

Diurnal measurements of honey mesquite transpiration using stem flow gauges

WILLIAM A. DUGAS, MARCUS L. HEUER, AND HERMAN S. MAYEUX

Authors are associate professor and research associate, Texas Agricultural Experimental Station, 808 E. Blackland Rd., Temple, Texas 76502; and range scientist, USDA Agricultural Research Service, 808 E. Blackland Rd., Temple, Texas 76502.

Abstract

Honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) stem flow was measured on days with contrasting environmental conditions during the 1989 growing season in Texas. Midday stem flow varied from near 10 to about 300 g hour⁻¹ and daily totals varied from about 1,000 to 2,000 g day⁻¹. On days with low potential evaporation, regardless of precipitation totals for the previous 20 days, stem flow mirrored potential evaporation. On a day with high potential evaporation and high precipitation totals for the previous 20 days, stem flow was greatest and the diurnal pattern was similar to that of potential evaporation. On a day with high potential evaporation and little precipitation for the previous 20 days, stem flow mirrored potential evaporation until about 1030 and decreased throughout the day, while potential evaporation remained high. Variability of stem flow between stems was large, with a C.V. of about 30% for midday rates and a seasonal average C.V. of 37% for daily rates. Stem flow gauges provide continuous and accurate measurements of honey mesquite transpiration. They respond to changing environmental conditions and are useful for evaluating short-term responses of stem flow to physiological and environmental factors in the field and glasshouse.

Key Words: *Prosopis glandulosa*, sap flow, plant evaporation, evapotranspiration

Accurate transpiration data for honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) and other shrubs are needed to assess the biologic and hydrologic implications of the increasing density of these species on watersheds of Southwestern rangelands. Honey mesquite transpiration has been measured primarily using porometers (e.g., Easter and Sosebee 1975; Nilsen et al. 1983; Ansley et al. 1990, 1991). Porometers measure either the diffusive resistance to transpiration, from which transpiration can be calculated if leaf and air temperature are recorded, or the transpiration itself (steady-state porometers). Both methods require periodic instrument calibration to maintain accuracy (Monteith et al. 1988). The inaccessibility of leaves, variation of transpiration between leaves (e.g., Wan and Sosebee 1990), and high cost of instrumentation are negative aspects of porometry. Also, transpiration measurements from porometers may be in error because of the effect of the instrument on leaf stomatal conductance and boundary layer and because of leaf temperature measurement errors (Tyree and Wilmot 1990). For a really representative transpiration value one must extrapolate from the leaf to total plant and population leaf area. Nevertheless, as there is often no alternative, they have been widely used.

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Constant power heat balance gauges are a method which can be used for direct, accurate, and continuous stem flow measurements on herbaceous plants (Sakuratani 1981, 1984; Baker and Van Bavel 1987; Dugas 1990) and small shrubs (Steinberg et al. 1989, 1990; Heilman and Ham 1990). Stem flow through a stem, which, except in unusual circumstances, is equal to transpiration for periods >1 hour, is calculated from a stem heat balance and is an integration of transpiration from all leaves on the stem.

The objective of this report was to present diurnal honey mesquite stem flow measurements to illustrate the potential of this method for range research. Results are presented which demonstrate the response of stem flow measurements to environmental conditions and the diurnal and daily variability of stem flow among stems.

Methods

Experimental Location

Measurements were made at the Texas Experimental Ranch (33° 20' N 99° 14' W, elevation = 450 m), 16 km north of Throckmorton, Texas. The density of the multi-stemmed mesquite trees was 486 trees ha⁻¹, and average tree height and canopy diameter were 2 m. Average leaf area (1 side) on each stem which had a gauge was 0.94 m², and mesquite foliar cover was 15.5% (Dugas and Mayeux 1991).

Stem Flow Measurements

Stem flow measurements were made from 26 Apr. through 13 July and from 23 Aug. through 25 Sep. 1989. Ten stem flow gauges¹ were used on 9 stems. To evaluate consistency between gauges, 2 gauges were placed on a single stem about 0.2 m apart with no intervening branches. Average daily stem flow for the season from these 2 gauges was 1,130 and 1,140 g day⁻¹, demonstrating the consistency of the method.

Stems were selected for stem flow measurements based upon stem diameter. A different set of 9 stems was used during each measurement period. Eight of the stems in each set had diameters from 15 to 20 mm and the other had a diameter of about 35 mm.

Gauges were placed on a stem for up to 56 days, although a period of 20 to 30 days was more typical. Gauges were placed on stems about 0.3 m above the soil. To increase stem/gauge contact, a small amount of dielectric silicon was applied to the stem before gauge attachment. Gauges were covered with a clear plastic 'cling film' for water protection and with foam insulation and aluminum foil to minimize externally induced temperature gradients.

Gauges consisted of a heater, an 8-junction thermopile (type T) mounted on both sides of high-density cork that encircled the heater, differentially wired thermocouple junctions (type T) positioned above and below the heater mounted on high-density cork, and foam insulation (Baker and van Bavel 1987). Stem flow (F, g s⁻¹) was calculated from the following:

¹Models SGB16, SGB19, and SGA35, Dynamax, Inc., Houston, Tex.

(1)

$$F = \frac{P - K_{st} \times A \times \frac{dT_b + dT_a}{dx} - K_g \times E}{C \times dT_{ba}}$$

where P is input power to the heater; K_{st} is stem thermal conductivity; A is stem area; dT_b and dT_a are vertical temperature gradients below and above the heater, respectively; dx is distance between the 2 junctions positioned both below and above the heater; K_g is gauge conductance used for determining radial heat flow; E is thermopile voltage; C is xylem sap (water) heat capacity; and dT_{ba} is temperature gradient across the heater.

A value of approximately 0.3 W was used for P and of 0.42 W $m^{-1} K^{-1}$ was used for K_{st} (Steinberg et al. 1989). The value of K_g , representing a 'zero set' for each stem/gauge configuration, was calculated between 0415 and 0530 daily from Eq. (1), assuming $F = 0$ at night (Steinberg et al. 1989). The assumption that honey mesquite stem flow ceased at night was supported by gravimetric transpiration measurements in a glasshouse at Temple, Tex. Fifteen-minute averages of P and gauge signals (dT_b , dT_a , E, and dT_{ba}) were calculated from 15 s measurements by a data logger².

To confirm method accuracy for honey mesquite, stem flow was compared to mass measurements from a potted honey mesquite plant. The plant had a stem diameter of 13 mm. The soil surface was covered with plastic to eliminate soil evaporation. Measurements were made in a heated glasshouse for 4 days in February 1988 at Temple, Tex. Cumulative gravimetric water loss and stem flow were similar (1,330 and 1,390 g, respectively). The root mean square error of daily rates (25 g day^{-1}) was comparable to previous measurements with this technique on other species. Measured transpiration was zero in the glasshouse for times when K was calculated in the field.

Stem flow rates were higher in the field than those measured in the glasshouse and these gauges may overestimate stem flow during periods of high flow (Ham and Heilman 1990). However, Dugas and Mayeux (1991) showed that both daily and seasonal honey mesquite stem flow totals were similar to transpiration totals calculated from Bowen ratio measurements.

Meteorological Measurements

In the field, 30-min. averages of net radiation³, wet and dry bulb temperatures⁴, and wind speed⁵ were recorded. Soil heat flux, precipitation, and leaf area on stems with gauges were measured following methods described by Dugas and Mayeux (1991). The atmospheric evaporative demand for water was estimated from these measurements (Pruitt and Doorenbos 1977).

Results and Discussion

Precipitation

Total precipitation for the period from 26 Apr. through 25 Sep. 1989 was 363 mm, a value about equal to the long-term average for the period from May through September (388 mm). Greatest daily precipitation totals occurred in late May, early June, and mid September (Fig. 1). A 30 day period without precipitation began on 13 June.

Diurnal Stem Flow

As a sample, 4 days with different but representative environmental conditions were subjectively selected for presentation of

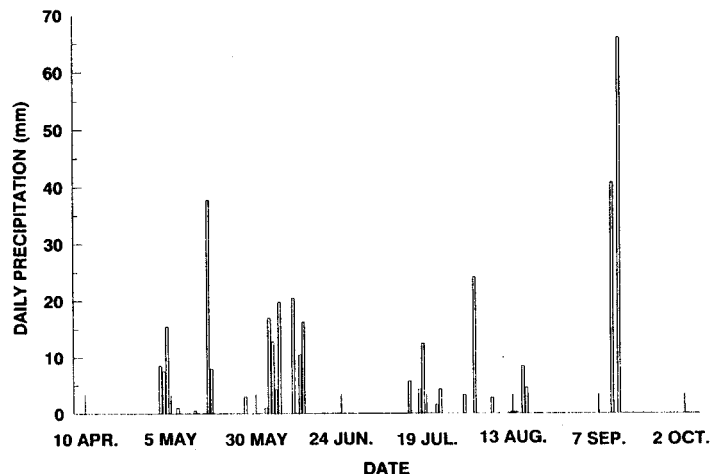


Fig. 1. Daily precipitation at the Texas Experimental Ranch from 26 Apr. through 25 Sep. 1989.

diurnal stem flow data—7 June, 15 June, 13 July, and 26 Aug. The dates of 7 and 15 June were in the middle and at the end, respectively, of a 35-day period with more than 100 mm of precipitation (Fig. 1). Thus, soil water levels likely were high. The date of 13 July was at the end of a 30-day period without precipitation, while only 17 mm of precipitation was measured in the 20 days before 26 Aug. (Fig. 1). The latter 2 dates, therefore, should reflect low soil water levels.

Vapor pressure deficits increased throughout the season (Fig. 2). Available energy (net radiation minus soil heat flux) reflected the clear skies on 15 June and 26 Aug. and cloudy skies on 7 June and 13 July (Fig. 2).

Daily stem flow varied by a factor of 2 on these 4 days (Fig. 2). The greatest average daily stem flow was on 15 June, a day immediately following heavy precipitation and with high potential evaporation. Daily stem flow totals on these 4 days were typical of other daily totals which averaged about 1,300 g day^{-1} for the season and varied from about 250 to 2,500 g day^{-1} (Dugas and Mayeux 1991).

Diurnal stem flow mirrored potential evaporation, especially on 7 June and 13 July when it was more variable (Fig. 2). There was a consistent time lag between potential evaporation (which was similar to available energy) and stem flow (Fig. 2). This lag is an indication of plant water capacitance of honey mesquite trees of this size. Potential evaporation increased before stem flow in the morning, implying that transpiration likely began earlier than stem flow, with the source of water for transpiration coming from leaves and stems above the gauge. In the late-afternoon, potential evaporation decreased before stem flow. This indicates water was moving past the gauge to replenish water in leaves and stems above the gauge. Schulze et al. (1985) documented a similar lag between transpiration and stem flow for 2 tree species and Hatton and Vertessy (1989) showed a lag between heat pulse-measured stem flow and Bowen ratio-measured evaporation for *Pinus radiata*.

Potential evaporation was similar on 15 June and 26 Aug. Daily stem flow on 26 Aug. was 36% less than on 15 June due to soil water deficit stress caused by the lack of precipitation (Fig. 1). Stem flow was about equal on these 2 days until about 1030 whereupon stem flow on 26 Aug. decreased throughout the day, though potential evaporation remained high. On 15 June the shape of stem flow and potential evaporation curves was similar.

On the cloudy days of 7 June and 13 July, the shape of stem flow and potential evaporation curves also was similar (Fig. 2). On both days, stem flow approached zero around 1330 and increased in the afternoon. The rapid response of stem flow to changing environ-

²Model 21X, Campbell Scientific, Inc., Logan, Utah.

³Model 6220, Science Associates, Princeton, N.J.

⁴Model WVU-7, Campbell Scientific, Inc., Logan, Utah.

⁵Model 014, Met-One, Inc., Grants Pass, Ore.

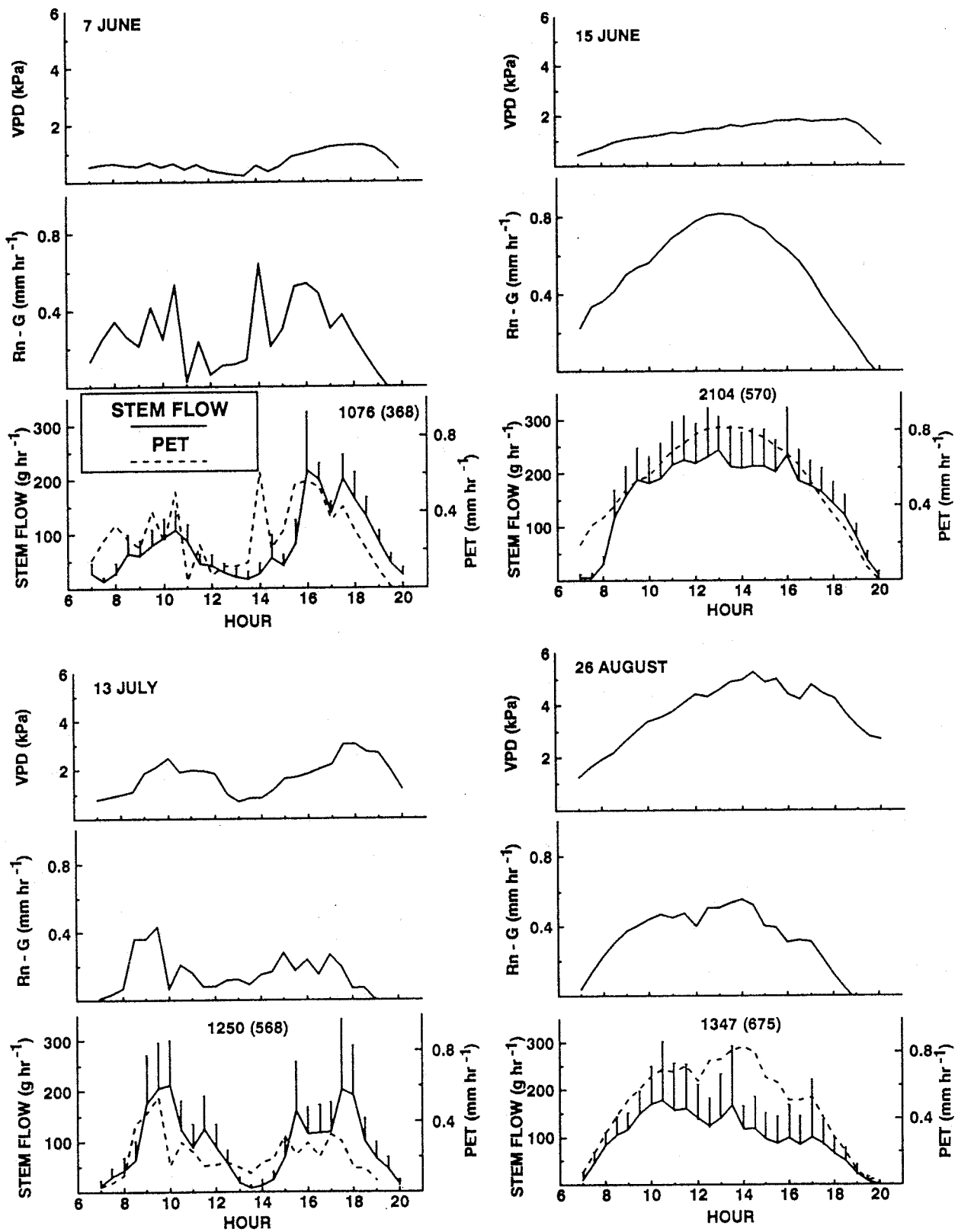


Fig. 2. Half-hour averages of vapor pressure deficit (VPD), the evaporation equivalent of available energy [net radiation (Rn) minus soil heat flux (G)], and stem flow and potential evaporation (PET) on 7 and 15 June, 13 July, and 26 Aug. 1989. Hour is Local Standard Time. Averages are plotted at the end of each half-hour period. The standard deviation of each half-hour stem flow ($n = 10$) is shown as a vertical line above each stem flow data point. The average (and standard deviation) of daily stem flow (g day^{-1}) for each day is also shown.

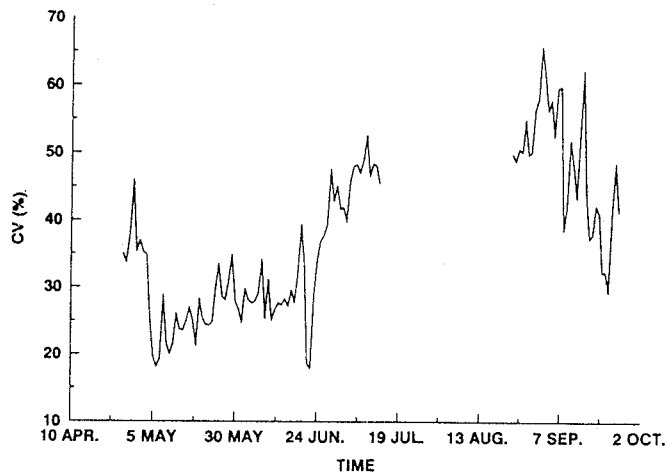


Fig. 3. Coefficient of variation (CV) of daily stem flow in 1989.

mental conditions is an indication of the short time constant of this method at moderate to high stem flow rates (Baker and Van Bavel 1987). These 4 days represent extremes in midday stem flow rates, i.e., near 10 to about 300 g hour⁻¹.

Half-hour stem flow rates were highly variable (Fig. 2). For example, the standard deviation of stem flow at 1200 on 15 June was 80 g hour⁻¹, yielding a C.V. of about 30%. This C.V. is similar to that for cotton (Dugas 1990) where, presumably, plant heterogeneity is less. This variability provides a means of estimating the number of stems required to obtain a given confidence interval about a mean stem flow. Since these gauges measure an integrated value representing transpiration for all leaves on a stem and since porometers typically only measure transpiration on a sample of leaves, stem flow measurements should, in principle, be less variable than porometer measurements.

Variability of Daily Stem Flow

The C.V. of daily stem flow totals fluctuated throughout the year in association with varying precipitation amounts (Fig. 3). It decreased in late April in association with a 50-mm precipitation event (Fig. 1), increased in early July in association with declining precipitation amounts, remained high during the first part of the second period when plant evaporation was low (Dugas and Mayeux 1991) and presumably soil water levels were low, and decreased after 100 mm of precipitation on 7 Sep. The pattern and magnitude of the C.V. of honey mesquite stem flow were similar to those measured for cotton (Dugas 1990). The average seasonal C.V. for honey mesquite was 37%, a value about equal to that for cotton (38%).

Conclusions

Continuous, nondestructive, and accurate measurements of honey mesquite stem flow (and, thus transpiration) were obtained using constant power heat balance gauges. These measurements responded to short-term changes in environmental conditions and are useful in studies of range plant physiology, water relations, and hydrology.

In this study, 300 g hour⁻¹ and 1,300 g day⁻¹ were typical midday maximum and daylight totals of stem flow, respectively. The variability in stem flow between plants was high. Therefore, as also shown by Hatton and Vertessy (1989) from heat pulse measurements on *Pinus radiata*, the use of this method for areal estimates of stem flow may require a large sample size.

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