The Dew Component of Strawberry Evapotranspiration

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Abstract. The objectives of this lysimeter study were to 1) evaluate the amount of dewfall, 2) determine the contribution of dew to daily evapotranspiration (ET) in fall-grown strawberries (*Fragaria ×ananassa* Duch.), and 3) determine the relationship between actual and potential ET (PET) of strawberry. Dewfall amounts averaged 0.8 mm·day⁻¹ and accounted for 33% of the daily ET during the 27 Sept. to 6 Nov. period. Daily ET was linearly related to PET calculated from the Penman–Monteith equation, with an accuracy of ± 3 mm based on lysimeter ET. Daily ET for 2- to 4-day periods was estimated with an accuracy of ± 1 mm using the Penman–Monteith. We conclude that dewfall cannot be ignored in the ET of fall-grown strawberries in the mid-Atlantic section of the United States.

Dew occurs when the temperature of objects declines to a temperature below the dewpoint of the surrounding air. This process is driven by radiational cooling that occurs following sunset. Nocturnal dewfall ranges from 0.01 to 5 mm (Wallin, 1967) and can provide up to 20% of the daily water consumption in some areas (Fritschen and Doraiswamy, 1973). The conditions necessary for heavy dewfall include clear skies, high relative humidity, and turbulent mixing near the soil surface (Monteith, 1957). These conditions are common in the fall season of the eastern United States.

There is little information on the contribution of dewfall in the water balance in the eastern United States (Wallin, 1967). Fritschen et al. (1977) and Gash and Stewart (1977) demonstrated that freestanding water on plant surfaces in coniferous forests contributes 25% to 40% of the seasonal evapotranspiration (ET). Freestanding water evaporates at a higher rate than transpiration (Stewart, 1977), and a Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] forest had 20% higher ET from a wetted canopy compared to a dry canopy (McNaughton and Black, 1973). Freestanding water on plant surfaces can be absorbed and contribute to the water economy of the plant (Stone, 1957), yet the primary value of dew is

that its evaporation, as freestanding water on plant surfaces, reduces transpiration and conserves soil water (Rosenberg et al., 1983). There are no specific data on the role of dewfall in meeting water use requirements for strawberry and many other horticultural and agronomic crops.

The objectives of this study were to 1) evaluate the amount of dew formation in strawberry plantings during the fall season, 2) determine the role of leaf area in dew formation, 3) determine the contribution of dewfall to daily evapotranspiration during the fall season, and 4) compare actual ET to potential ET (PET) estimated using a class A evaporation pan and the combination Penman–Monteith equation.

Materials and Methods

The study was conducted from 23 Sept. to 6 Nov. 1994 at the U.S. Dept. of Agriculture, Agricultural Research Service, Appalachian Fruit Research Station, Kearneysville, W.Va. Two weighing lysimeters were used to record the increase in weight from nightly dewfall. The lysimeters were 2.5 × 2.5 × 2.0 m (length × width × depth) and contained an undisturbed monolith of soil weighing ≈ 20 Mg. The soil was a Hagerstown silt loam (Mixed, mesic Typic Hapludalf) with a 30- to 45-cm-deep A-horizon. The monolith-steel box complex was weighed on a Cardinal FS-8 scale (Cardinal Scale Manufacturing, Webb City, Mo.). The scale system had a 100× weight reduction to the transverse lever, and the weight of the steel box and dry soil were tared with a 218-kg counter weight. The dynamic range of water was ≈ 5 Mg. A 2-kg weight change was the minimum detectable dewfall (0.03-mm dewfall).

The weight of the lysimeter was monitored with a load cell. The two lysimeters were located 25 m apart with one lysimeter planted to 'Allstar' and the other planted to 'Tribute' strawberry. Both cultivars were planted in Sept. 1993 with 30 cm between plants and 60

cm between rows. 'Allstar' is a spring-bearing strawberry and 'Tribute' is a day-neutral cultivar that produces fruit in spring and fall. 'Tribute' was fruiting and harvested weekly during the study. The initial ground cover estimate of 'Tribute' was 40%, while 'Allstar' had 100% ground cover due to its vigorous stolons. Leaf area was estimated at the conclusion of the study by harvesting all leaves and stems from each cultivar and developing an allometric relationship between leaf and stem weight and leaf area from subsamples of the total biomass.

The following meteorological data were collected every 15 min from 23 Sept. to 6 Nov.: aspirated wet bulb and dry bulb temperature at canopy height at each lysimeter and at a 2-m height midway between each lysimeter; incident and reflected radiation 30 cm above the canopy at each lysimeter (model 3023 albedometer; Qualimetrics, Sacramento, Calif.); canopy temperature of 'Allstar' using an infrared sensor aimed down the row and positioned 10 cm above the canopy and inclined $\approx 20^\circ$ below horizontal (Carborundum Co., Solon, Ohio); precipitation with a Texas Sensors (Dallas) tipping bucket rain gauge at the 'Allstar' lysimeter; and wind speed (Met One; Campbell Scientific, Logan, Utah) 2 m above the canopy at each lysimeter. Data, including lysimeter weight, were collected by a CR7 datalogger (Campbell Scientific). Class A pan evaporation data and precipitation were collected Monday, Wednesday, and Friday of each week from a site ≈ 200 m from the lysimeters.

PET was calculated using the combination Penman–Monteith equation (Monteith, 1973). Net radiation was calculated as 70% of incident radiation. Actual lysimeter ET/m² was based on leaf area + exposed soil surface area of 0 and 3.87 m² soil for 'Allstar' and 'Tribute', respectively.

Daily ET was calculated as the weight loss from sunrise to sunset. Sunrise and sunset were approximated by values of net radiation equal to 0 W·m⁻². The actual times ET began and ceased were determined by examining each daily water use pattern and selecting the time and corresponding weight when the lysimeter weight was notably changing or stable in relation to sunrise or sunset. To compare lysimeter ET to pan evaporation, the lysimeter data were pooled over the 2- to 4-day intervals that pan evaporation data were collected ($n = 30$).

The amount of dewfall was calculated as the increase in lysimeter weight following sunset when no precipitation was recorded. When precipitation occurred, dewfall could not be calculated. During the study, 23 days had measurable dew, 7 days had no measurable dew, and 15 days had measurable precipitation.

The load cell calibration was checked before and after the study with 90-kg weights in 20- to 25-kg increments. Lysimeter weight change during calibration was within 2% of actual weight change. An additional test of the calibration compared the lysimeter weight change during periods of precipitation to the amount of rain captured in the rain gauge at the

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class A pan site. Precipitation data were analyzed in a randomized complete-block design with three treatments: rain gauge and the two lysimeters. The 15 dates of precipitation were replications. There was no significant difference ($P \leq 0.01$) between the average rain gauge precipitation and the two lysimeters (mean precipitation was 10 mm for all sensors). Analysis of variance of all other data was performed based on the presence or absence of dewfall. Each sampling date was a replication, and each lysimeter as a treatment in a randomized complete-block design.

Results and Discussion

Dewfall began to accumulate at or slightly before sunset in all dewfall events. Canopy temperature declined below air temperature at 2 m during these events (Fig. 1). Monteith (1957) observed that dewfall occurs at relative humidities of 91% to 99% when leaves are cooler than air and are at the dewpoint. The lysimeter with 'Allstar' accumulated about the same dewfall as the one with 'Tribute' despite a larger leaf area (11.7 vs. 5.7 m², respectively) (Table 1). However, Sudmeyer et al. (1994) demonstrated that leaf area is a component of the dewfall mechanism and can increase the amount of dew captured. This difference suggests that in our climatic region, dewfall is often limited by the amount of water vapor and environmental conditions rather than surface area for condensation.

Dewfall accounted for 33% of daily ET during this study. Dew formation occurred on all but 7 of 30 days. Mean daily ET for the study period was 2.4 mm for 'Allstar' and 'Tribute', and there was not a significant difference in daily ET due to the cultivar (Table 1) measured for days with and without dewfall.

ET and ET-dew for dates with dewfall were similar to ET for dates without dew (Table 1).

Conditions for dew formation include clear and calm skies at night that are commonly followed by clear to partly cloudy skies and wind during the day. Clear and windy days favor high ET, whereas conditions of cloudy, calm winds suppress dew and ET. In contrast, evaporation from the class A pan and PET from the Penman–Monteith equation indicated no difference in PET for days with or without dewfall (Table 1). The lack of measurable differences attributable to climatic conditions associated with dew are the result, in part, of the low ET rates during the fall season.

Daily ET was linearly related to daily PET calculated from the Penman–Monteith equation (Fig. 2). The slope and intercept of the regression were not significantly different from 1 and 0, respectively ($P \leq 0.05$). The estimate of daily ET using the Penman–Monteith equation had an accuracy of ± 3 mm·day⁻¹ based on the standard error of the differences between lysimeter ET and PET. When daily ET was estimated by the Penman–Monteith equation for 2- to 4-day periods, there was a linear relationship with slope and intercept not significantly different from 1 and 0, respectively

Fig. 1. Environmental measurements during a typical dew event. (—) 'Allstar'; (▼) canopy temperature; (□) net radiation; (Δ) relative humidity; (.....) 'Tribute'; (◆) air temperature 2 m.

Table 1. Relationship of dew and evapotranspiration (ET) in strawberry grown in lysimeters.

Cultivar	Dewfall (mm)	ET ^y (mm)	ET-dew (mm)	PET ^z		ET/PET		ET-dew/PET	
				PAN ^s	P-M ^w	PAN	P-M	PAN	P-M
				(mm)	(mm)				
<i>Days with dew</i>									
Allstar	0.9	2.4	1.5			1.27	1.18	0.79	0.73
Tribute	0.8	2.5	1.7			1.32	1.26	0.86	0.84
Mean (n = 24)	0.8	2.4	1.6	2.0	2.1	1.29	1.22	0.82 ^v	0.79 ^v
<i>Days without dew</i>									
Allstar	0	1.8	1.8			0.80	0.94	0.80	0.94
Tribute	0	2.4	2.4			1.13	1.28	1.13	1.28
Mean (n = 7)	0	2.1	2.1	2.3	2.1	0.97	1.11	0.97	1.11

^zPET = potential ET.

^yET measured from lysimeter data.

^sPET from a class A evaporation pan.

^wPET calculated from the Penman–Monteith equation.

^vThe presence or absence of dewfall was a significant factor ($P \leq 0.05$). Cultivar had no significant effect.

Fig. 2. Relationship between daily evapotranspiration (ET) in two lysimeters and ET predicted by the Penman–Monteith equation. (■) 'Allstar'; (●) 'Tribute'.

Fig. 3. Relationship between daily evapotranspiration (ET) in two lysimeters and ET predicted by the Penman-Monteith equation (**upper**) and class A pan (**lower**) for 2- to 4-day periods. The 1:1 line is presented for the nonsignificant relationships. (■) 'Allstar'; (●) 'Tribute'.

Fig. 4. Relationship between daily evapotranspiration (ET) in two lysimeters and ET predicted by the Penman-Monteith equation (**upper**) and class A pan (**lower**) for 7-day periods. The 1:1 line is presented for the nonsignificant relationships. (■) 'Allstar'; (●) 'Tribute'.

($P \leq 0.05$) (Fig. 3, top). This estimate of daily ET for 2- to 4-day periods had an accuracy of $\pm 1 \text{ mm} \cdot \text{day}^{-1}$. When daily ET was estimated from the class A pan for 2- to 4-day periods, there was no significant correlation ($P \leq 0.05$) between lysimeter ET and PET calculated from the class A pan (Fig. 3, bottom). Daily estimates of ET using both the class A pan and the Penman-Monteith equation for 7-day periods demonstrated no significant linear relationship ($P \leq 0.05$); however, the range of ET on a weekly basis was only 1.6 to 3 $\text{mm} \cdot \text{day}^{-1}$ in both (Fig. 4). The Penman-Monteith equation has been a reliable predictor of daily PET (Allen et al., 1989), whereas the class A evaporation pan is more suitable to weekly or monthly estimates of PET (Jensen, 1973) due to heat storage in the mass of water (Thom et al., 1981). These data confirm that the class A pan is inappropriate for estimating ET in the fall season for periods <7 days.

In the mid-Atlantic section of the United States, fall strawberry production is an expanding industry. Dew is typically considered a minor component of the water budget of plants, except in dew deserts of the world (Jones, 1983). Yet, we found that during fall, in this region, dew can account for about one-third of daily water use by strawberry, potentially reducing soil water depletion. Models have been developed for dew formation (Deshpande et al., 1995; Monteith, 1957; Sudmeyer et al., 1994; Wittich, 1995 and citations included therein). Simple methods are available for measuring dew formation (Wales-Smith, 1983) and for incorporating dewfall into irrigation scheduling criteria. Dew formation is common in the fall and relatively accurate daily ET rates can be estimated by summing PET and dewfall.

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