in maintaining consistent management of the irrigation system and field.

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