Measuring Transpiration of Undisturbed Tamarisk Shrubs [1]

John P. Decker, William G. Gaylor, & Frank D. Cole

Rocky Mountain Forest & Range Experiment Station, Tempe, Arizona [2]

Scarcity of water suitable for human use has influenced the history of mankind profoundly (4) and is now of major concern in the United States. It is of acute local concern in Phoenix, Ariz. and desert environs, where a rapidly increasing human population depends on one remote watershed (Salt River) for its primary water supply (2). Here, problems of watershed management are not of mere scholarly interest; they are of intense and immediate public concern.

One of the major problems is how to reduce evaporative losses from the watershed itself. This is a general problem in watershed management (6), and its importance increases with aridity of a region. On one experimental part of the Salt River watershed, evaporative losses of summer rainfall ranged from 89 to 100 % (12).

Evaporative losses from soil and vegetation, usually considered together as evapotranspiration (ET), can be changed by altering vegetation (6). Much more information is needed about what kind, size, age, and arrangement of plant cover is least wasteful for specific situations and there is acute need for a convenient method for direct measurement of ET in undisturbed situations (6).

In the present paper is reported the development of one such method and its use on thickets of five-stamen tamarisk (*Tamarix pentandra* Pall). Tamarisk, also known as saltcedar (7), is an important phreatophyte along the Salt River and throughout much of the Southwest. Replacement of tamarisk by plants that transpire less has been suggested as a means of reducing ET (13). Bermuda grass [*Cynodon dactylon* (L) Pers] may be a feasible replacement along the lower stretches of the Salt River (8).

General Methods

A plot 10 ft in diameter was enclosed by a transparent tent that was ventilated at a known rate. Absolute humidity of inflow and outflow was measured with an infrared gas analyzer (Beckman L/B 15 A, sensitized to water vapor). Humidity difference multiplied by ventilation rate yielded vapor production rate of the enclosed plot. This method was a direct adaptation of that described by Thomas and Hill (14) and differed from it mainly in kind of hygrometer used and in design of the tent.

The tent was a frameless and bottomless vertical cylinder of thin plastic film that was inflated by a ventilating blower. Upward lift was limited by ropes thrown across the top and tied to stakes. The lower edge was sealed to the ground with sandbags.

The ventilating blower was a radial-flow fan driven by a gasoline engine or an electric motor. Ventilation rate was computed from average velocity of inflow or outflow as measured with a Florite indicating anemometer or an Alnor Velometer.

The sampling system consisted of two small electrically driven air pumps (Thiberg model 1) and plastic tubing. Continuous air samples were withdrawn at a rate of about one liter per minute from inlet and outlet of the tent and were directed alternately into the analyzer.

A calibration curve for the analyzer was based on five points (3). Zero was set as the equilibrium reading for air recycled through Drierite. Next, gain (electronic amplification) was set so that air recycled to equilibrium with a bubbler of distilled water held at 30.0 C gave a full scale reading. Intermediate points were obtained with bubblers of distilled water, saturated aqueous sodium acetate and potassium acetate, all held at 20.0 C. Humidities thus established in the analyzer were computed as 0.0, 30.0, 17.1, 12.9, and 3.4 mg/liter, respectively, according to the tables on pages 2304 and 2317 of Hodgman et al. (5). In field operations, the analyzer was checked against zero and 20.0 C or 30.0 C water standards once or twice each hour.

► Direct Comparison of Tamarisk With Bermuda Grass. The apparatus used in this study included two tents made of 6-mil (0.006 inch) polyethylene film, two gasoline powered blowers, a sampling system, and the analyzer. Transparency of the film, as measured in direct sunlight with an Eppley pyrheliometer, ranged from 91 % for new film to 70 % for dirty and cloudy film. Blower speed was automatically governed and was tested frequently with a mechanical tachometer. Power (110 volts, AC) was supplied by a portable generator monitored continuously by a frequency meter. All equipment could be fitted into a 4-wheel drive vehicle for convenient transport beyond established roads.

The experimental site was a nearly level area in an old bed of the Salt River about 20 miles upstream

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from Tempe, Ariz. The area was covered with closely grazed sod of Bermuda grass overtopped by occasional clumps of browsed tamarisk. Soil consisted of 1 to 3 inches of silty clay overlaying coarse sand. The water table was 2 to 10 inches below the surface during the study period (July 22 to Aug. 15, 1958).

Two plots were laid out about 6 to 10 ft apart. One included only grazed Bermuda grass sod, the other included sod overtopped by one or more tamarisk shrubs. Tents were erected; blower speeds were adjusted, and the analyzer was standardized. Starting at 10:00 AM, humidity was measured alternately at inlet and outlet of one tent for a total of ten measurements (5 inlet, 5 outlet). Sampling tubes were moved to the other tent, and the measurements were repeated. The two sets of measurements were repeated every half hour through 2:30 PM. An average was computed for each group of five humidity measurements. Twenty ET rates (one per tent per half hour) were computed from these values.

Eight pairs of plots were used, each for 1 day only. A mean ET rate for the period 10:00 AM through 2:30 PM was computed for each plot. An index of size and density of tamarisk clumps was obtained from the shade pattern cast on the ground between 11:30 and 12:30 of clear days. A Weston 756 light meter was used to locate boundaries of the shadow where light intensity was reduced to 50 % of full sunlight or less. Boundaries were staked; enclosed area was divided into triangles and rectangles; dimensions were measured, and ground area of 50 % or denser shade was computed.

ET rates of the plots increased linearly with amount of tamarisk (fig 1). From these data it is suggested that ET of heavily stocked plots could be reduced 50 % or more by substitution of Bermuda grass for tamarisk.

► Diurnal Time-Course of ET. Relationship of daily ET to that for the period 10:00 AM to 2:30 PM was determined from diurnal time-course studies. A slightly altered apparatus and a different experimental site were used.

Polyethylene film was discarded as a tent material because it became cloudy after a few days in the field. A single tent was made of 1-mil polyester film (Dupont Mylar). The analyzer and ventilating blower were supplied with power from urban electric lines. To simplify operation and computations, the analyzer was modified as follows: the optical pathway was shortened to decrease curvature of response; reference air was recycled continuously through a drying agent to minimize zero drift; the meter was rescaled to read directly in milligrams of water vapor per liter of air.

Tamarisk seedlings were transplanted early in 1957 on a residential lot (formerly a cotton field) in the city of Tempe. By early summer of 1959 they had become shrubs up to 10 ft high. The soil, a heavy clay loam, was kept near field capacity throughout the experiments by irrigation at 10 to 14 day intervals supplemented by watering with a garden hose the day before a run if the surface appeared dry.

All ET measurements were made on one plot. The shrub was roughly spheroid, was about 10 ft high, and was not conspicuously dense or sparse compared with wild shrubs. Surrounding ground was covered with a mowed lawn of Bermuda grass.

The tent was erected about 8:30 AM, and the analyzer was standardized. Beginning at 9:00 the following measurements were taken: outlet and inlet humidity (five of each, alternately), outlet and inlet air temperatures, light intensity (with target of Weston 756 meter aimed at the sun), and outflow air velocity. These measurements were repeated every half hour until the following 8:30 AM. The analyzer was standardized every hour.

Five runs were completed (several others were halted by storms or mechanical failures). Mean humidity for each set of five readings was computed. An ET rate was computed as before (mean outlet humidity minus mean inlet, multiplied by ventilation rate). A humidity deficit was computed (saturation humidity minus inlet humidity). Data for 3 of the 5 days are presented in figure 2. Data for the other 2 resemble those for June 24.

The ET curves (fig 2) resemble those for alfalfa plots (14) except for the inconstancy of daytime rates (especially July 14). The rapid fluctuations cannot be explained at present. They are not related to gross changes of microclimate. They appear to result from real changes of transpiration rate and not from instrumental discrepancies (these would have caused variations in humidity deficit readings also). Similar rapid fluctuations were noticed occasionally during the 1958 studies. The overall rapidity of ET for July 14 is puzzling also in that this day was cooler and more humid than, for example, June 24, as shown by the humidity deficits (fig 2) and by the averages of semihourly measurements of inlet temperatures and humidities from noon through 4:00 PM (respectively, 38.8 vs. 42.1 C, & 12.0 vs. 5.9 mm). Otherwise, ET followed generally the trends of light intensity and humidity deficit.

Total ET for each 24 hour period was estimated by dividing the figures under the curves into trapezoids and triangles and measuring the included areas. These values, along with corresponding values for the midday periods (10:00 AM–2:30 PM) and for the nights (8:30 PM to 5:30 AM), are listed in table I. ET for the midday period of clear days was about 36 % of daily total.

► Effect of Enclosure. Enclosing plots for measurement was expected to reduce their ET rates, but such an enclosure effect could not lead to exaggerated estimates of comparative water loss by tamarisk, and no attempt was made to evaluate it in the preceding studies. Reducing actual rates would tend to minify rather than to magnify differences between plots, and error thus introduced would be in the direction of underestimation of differences.

Although enclosure effect could not create serious

Table I

Kilograms** of Water Evaporated From Tamarisk Plot During 5 Days in 1959*

Date	D	M	N
6/10	112.35	42.35	13.60
6/17	115.44	40.79	14.64
6/24	116.52	37.39	12.17
7/9	95.47	35.03	9.52
7/14	130.53	49.15	10.57
Average***	118.71	42.42	12.75
Proportion***	100	35.7	10.7

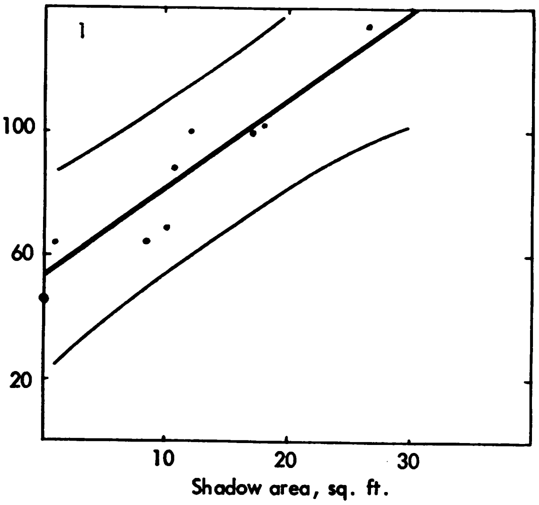
* Complete 24 hr periods (D) vs 10:00 AM to 2:30 PM (M) and 8:30 PM to 5:30 AM (N).

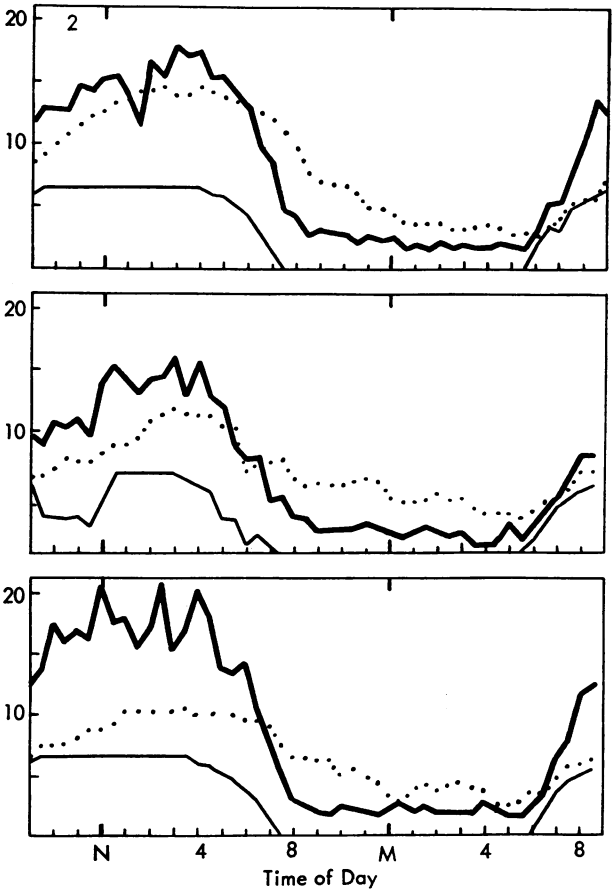
** Multiply by 0.00539 to convert to vertical inches.

*** Based on clear days only, 7/9 was excluded.

difficulty in the primary use for which the technique was intended, analysis and evaluation of it would enable one to compute rates for unenclosed plots and would thus extend the usefulness of the technique. Several exploratory studies were made of potential methods for evaluation and analysis. Although no completely satisfactory method was found, results of the studies permit first approximate descriptions of the enclosure effect. Further, these studies provide initial confirmation of the linear effect of vpd on transpiration rates and provide an explanation of the well-known but previously unexplained disproportional responses of plants and atmometers.

Potted plants of tamarisk and seepwillow (*Baccharis glutinosa* Pers) and atmometers were exposed





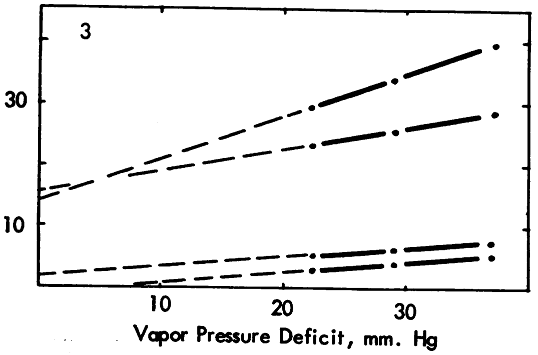


Fig. 1 (*upper left*). Increase of ET rate (scaled in g/min, multiply by 0.000324 for vertical inches per hour) with increasing amount of tamarisk on a plot (scaled in terms of area of shadow cast on the ground near midday). Regression equation is $Y = 52.9 + 2.85X$, with slope significant beyond 0.01 probability. Confidence band is 0.05. Mean ET for eight plots with no tamarisk is shown as large dot on ordinal axis.

Fig. 2 (*right*). Time-courses (MST) of ET (*heavy solid line*, multiply by 10 for g/min), of humidity deficit (*dotted line*, multiply by 4 for mg/liter), and of sunlight intensity (*light solid line*, multiply by 2,000 for ft-c) for a plot containing a large tamarisk shrub. Records are for 24 hour periods beginning June 24, July 9, and July 14, 1959 (*upper, middle & lower graphs respectively*).

Fig. 3 (*lower left*). Water loss rates (g/hr) of oleander, pine, black atmometers, and white atmometers (*from top to bottom, respectively*) as affected by vpd. Each point represents the mean of 24 measurements.

for 1-hour periods alternately inside and outside a tent during a routine run with a large tamarisk shrub. The tent was made of 4-mil polyvinyl, which was the most satisfactory material used in the study because it is easily cemented, it does not become cloudy as polyethylene does, and it does not crinkle and crack with repeated folding as Mylar does. The plants were grown from cuttings, and the pots were sealed temporarily with heavy aluminum foil and plastic film. Soil was kept near field capacity. One set (2 tamarisks, 2 seepwillows, 1 black & 1 white atmometer) was exposed near the top of the shrub on a small platform. Another set was exposed nearby on open lawn. After an hour the sets were reweighed and interchanged. Three such series were run during a day. Fresh plants were used for each series to avoid any possibility of wilting. The procedure was followed for three successive, cloudless days.

Water loss rates were reduced by enclosure (table II). Absolute and relative humidities increased, but there was no corresponding decrease of vpd. Thus the results seem, at first glance, to be at variance with the widely accepted belief (1, 11) that evaporation rates are generally more nearly correlated with vpd than with any other humidity expression. However, the results probably just confirm the already well-known fact (1, 11) that according to simple kinetic theory, evaporation rates cannot be related as directly to any humidity expression (that is, to any expression that characterizes only the gas phase) as they can to the difference of vapor pressure between liquid and gas phases. Computation of this latter quantity requires knowing the liquid temperature at the evaporating surface, and satisfactory instrumentation for this measurement was not available. However, if evaporating surface temperatures did not increase at least 3.2 C (the temperature-equivalent for the observed increase in absolute humidity), vapor pressure difference decreased and resulted in at least a part of the enclosure effect. Further pursuit of this problem will require development of delicate instrumentation for measuring internal temperatures in the minute leaves of tamarisk,

Transpiration rate of tamarisk (table II) was reduced 22 % by enclosure; whereas evaporation rate of white atmometers was reduced 50 %. Disproportional behavior of plants and atmometers is well known (9) but has not been explained.

Table II

Effect of Tent on Mean Water Loss Rates (g/hr) of Phytometers & Atmometers, on Air Temperatures, & on Vapor Pressure Quantities (mm Hg)

	No. obs. per entry	Outside	Inside
Tamarisk	36	9.00*	7.03*
Seepwillow	36	15.97	13.40
Black bulbs	18	8.53	5.19
White bulbs	18	6.11	3.06
Temp., C	90	36.3	39.5
Saturation vp	90	44.9	53.4
Observed vp	90	13.7	22.1
vpd	90	31.2	31.3
% Relative humidity	90	30.5	41.4

* Standard error 0.30.

For a more detailed study of the disproportionality, hourly weight losses were measured for phytometers and atmometers exposed to three humidities in a framed tent (8 × 8 × 8 ft) of Mylar. Low, medium, and high humidities were obtained by connecting the ventilating blower intake to a vertical pipe 8 ft high, to 8 ft of low flat tunnel laid on lawn, or to 24 ft of tunnel. All six possible sequences of the three humidities were run with the same set: two Aleppo pines (*Pinus halepensis* Mill), two oleanders (*Nerium oleander* L), two black and two white atmometers. Each sequence was begun at 9:00 AM on a cloudless day, and each was repeated that afternoon with the same atmometers but with a second set of plants that had been shaded during the morning to avoid mid-afternoon wilting. Five measurements each of outlet humidity and air temperature were spaced throughout each hour. Loss rates (fig 3) varied disproportionally with vpd. For example, as vpd decreased from 37.1 to 22.4 mm, loss rates decreased 48.5 % for white atmometers but only 17.9 % for pine. Both rates were linear functions of vpd. A linear function that passes through the origin is proportional, so the disproportionality must have resulted from intercept values. Presumably, the intercept values indicate that evaporating surfaces in the leaves were slightly above air temperature and on the white bulbs slightly below, for in accordance with simple kinetic theory if the temperatures were equal the function would pass through the origin. Experimental confirmation of this probable relationship will have to await development of instrumentation for measuring liquid temperature at the evaporating surfaces.

It is interesting that although a linear dependence of transpiration rate on vpd has been accepted widely in principle, experimental confirmation of the relationship has been lacking or at least not cited in readily accessible sources. Some of the data reported by Martin (10) suggest a linear relationship.

Summary

A method was developed for direct measurement of evapotranspiration (ET) by undisturbed plots of natural vegetation in the field. A circular plot, 10 ft in diameter and containing shrubs up to 10 ft high, was enclosed temporarily in a frameless transparent plastic tent that was ventilated at a known rate. Absolute humidity of inflow and outflow was measured with an infrared gas analyzer. ET rate was computed as humidity difference multiplied by ventilation rate. The technique can be used to measure comparative ET of plots and is thus directly applicable to a primary and recurring question in watershed management research, "Would this land lose less water if the vegetational cover were altered?" If ET of an unenclosed plot is desired, a correction must be

made for the retarding effect of enclosure, which was found empirically to be about 22 % for tamarisk for one set of conditions. Analysis of the enclosure effect as a basis for deriving a set of corrections of general applicability is still in the early stages.

ET of Bermuda grass-tamarisk plots increased linearly with amount of tamarisk. A reduction of ET could thus be expected to follow conversion of tamarisk stands to grass cover. Diurnal time-course of ET followed generally the changes of light intensity and humidity deficit. On clear days ET for a midday period (10:00 AM–2:30 PM) and for the night (8:30 PM–5:30 AM) was 36% and 11 %, respectively, of the daily total.

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