9-1-1997

Testing of a Water Loss Distribution Model for Moving Sprinkler Systems

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Thompson, Allen L.; Martin, Derrel L.; Norman, John M.; Tolk, Judy A.; Gilley, James R.; and Schneider, Arlan D., "Testing of a Water Loss Distribution Model for Moving Sprinkler Systems" (1997). *Biological Systems Engineering: Papers and Publications*. 32.
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TESTING OF A WATER LOSS DISTRIBUTION MODEL FOR MOVING SPRINKLER SYSTEMS

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ABSTRACT. *Field water balance measurements using monolithic lysimeters were used in validating the Cupid-DPE model for predicting water loss partitioning during sprinkler irrigation from a moving lateral system fitted with impact sprinklers and spray nozzles. The model combines equations governing water droplet evaporation and droplet ballistics with a comprehensive plant-environment energy balance model. Comparisons indicate good agreement between measured and modeled transpiration, and the measured and modeled soil evaporation during the day of irrigation. Total predicted evapotranspiration during the day of irrigation was greater than measured totals using the monolithic lysimeters. However, part of this difference was because the lysimeters could not measure water use during irrigation. Total measured and predicted evapotranspiration agreed well for the day following irrigation. Predicted soil evaporation rates matched well for the period immediately following irrigation, and cumulative soil evaporation was nearly identical to the measured total through the end of the next day. During irrigation, the main water loss was shifted from transpiration to evaporation of the wetted-canopy. For equal application volumes, the duration of this effect was greater using impact sprinklers due to the greater wetted diameter and lower average application rate compared to spray nozzles. Predicted water flux rates during irrigation were up to 50% greater for canopy evaporation than for transpiration rates predicted immediately prior to the start of irrigation. Canopy evaporation amounted to 69% and 63% of the total predicted water use during impact and spray irrigation, respectively. It also was 0.69 and 0.28 mm greater, respectively, than the predicted transpiration total during this same time span assuming no irrigation had been applied. About 13 and 5% of the water applied by overhead sprinkling was evaporated or transpired during impact and spray irrigation, respectively. However, the net increase in predicted water loss during irrigation was only 5.8% and 2.4% of the irrigated water depth applied for the impact and spray cases, respectively, because transpiration and soil evaporation would have occurred even without irrigation. Although droplet evaporation represented less than 1% of the total water loss for the day using either type of sprinkler, irrigation water did influence the energy transfer between the plant-environment and water droplets during flight, on the canopy, and the soil.* **Keywords.** *Irrigation, Sprinkler systems, Modeling.*

Water distribution and application efficiency are important parameters to consider when evaluating the performance of an irrigation system. Water that is applied to crops is most effective when it enters directly into the transpiration stream and contributes to dry matter accumulation. However, water applied by overhead sprinkler systems is subject to environmental effects, including direct evaporation of droplets before they reach the canopy, and evaporation from the wetted leaves and soil. The amount of evaporation from the soil and wetted canopy is influenced by energy exchanges associated with the application of water at temperatures different than its surroundings, and by the amount of leaf area. Transpiration occurs even without irrigation, but the total amount will decrease as evaporation of water from the wetted canopy increases (Norman and Campbell, 1983). Because of the numerous interactions, predicting the actual loss from an irrigated crop requires careful analysis which is best accomplished by considering the energy balance of the plant environment with a droplet evaporation model.

Thompson et al. (1993) have presented a combined droplet evaporation-trajectory and plant-energy balance model, Cupid-DPEVAP. This model was validated for a solid-set irrigation system with impact sprinklers watering a corn canopy. The model was used to quantify the partitioning of water losses among droplet evaporation, evaporation from the wetted canopy and soil, and transpiration during irrigation.

The objective of this study was to validate the model during overhead sprinkler irrigation of a crop canopy when using a moving lateral system. Field measurements included soil evaporation, transpiration, total crop evapotranspiration (ET), irrigation applications, plant growth, soil water content, and required climatic parameters. Using a moving sprinkler system would be expected to be a more stringent test than for a solid-set system because of the dynamic

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Article has been reviewed and approved for publication by the Soil & Water Div. of ASAE. Presented as ASAE Paper No. 94-2174 (rev.).

Scientific Journal No. 12,267, Missouri Agricultural Experiment Station, University of Missouri, Columbia, Mo.

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nature of the application rate, as well as the environmental parameters and potential advection affects.

PROCEDURE

INSTRUMENTATION

Field measurements were conducted in 1989 at the USDA-ARS research laboratory located near Bushland, Texas (lat 35.2°N; long 102.1°W; 1170 m elev.). Two weighing lysimeters (Marek et al., 1988) containing monoliths of Pullman clay loam soil (Schneider et al., 1988), 3 × 3 m with a depth of 2.3 m, and centered in a 4.2 ha field, were used in collecting data. Mass changes in water for evapotranspiration (ET) were measured with a lever balance having a 100:1 mechanical advantage and counterbalanced with a 22.7 kg load cell resulting in a sensitivity of 0.05 mm of water. Measurements included crop transpiration, evaporation from the soil and canopy, and net irrigation applications. Micrometeorological measurements were recorded within each lysimeter. Air and dewpoint temperatures, humidity, and barometric pressure were measured in a standard weather shelter at 1.5 m elevation. Solar radiation, air temperature, and wind speed were measured at an elevation of 2 m, with additional measurements of wind speed and air temperature measured at 10 m elevation. The lysimeter and field energy balance instrumentation were sampled at 1 Hz and averaged for 5 min. The 5-min means were then composited into 30-min means.

Transpiration was measured in three to eight plants in each lysimeter by the heat balance method using Dynamax Inc. sap flux gauges based on designs by Baker and Van Bavel (1987). Measurements were recorded during 15-min intervals for selected days of irrigation. Total transpiration was estimated by multiplying the mean measured plant transpiration by the mean lysimeter plant density (approximately 6 plants m^{-2} over an area of 9 m^2). The plant canopy was a Pioneer corn variety (3124) with row spacings of 0.75 m.

Soil evaporation was measured outside of the monolithic lysimeters using two types of small lysimeters based on the techniques described by Klocke et al. (1990). The volumes of the micro and minilysimeters were 442 mL and 472 mL, respectively. The microlysimeters consisted of small aluminum rings which were refilled in the field daily. Soil samples were taken from the surface following irrigation, with evaporation measured two or three times a day for up to three days following an irrigation by weighing the change of mass of the microlysimeter and a support can. Minilysimeters were constructed of PVC pipe. These were filled with soil early in the growing season and capped on the bottom with an aluminum flashing sealed with silicon. The minilysimeters were weighed daily and removed from the field before irrigation. The amount of water to add to the minilysimeters was determined by measuring soil water content of the surface soil (down to 20 cm) the morning after an irrigation.

The lysimeter field was irrigated with a 450-m-long electrically powered, lateral-move sprinkler system capable of irrigating the two lysimeters simultaneously. At 100% timer setting, the control tower speed was about 2 m min^{-1}. Both ends of the lateral-move system operate for the selected time as determined by the system timer using a 1 min repeating cycle. The system was equipped to use impact sprinklers, spray nozzles with serrated plates, and LEPA devices (not reported here). Impact sprinklers were placed atop the 168-mm OD pipeline, 6.1 m apart and 4.3 m above the ground. Spray nozzles were spaced 1.52 m apart on drop tubes 1.5 m above the ground. Average discharge rates were approximately 6.0 and 6.4 L min^{-1} m^{-1}, respectively, for the impacts and sprays. Water pressure was approximately 220 and 234 kPa, and nozzle sizes were 6.7 and 3.2 mm, respectively, for the impact sprinklers and spray nozzles. Three 200-mm diameter tipping bucket rain gauges (0.25 mm tip^{-1}) were used to measure application depth which averaged approximately 25 mm/irrigation.

An adjustable mast was located near each lysimeter to support equipment for measuring air temperature, humidity, and wind speed at 1.0, 1.3, 2.0, and 2.8 m above the crop canopy. As the linear-move system approached the lysimeters, each mast was lowered to permit the system to pass. Measurement elevations during this time were 0.32, 0.62, 1.32, and 2.12 m above the soil surface. Air temperature within the crop canopy of the lysimeter and soil heat flux using soil heat flux plates were also measured. Plant height and leaf area index (LAI) of the crop were measured throughout the growing season. Soil water content was measured using neutron probes. Soil water content was maintained above 75% of field capacity during tests reported in this study. A more complete description of the field instrumentation and procedures can be found in Tolk et al. (1995) and Martin (1991).

MODELING PROCEDURES

Two irrigation events were selected for simulation to compare with measured water losses for each sprinkler type. These were days 186 (5 July) and 192 (11 July). Summaries of hourly measured weather input values for these two days are listed in tables 1 and 2, respectively. Irrigation water temperature for day 186 was 17.8°C, and 22.1°C for day 192. (Water was supplied from a reservoir filled from ground water wells, therefore water temperature

Table 1. Summary of diurnal environmental parameters for day 186 (5 July 1989)

Hour of Day	Wind Speed ($m\ s^{-1}$)	Solar Radiation ($W\ m^{-2}$)	Dry Bulb Temp (°C)	Vapor Pres (kPa)
0.25	4.1	0.0	20.2	1.35
1.25	3.4	0.0	18.7	1.38
2.25	4.3	0.0	18.9	1.35
3.25	3.9	0.0	17.9	1.35
4.25	3.6	0.0	17.8	1.33
5.25	3.4	0.0	15.9	1.29
6.25	3.1	56.6	16.1	1.24
7.25	4.3	233.8	18.9	1.40
8.25	5.6	435.0	21.6	1.51
9.25	5.9	635.3	23.9	1.59
10.25	5.6	805.2	25.5	1.57
11.25	4.1	937.3	27.1	1.44
12.25	4.5	995.0	28.4	1.37
13.25	4.6	991.8	29.7	1.19
14.25	5.2	948.8	30.6	1.09
15.25	4.9	843.5	31.0	1.04
16.25	5.5	676.6	31.3	1.02
17.25	5.8	476.5	31.1	0.96
18.25	5.7	267.3	30.7	1.00
19.25	5.7	81.3	29.5	1.07
20.25	4.9	0.0	26.3	1.67
21.25	3.7	0.0	23.4	1.09
22.25	3.1	0.0	21.3	1.07
23.25	3.8	0.0	20.3	1.07

Table 2. Summary of diurnal environmental parameters for day 192 (11 July 1989)

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

varied depending on when the reservoir was refilled.) Each simulation consisted of five total days; three prior to the irrigation to establish the required environmental profiles, the day of irrigation, and the day following irrigation. The model was executed using one-hour time increments, except that 5-min increments were used beginning 15 min before the start of irrigation and ending approximately 70 min after irrigation had ceased.

The upper boundary layer of environmental conditions was assumed to be unaffected by irrigation, and was fixed at a height of 6 m above the ground. To get environmental parameters at this height, wind speeds at 10 m were interpolated downward to 6 m based on the log wind profile and canopy height. Air temperatures measured at 1.5 and 10 m were nearly identical, therefore interpolations for temperature were not used. Dewpoint temperature and humidity were only measured at 1.5 m elevation, and were used without adjustment.

Although the model is one dimensional, advection can be approximated by varying the height of the upper boundary condition. The closer it is placed to the sprinkler and canopy, the greater the assumed effect of advection because of the steeper vapor pressure and temperature gradients. The prevailing hot, dry, windy conditions near Bushland lend themselves to greater advection effects. For an upper boundary height of 6 m, a difference of 1.5 m exists between the maximum droplet trajectory elevation (0.2 m above the impact sprinkler) and the height of the upper boundary condition. For situations where the advective conditions are less pronounced, this upper boundary can be raised. During irrigation, the environment below this boundary is influenced by the evaporation and transpiration through the energy balance. This feedback mechanism permits prediction of a realistic environment where previous water losses influence future losses.

To improve computational speed of the DPEVAP model, an empirical regression model (DPE), consisting of both linear and non-linear terms, was developed based on output from the DPEVAP model as a function of irrigation water temperature, droplet size, wind speed, air temperature, and vapor pressure. This permitted the use of 40 droplet sizes to represent the volume frequency distribution for each sprinkler type instead of the fewer than 10 droplet sizes that could only be used in the combined Cupid-DPEVAP model due to the computational time requirements of the DPEVAP model. The DPE regression model fit the DPEVAP predictions very closely, with R^2 values greater than 0.98 for all energy balance terms.

RESULTS AND DISCUSSION

A summary of field conditions during days 186 and 192 are listed in table 3. Figure 1 shows the application rate pattern for the impact sprinkler and spray nozzle for an application depth of approximately 25 mm. These values were determined using the lysimeters for an actual irrigation. Note that the impact sprinkler applied water over the lysimeter for about 115 min while the spray sprinkler application duration was about 45 min. Peak application rates were approximately 18 mm h^{-1} and 68 mm h^{-1} for the impact and spray, respectively. These application rates and distributions are similar to what would be found under a center pivot about midway from the pivot on a 400 m long lateral, with a system flow rate of approximately 2700 L min^{-1}. Under similar environmental conditions, the longer irrigation duration of the impact sprinkler should result in greater canopy evaporation for the same application depth. Soil evaporation might also be greater for the impact sprinkler because the wetted diameter is larger, therefore a given area would be wetted sooner than with the spray.

Table 3. Summary of field conditions for days 186 and 192

		Lysimeter					
		NE		SE			
Day	Water Temp (°C)	Sprinkler	Appl Depth (mm)	Sprinkler	Appl Depth (mm)	Plant Height (m)	LAI
186	17.8	—	—	Spray	22	0.83	2.4
192	22.1	Spray	27	Impact	23	1.14	3.3

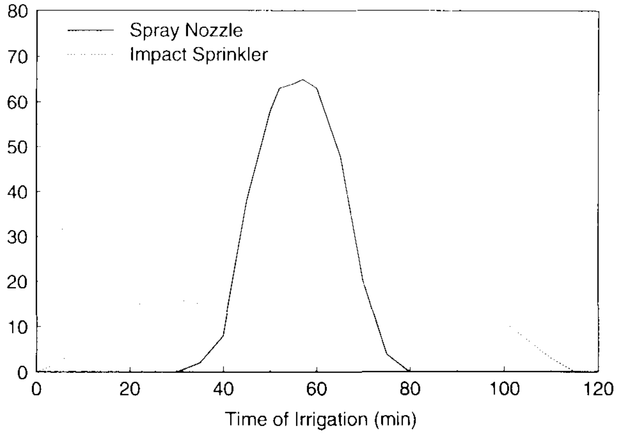

Figure 1–Application rate patterns for the impact sprinkler and spray nozzle.

Comparisons between transpiration amounts predicted by the model and sap flux measurements with irrigation for day 186 for the spray nozzle, and day 192 for the spray and impact sprinklers are shown in figures 2, 3, and 4, respectively. Sap flux measurements were based on eight plants within the lysimeter for day 186 and three plants for each of the lysimeters on day 192. Irrigation began at 12:05 on day 186 with the spray nozzle (southeast lysimeter, SE-lys), and lasted for 45 min. Values shown are 15 min averages. Note that the predicted rate is about 0.05 mm h^{-1} greater than the measured rate prior to irrigation. The measured rates began to decrease slightly as the irrigation lateral approached the lysimeter. The model predicted a more rapid decrease in transpiration with the onset of irrigation than was measured, and a faster recovery of transpiration rates after irrigation was completed. The measured minimum rate was about 0.08 mm h^{-1} less than predicted. Predicted rates were near pre-irrigation levels within 25 to 30 min after irrigation. The sap flux readings during the mid portion of irrigation indicated a slightly lower measured transpiration rate than the model predicted for two of the three irrigations. On average, predicted transpiration rates were lowered 80% during irrigation while measured rates were reduced about 83%. Predicted transpiration totals for the time period from 9:15 to 20:15 were 0.47 mm greater than measured (13% greater). This was primarily due to the quicker predicted recovery of transpiration after irrigation was completed. Because the reduction in transpiration rate is mainly due to water covering the plant leaves, differences between predicted and actual time of canopy drying will be reflected in these results. Predicted and measured rates were nearly identical from about 14:00 until the end of the day.

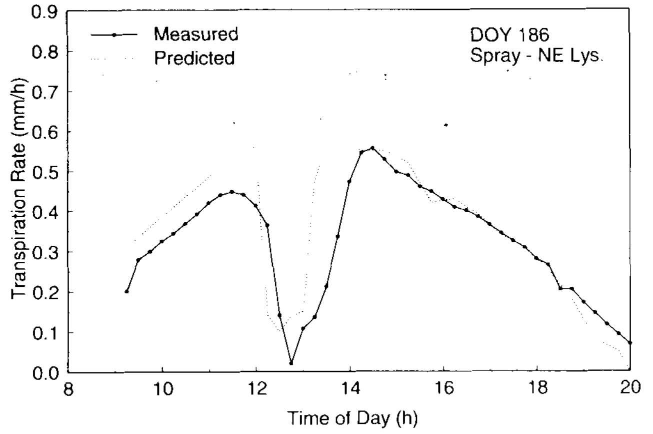

Figure 2–Comparison of measured and predicted transpiration rates for day 186, Spray irrigation. Irrigation was from 12:10 to 12:55 P.M.

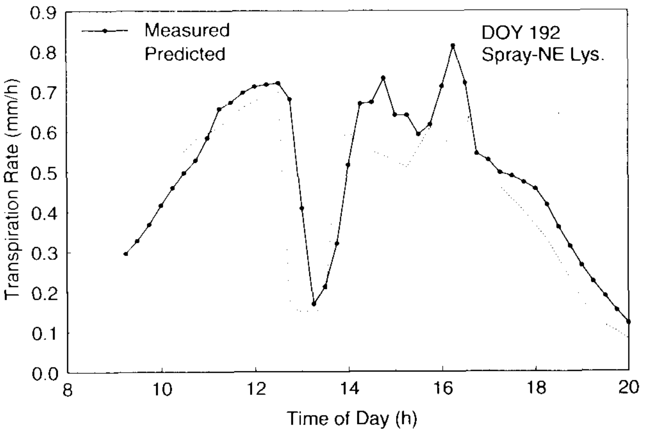

Figure 3–Comparison of measured and predicted transpiration rates for day 192, Spray irrigation. Irrigation was from 12:35 to 13:20 P.M.

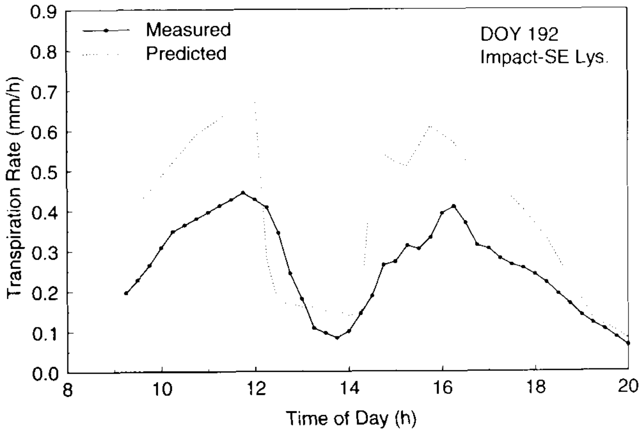

Figure 4–Comparison of measured and predicted transpiration rates for day 192, Impact irrigation. Irrigation was from 12:10 to 14:05 P.M.

Results shown in figures 3 and 4 are for day 192 for the spray (northeast lysimeter, NE-lys) and impact sprinklers (SE-lys), respectively. Wind velocities exceeded 7 m s^{-1} during much of the irrigation for day 192, but were about 4.5 m s^{-1} on day 186. For day 192, predicted transpiration rates compared very closely with measured rates prior to irrigation. Again, predicted rates decreased more rapidly with the start of irrigation, but the minimum rate and duration of the effect of irrigation was very well modeled. The overall trends between measured and predicted transpiration were very similar as was also the case for day 186. Total predicted and measured transpiration amounts from 9:15 to 20:15 were within 0.6 mm (11%). For the impact irrigated case, although the trends were well modeled, the predicted rates were significantly greater than measured, but very similar to the rates predicted for the spray irrigated lysimeter which was irrigated on the same day and at nearly the same time. The transpiration depth measured from 9:15 to 20:15 was only 67% of that measured for the spray irrigated lysimeter, even though the soil moisture, leaf area index (LAI), and plant height of the two lysimeters was nearly the same. Because only three sap flux gauges were available for use, any error in readings with a single gauge would have a large effect on the measured average and is most likely the cause for the differences here.

The comparison of measured soil evaporation rates with values predicted by the model are shown in figure 5. The time period covered is from three and a half hours after the end of irrigation on day 192 through day 193. Measurements are shown for the small portable lysimeters placed in both the furrow and wheel tracks of the lateral. The model uses a transfer coefficient to predict the soil evaporation rate, calibrated using measured air temperature and relative humidity 30 cm above the soil surface (Sauer et al., 1995; Norman et al., 1995). The predicted cumulative evaporation shown in figure 5 is for the spray irrigation case. The impact

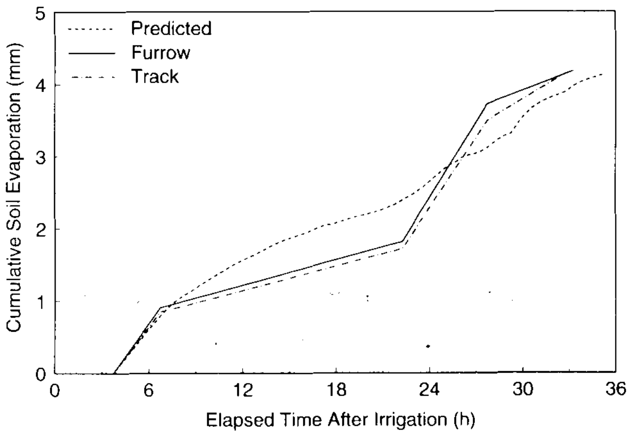

Figure 5–Comparison of measured and predicted soil evaporation rates for days 192 and 193 following irrigation on day 192.

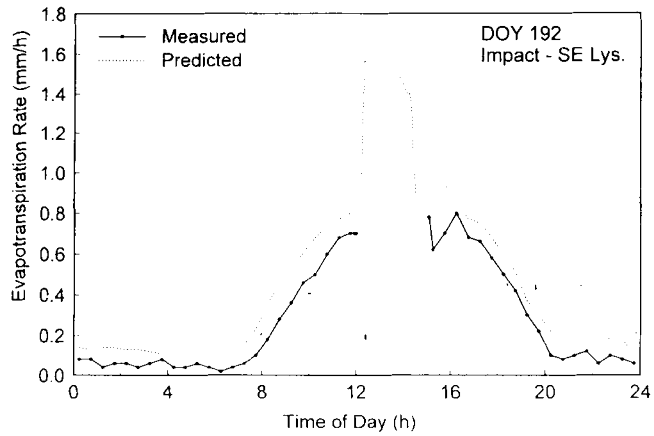

Figure 7–Comparison of measured and predicted evapotranspiration rates for day 192, Impact irrigation. Irrigation was from 12:10 to 14:05 P.M.

values were similar and are not included here. The predicted rate is nearly identical to the measured rate immediately after irrigation. Soil evaporation was overpredicted during the nighttime, but the maximum rate was again nearly identical to that measured for the day following irrigation but only of shorter duration. Total predicted soil evaporation for this entire time period was essentially the same as that measured.

The evapotranspiration (ET) for the spray and impact irrigated lysimeters on day 192 are shown in figures 6 and 7, respectively. The predicted ET rate for the spray application is slightly greater than the measured rates during the morning, but nearly identical after irrigation until sunset. During irrigation (12:35 to 13:20), the model indicated an increase in ET rates as the canopy and soil were wetted. (It was not possible to determine an exact measurement of ET from the lysimeter during irrigation because of the simultaneous addition of water; therefore direct measurements during this time are not shown.) During irrigation, the model predicted a sharp rise in ET rates due primarily to canopy evaporation from the wetted leaves. For the impact irrigated case (fig. 7), the model predicted a somewhat higher ET rate than measured during the entire day, the two being more similar after irrigation than before. Again, no measurements of ET from the lysimeter were available for comparison during irrigation. Maximum predicted rates were similar for the impact and spray irrigation, the duration of this effect lasting longer for the impact case because of the longer duration of irrigation compared to the spray. The drop and then sharp increase in both predicted and measured ET rates following irrigation was due to intermittent cloud cover between 15:00 and 16:00 in the afternoon. The same effect is apparent in figure 6 for the spray case although not as pronounced.

Because the lysimeter cannot be used to make measurement comparisons during irrigation, additional comparisons were made for the day following irrigation. Results shown in table 4 are for measured and predicted ET for each day of and the day following irrigation. For each irrigated case, the predicted ET totals are nearly 3 mm, or more, greater than the measured lysimeter values. However, during day 186 and 192 for the spray irrigation, the lysimeter could not record ET for 1.5 h during and immediately after irrigation. Likewise for day 192 for impact irrigation, the lysimeter could not record ET for 2.25 h during and after irrigation. Because of canopy wetness, this is the very time when the model predicted the greatest water loss rates for the day. Unfortunately, there

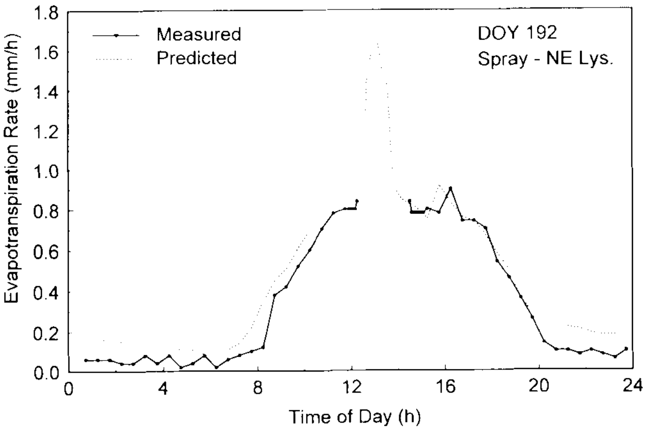

Figure 6–Comparison of measured and predicted evapotranspiration rates for day 192, Spray irrigation. Irrigation was from 12:35 to 13:20 P.M.

Table 4. Measured and predicted evapotranspiration totals for the day of and the day after irrigation, and transpiration totals measured from 9:15 to 20:15 for the day of irrigation

		ET Summation (mm)		Transpiration* (mm)	
	DOY	Lysimeter Measured	Pre-dicted	Stem Gage Meas.	Pre-dicted
Spray-SElys	186	7.29†	10.27	3.55	4.02
	187	9.30	10.14		
Spray-NElys	192	7.38†	10.97	5.44	4.84
	193	8.91	8.53		
Impact-NElys	192	5.96†	11.51	2.87	4.33
	193	7.95	8.68		

* Transpiration totals from 9:15 to 20:15.

† For spray and impact irrigation, no measured values were available for approximately 1.5 and 2.25 h, respectively during the period of irrigation.

currently is no easy method to measure canopy evaporation during irrigation. In order to estimate water loss during irrigation, the amount of water held on the leaves must be known. However, this amount can change due to the length of time that leaves have been wetted and age of the leaf: younger leaves have more pubescence and therefore are capable of holding more water than older leaves for the same LAI. Under most conditions, if wetting of the leaves by sprinklers is less than 10 to 15 min, water will remain as droplets. If irrigation continues past this point, droplets tend to coalesce on the leaves resulting in thin films and less total water held than when stored as droplets. These films form on both sides of the leaf. J. M. Norman (based on unpublished field measurements on corn canopies in Nebraska) found that the amount of water held on leaves after films form is approximately equivalent to a typical film thickness of 0.05 mm per side of leaf for a total of 0.1 mm per leaf. This is the value that has been used in the model. The thicker this water film layer, the greater the influence of canopy evaporation, the lower the daily transpiration, and the longer the time required for leaves to completely dry after irrigation has ended. In this study, leaves were visually observed to dry within 30 min after irrigation ended. This was subsequently observed by Tolk et al. (1995) in a later study using these same lysimeters and irrigation system. As noted previously, the Cupid-DPE model also predicted a drying time of 25 to 30 min. Thicker films up to 0.15 mm/side were also tested in the model, but predicted leaf drying required an additional 30 to 60 min, indicating that those amounts were too large. Therefore, even though independent measurements of canopy evaporation were not available for this study, the predicted drying behavior is consistent with field observations made during the study.

In table 4, for the day following each irrigation, predictions for total daily ET for the spray irrigated case were within 9% (high) for day 187 and within 4% (low) for day 193. For the day following impact irrigation, the model was 9% higher than measured. Therefore, based on these and the previous comparisons, the model appears to be very reasonable in its predictions.

Following the independent validation-comparisons based on soil evaporation, transpiration, and total ET rate, the model was used to predict the partitioning of water losses for both the spray nozzles and impact sprinklers, including droplet evaporation losses. Figures 8 and 9 show these rates for the spray and impact cases, respectively, for day 192. Figure 10 is included to show what the predicted losses would have been had irrigation not been applied that day.

As expected, the model predicted nearly the same rate of water usage prior to irrigation, as noted in each of the three figures. Transpiration represents the dominant water usage until the canopy was wetted, at which time canopy evaporation became the major water loss component, with transpiration about 20% of its former rate and peak canopy evaporation over 50% greater than peak transpiration rate had been (figs. 8 and 9). Because the irrigation duration with impact sprinklers was greater, the loss due to canopy evaporation continued longer than for the spray irrigated area. In each case, recovery of transpiration was complete within 30 min after irrigation ended. The decrease and subsequent increase in transpiration rate at about 15:00, as shown in each of figures 8, 9, and 10, was from a reduction in solar radiation due to cloud cover, as noted earlier. Soil evaporation for the impact simulation was water limiting prior to irrigation, as noted in figure 9. However, during and immediately after irrigation, this rate increased, being nearly three times as great as for the non-irrigated case shown in figure 10. Although this may seem high for soil

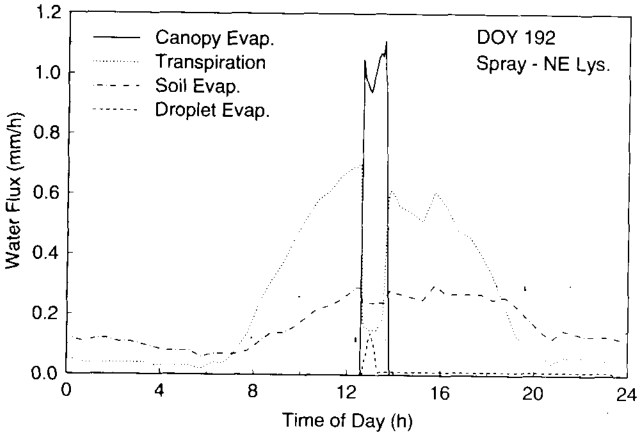

Figure 8–Predicted diurnal water budget for day 192, Spray irrigation. Irrigation was from 12:35 to 13:20 P.M.

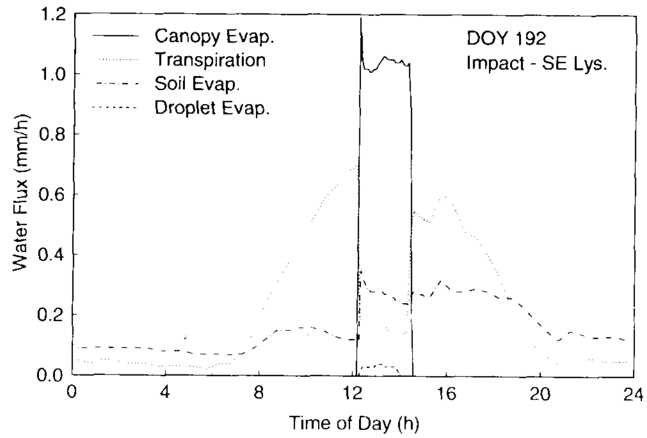

Figure 9–Predicted diurnal water budget for day 192, Impact irrigation. Irrigation was from 12:10 to 14:05 P.M.

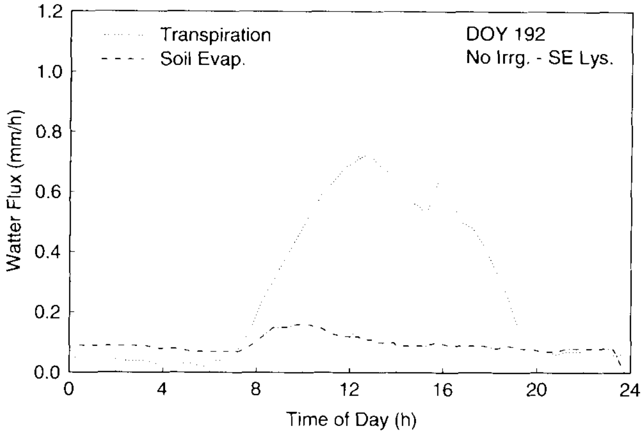

Figure 10–Predicted diurnal water budget for day 192, assuming no irrigation.

evaporation, the wind speeds during the afternoon of day 192 were in excess of 8 m s^{-1} which has a significant influence on this drying rate. For the spray irrigated case shown in figure 8, soil water was not limiting prior to irrigation as noted by the lack of any significant change in the predicted rate after irrigation began. The initial surface soil water content of the spray compared to the impact irrigated lysimeter was about 5% wetter by volume.

Maximum droplet evaporation rate of water between the sprinkler and canopy was 0.14 mm h^{-1} and 0.04 mm h^{-1}, respectively, for the spray and impact irrigation. The higher rate for the spray case was due primarily to the smaller droplet sizes produced by the spray nozzle. However, because the duration of irrigation was greater for the impact sprinkler, the cumulative evaporation of droplets was nearly the same for each application method (approximately 0.05 mm). This represents less than 1% of the total water loss for the day, even under the high evaporative demands of Bushland. The model does not consider drift loss under these conditions which could be of some significance under the windy conditions. However, drift is typically ignored under moving lateral systems because of the large areal deposition provided by the surrounding canopy. Also, because of the small droplet fall heights, especially for the spray nozzles which was only 0.3 m on day 192, this would be expected to have a relatively small affect.

Figure 11 shows the cumulative depth of predicted water loss distribution for day 192 for spray, impact, and the assumed non-irrigated condition. As noted previously, canopy evaporation was greater for the impact irrigated case due to the longer duration of leaf wetness. Transpiration was greatest for the non-irrigated case; the total of transpiration and canopy evaporation for spray irrigation was nearly equal (5% greater) to that of transpiration under non-irrigation. The predicted sum of transpiration and canopy evaporation for impact irrigation was 17% greater than for predicted transpiration alone for the non-irrigated condition. Soil evaporation was greater for the spray condition than for the impact, and both were greater than predicted for the non-irrigated case (which was based on conditions in the impact irrigated lysimeter) indicating that soil water for evaporation was somewhat limiting prior to irrigation. Canopy evaporation amounted to 69% and 63% of the total predicted water used during impact and spray irrigation, respectively. It was also 0.69 and 0.28 mm greater, respectively, than the predicted transpiration total assuming no irrigation had been applied. About 13 and 5% of the water applied by overhead sprinkling was evaporated or transpired during impact spray irrigation, respectively. However, because transpiration and soil evaporation would have occurred even without irrigation, the net increase in predicted water loss during irrigation was only 5.8% and 2.4%, respectively, of the water depth applied for the impact and spray irrigation.

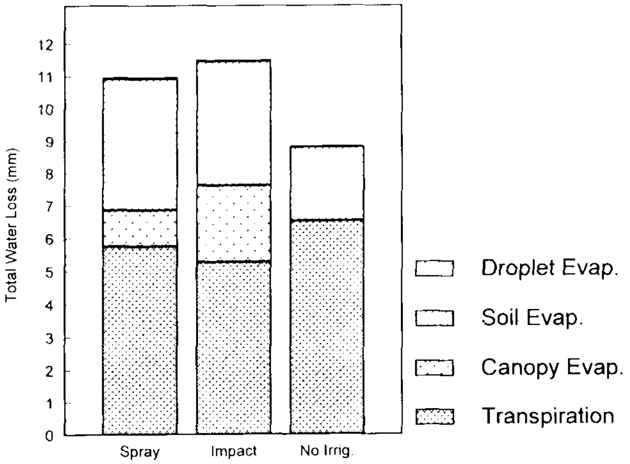

Figure 11–Cumulative water budget predicted for day 192 for Spray, Impact, and no irrigation.

Droplet evaporation was 0.053 mm and 0.055 mm for the impact sprinkler and spray nozzle, respectively, representing less than 1% of the total water loss for the day. However, irrigation water did influence the energy transfer between the plant-environment and water droplets during flight, on the canopy, and on the soil.

SUMMARY

Field water balance measurements using monolithic lysimeters, micro and minilysimeters, sap flux gauges, rain gauges, and meteorological parameters were used to validate the Cupid-DPE model for predicting water loss partitioning during sprinkler irrigation with a moving lateral system. Comparisons indicate good agreement between measured and modeled rates for transpiration and soil evaporation for the day of irrigation. Total predicted ET during the day of irrigation was greater than measured using the monolithic lysimeters, partly because lysimeters cannot measure water use during an irrigation event. This off time was approximately 1.5 and 2.25 h during spray and impact irrigation, respectively. Total measured and predicted evapotranspiration agreed well for the day following irrigation. Droplet evaporation represented less than 1% of the total water loss for the irrigated day.

The greatest effect of sprinkler irrigation on water loss partitioning was in the reduction in transpiration and increase in canopy evaporation. Although not explicitly reported here, it was also reflected in the energy balance of the canopy as water was evaporated from the wetted leaves. For equal application volumes, the duration of this effect was greater using impact sprinklers, due to the greater wetted diameter and lower average application rate. Predicted water flux rates during irrigation were up to 50% greater for canopy evaporation than what it had been for transpiration immediately prior to the start of irrigation.

The model should prove useful for evaluating various sprinkler irrigation systems and management schemes with respect to water efficiencies during irrigation of a crop. Future comparisons of interest for the Cupid-DPE model would be to compare results with two-dimensional horizontal advection models using various heights for the upper boundary layer. This would help address the question of the most appropriate height to use for different environmental conditions. Other areas of interest would include parameterization for one-dimensional drift loss.

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