Evapotranspiration from riparian vegetation: Water relations and irrecoverable losses for saltcedar

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*ABSTRACT: Evapotranspiration (ET) from saltcedar (*Tamarix chinensis Lour*) varies with weather factors as well as with stand density and water availability. In California, ET in July for a unit ground area of saltcedar in large drums varied from 2 millimeters per day in sparse stands, to 16 millimeters per day in dense stands; ET declined and diffusive resistance increased when saltcedar plants were subjected to stress brought on by low soil water availability and/or high evaporative demand. In a natural salt-cedar stand in New Mexico, ET in June varied from 3 millimeters to 11 millimeters per day, depending upon weather and plant density. Extrapolation of experimental transpiration data to field sites must, therefore, be done carefully when assessing irrecoverable ET losses.*

WATER conservation, while readily acceptable in principle, is embroiled in economic, environmental, and political issues in the semiarid western United States. Controversies stem in part from people's lack of understanding about the destinations of water.

So far as agricultural water conservation is concerned, two basic concepts must be understood (*4*).

1. Water that remains on or below the land surface after initial use is usually recoverable. Water passing into the air, by evaporation or transpiration, or into highly saline bodies is irrecoverable (though it remains part of the hydrologic cycle).

2. Reducing recoverable water "losses" and/or reusing wastewaters generally saves water locally, but not for the basin or state, except where wastewaters flow into saline sinks. Reducing irrecoverable water losses saves water for the farm or locale where the reduction is made and for the basin or state.

Although irrecoverable evapotranspiration (ET) losses from agriculture are enormous—about 28 million acre-feet from 10 million acres of irrigated land in California alone—considerable water is also transpired from nonagricultural vegetation, particularly riparian phreatophytes, which usually have access to groundwater along streams and their floodplains.

Graf (*8*) cited studies (*6*, *11*) reporting saltcedar ET rates of 1.2 to 3.1 meters (4-10 feet) per year. But he also mentioned work (*1*) suggesting that phreatophytes transpire much less water than previously thought. Saltcedar ET can vary with water table depth and soil salinity (*9*). Fluxes of water vapor and carbon dioxide above saltcedar canopies can also decline during hot afternoons because of increased stomatal resistance (*10*). These facts provide further evidence that saltcedar does not always transpire at potential rates, and projections of water losses based on multiplying saltcedar area by potential rather than actual rates could be exaggerated.

We present here data on rates of irrecoverable ET losses from saltcedar and the variability in those rates due to stand density, soil water availability, and stomatal

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resistance. Another report (5) describes field trials to reduce transpiration by spraying saltcedar with a nontoxic antitranspirant.

Study methods

Saltcedar plants (produced by cuttings from a single mother plant to eliminate genetic variability) were grown outdoors at Davis, California, in 0.57-cubic-meter (15-gallon) drums to a height of more than 1 meter (3.3 feet). We weighed the 100 irrigated drums periodically to determine transpiration. Plastic on the soil surface eliminated evaporation.

We measured ET in natural saltcedar stands on the Rio Grande floodplain near Bernardo, New Mexico, using the Bureau of Reclamation's lined lysimeters. These tanks are 93 square meters (1,000 square feet) in area and 3.7 meters (12.1 feet) deep. Though each tank was originally planted at a density of 1 plant per 3 square meters (100 plants per tank) to match surrounding natural stands, there were distinct differences among tanks in stand height and density. Flow meters automatically measured the water added to each tank to replace ET. Water depth was maintained at 1.5 meters (4.9 feet).

Measurement of foliar diffusive resistance, which expresses the variable restriction that stomata place upon free flow of water vapor, provided an indirect index of transpiration. We used a pressure chamber to measure xylem water potential, giving us an index of water balance in saltcedar twig samples. Our methods are described in more detail elsewhere (3).

Evapotranspiration rates

Drum studies in California. Uniformity trials showed that absolute transpiration among the 100 saltcedar drums on any one summer day varied considerably [from 2.4 to 6.6 kilograms/plant/day (5.3 to 14.6 pounds/plant/day)] depending upon plant size and exposure. The transpiration rate, however, should be expressed per unit of transpiring surface, a difficult determination for the feathery saltcedar foliage. The next best alternative was to express transpiration per unit of foliage fresh weight. This largely eliminated the effect of inherent plant size differences and showed that in October saltcedar daily transpired 2 to 10 times its own fresh weight in water and 6 to 30 times its dry weight. These values would be higher in midsummer.

Although interesting, these data do not provide a realistic measure of irrecoverable losses of water to the atmosphere from unit areas (per hectare, for example) of plant canopies, particularly where neighboring plants mutually influence each other to a degree that depends upon canopy density. Such evaluation was made possible by grouping the 100 drums into 10-drum by 10-drum square canopies to create densities that could be varied by changing the spacing between drums. We determined transpiration rates for each of the central 16 drums (4 drums x 4 drums), then expressed these rates per unit area of land (cubic meters of water loss/hectare/day) and as equivalent depth (millimeter/day) for each canopy density (Table 1). We also measured daily transpiration for isolated drums of saltcedar and for irrigated, close-clipped grass growing in a nearby lysimeter (29.2 square meters). Because we selected only dates with similar values of ET for grass (about 7 millimeters/day), differences in saltcedar canopy ET were due solely to canopy density.

Except for August 25-26, the potential ET of grass (millimeter/day) and transpiration of isolated saltcedar drums (kilograms/plant) were fairly similar for each of the dates (Table 1). As the spacing between plants declined from 1.6 to 0.4 meters (5.2 to 1.3 feet), the transpiration rate per plant declined, but increased per unit area of land from 22 to 158 cubic meters per hectare (about 2,400 to 16,900 gallons/acre). At sparse density, saltcedar transpiration per plant was about the same (97 percent) as that of an isolated plant; at high density, it was 44 percent of that of an isolated plant because of mutual interference. Because of the large amount of land unoccupied by saltcedar plants at sparse density, the transpiration rate (millimeters/day), based on land area, was only 31 percent of that for grass. At moderate density (0.8-meter spacing), ET was about the same (96 percent) as that for grass; but at heavy density, it was about 2.4 times the ET rate of grass. Thus, under these experimental conditions during summer in California, a moderately dense stand of saltcedar can use 6.5 millimeter per day of water (.26 inch/day), whereas with 4 times that density water use may more than double. The relation between saltcedar ET and canopy density is shown graphically elsewhere (3).

Lysimeter studies in New Mexico. Although the saltcedar plants in California actively transpired and looked healthy, they were growing in an unnatural setting. On the other hand, ET rates from the saltcedar lysimeters in New Mexico were reasonably representative of a natural stand because a large tank was used, the water table was maintained at the same level as the natural water table, and the plants in the lysimeters blended fairly well with the surrounding natural stand of saltcedar. Nevertheless, variations in transpiration rate occurred among tanks because of differing plant densities. An ET rate of 379 liters per day per tank was about equal to 4 millimeters (.16 inch) of ET per day. During June, ET rates varied, depending upon weather conditions, from 2.6 to 5.0 millimeters per day (.1 to .2 inch/day) in the lysimeter with the sparse stand. In a tank with a much taller, dense stand of saltcedar, the range was from 4.2 to 11.1 millimeters per day (.16-.44 inch/day).

Hourly ET from two lysimeter tanks measured over a 24-hour period in June ranged from 0.56 millimeter per hour (.02 inch/hour) in the early afternoon to 0.07 millimeter per hour (.003 inch/hour) at night (Figure 1).

Two nearby lysimeters contained tall, dense stands of Russian olive (*Elaeagorus angustifolia*) that transpired at rates differing from each other due to plant density differences and greatly exceeding those for saltcedar because their canopies were more dense and taller (1-1.5 meters) than saltcedar. Exposure of the Russian olive was somewhat artificial also because the trees

Table 1. Transpiration of saltcedar per day in drums arranged at various canopy densities and the relation of the saltcedar plantings to isolated saltcedar and to grass.

			Saltcedar Transpiration/Day						
			Canopy			Isolated			
Date	Plant Spacing (m)	Plants/ Hectare	Kilograms/ Plant (a)	Cubic Meters/ Hectare	Millimeters (b)	Kilograms/ Plant (c)	Percent [(a)/(c)]	Grass ET (d) (mm/day)	Percent [(b)/(d)]
July 29-30	1.6	3,905	5.65	22.12	2.21	5.84	97	7.04	31
July 22-23	0.8	15,618	4.13	64.81	6.46	5.64	73	6.73	96
August 25-26	0.6	27,768	3.48	97.03	9.67	-	-	5.87	165
July 26-27	0.4	62,474	2.53	158.57	15.80	5.71	44	6.71	236

were not surrounded by a natural stand of like trees. Thus, even a fairly dense stand of saltcedar transpired less than half as much water as the densest stand of Russian olive (Table 2).

ET rates are also influenced by weather parameters. On June 17-18, when solar radiation, maximum temperature, and total wind run were considerably higher than on June 7-8, ET rates nearly doubled, to as much as 21.4 millimeters per day (.8 inch/day) for the dense Russian olive and 10.3 millimeters per day (.4 inch/day) for saltcedar.

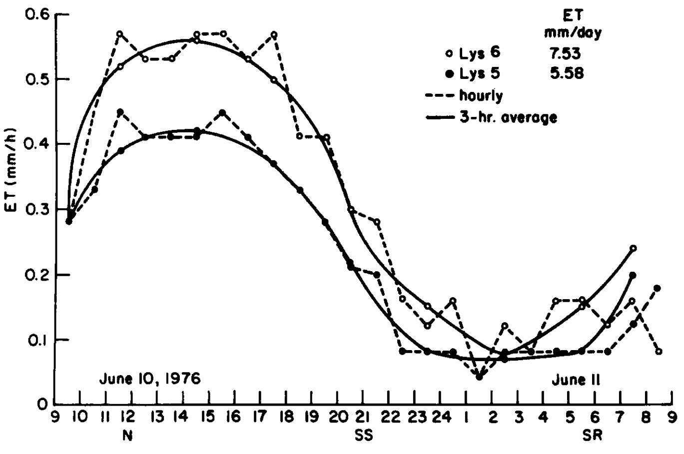
Table 2. Influence of weather conditions on evapotranspiration in two tanks of Russian olive and one tank of saltcedar in June at Bernardo, New Mexico.

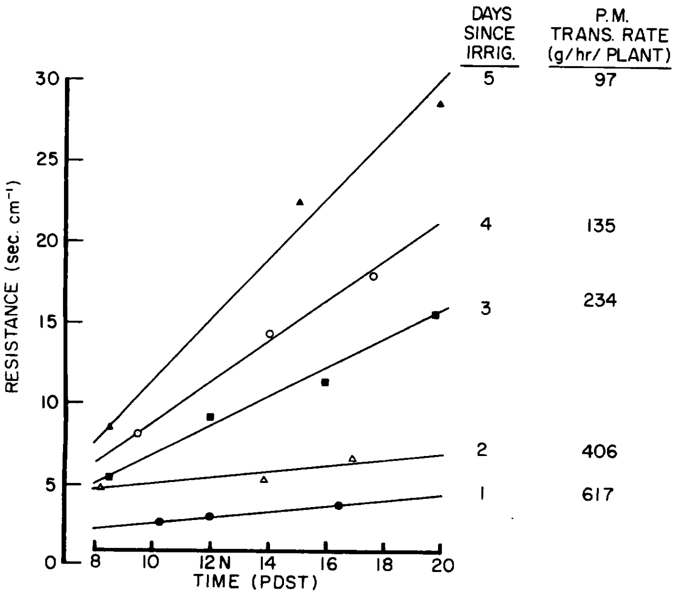
Date	ET (mm/day) Russian Olive Tank One	ET (mm/day) Russian Olive Tank Two	ET (mm/day) Saltcedar	Solar Radiation (Ly/day)	Maximum Temperature (°C)	Wind (km/day)
June 7-8	11.2	7.7	4.6	514	28	97
June 17-18	21.4	15.5	10.3	733	35	282

Diffusive resistance, water potential

Although measuring leaf resistance (r_l) with a diffusion porometer provides a convenient and quick means of determining whether saltcedar foliage is transpiring rapidly or slowly, it does not indicate the magnitude of transpiration. The nonlinear relationship during daylight hours between leaf resistance and transpiration showed that at low levels of resistance, transpiration declined rapidly for small increments in resistance. At high levels of resistance (caused by soil water stress), large increments in resistance were related only to small declines in transpiration (Figure 2). On the other hand, plant water potential remained at nearly the same level (about − 15 bars) for all values of transpiration and resistance in daylight. This suggests that saltcedar plants can adjust their water potential to progressively applied stress, whereas resistance exhibits greater sensitivity to this stress.

An increase in leaf resistance can occur not only when soil moisture availability becomes limiting but also when a high evaporative demand (on hot, dry afternoons, for example) causes plant water stress. A combination of drying soil and high evaporative demand would, of course hasten plant stress and the concomitant increase in leaf resistance. Thus, we observed in summer at Davis that the leaf resistance of saltcedar foliage tended to increase in the afternoon, especially as soil moisture became more deficient (Figure 3). The degree of plant stress is indicated by the declining afternoon transpiration rates. For example, water loss per plant 4 days after irrigation was about 20 percent of the rate on the first day. Even when soil water was not limiting, as in most natural stands





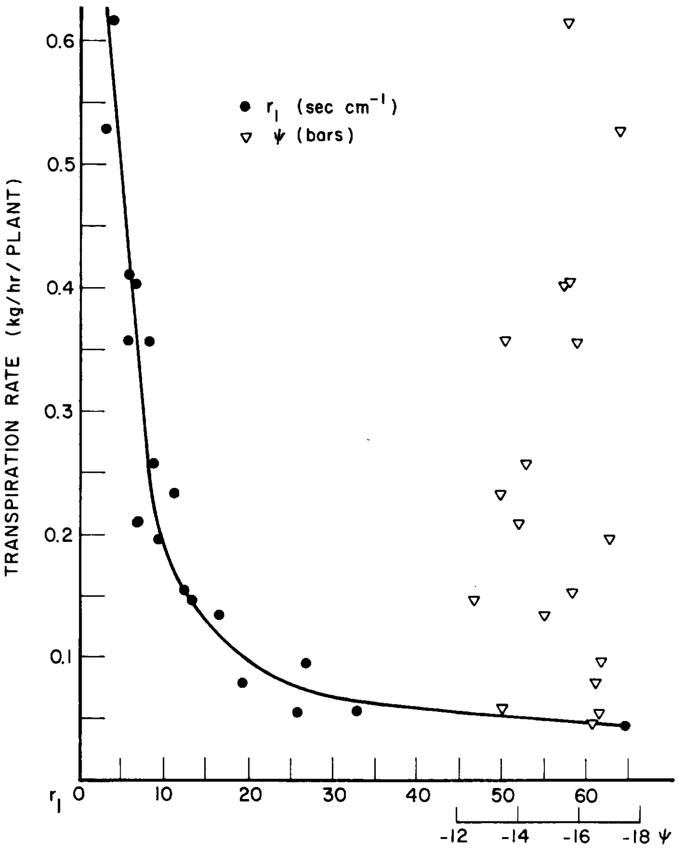


Figure 1 (top left). Saltcedar evapotranspiration (ET) rates per hour for lysimeters 5 and 6, based on hourly readings.

Figure 2 (top right). Relation between daytime transpiration rate (T) and diffusive resistance (r_l) and water potential (Ψ) for saltcedar foliage.

Figure 3 (bottom left). Increases in saltcedar diffusive resistance (1) with drying soil, and (2) in the afternoon.

of saltcedar, there was some increase in diffusive resistance in the afternoon. However, if soil water becomes less available, as with rapidly dropping water tables under natural stands, resistance could increase considerably by late morning and become extremely high, resulting in lower transpiration rates.

Stomatal aperture, hence, diffusive resistance and transpiration rate, are light-dependent. Because of mutual shading, the foliage on a plant can be exposed to a variety of light conditions ranging from full sun to deep shade. This, along with accompanying variations in canopy microclimate (incident radiant energy, temperature, humidity, wind), results in variations of water-loss rates from leaves at different locations on the same plant. Thus, on saltcedar in California, transpiration rates on the same plant could be 10, 40, or 70 percent of that in full sunlight, depending upon the degree of shading (*2*).

Porometer and pressure chamber measurements on saltcedar in the New Mexico lysimeters showed that for the same plant leaf resistance could be 3.8 and 9.4 seconds per centimeter, respectively, for foliage in the sun and in shade. Corresponding water potential values were − 14 and − 9 bars, indicating that shaded branches had lower water loss rates and a higher water status. Nocturnal porometer measurements indicated that, despite high foliar resistance (35-50 seconds/centimeter), saltcedar stomata did not shut completely at night. Contrary to popular belief, therefore, some nocturnal transpirational loss does occur. At least some of ET loss (0.07 millimeter/hour) shown in figure 1 could be attributed to transpiration and some to soil surface evaporation.

Research implications

Water lost by evapotranspiration is irrecoverable. The magnitude of such losses from a riparian phreatophyte, such as saltcedar, given certain climatic and soil conditions, depends upon stand density. Under our experimental conditions, saltcedar ET per unit area of land in summer (when potential ET was 7 millimeters/day) varied from 2.2 millimeters per day in a sparse stand to 6.5 millimeters per day in a stand of medium density to 15.8 millimeters in a dense stand. In comparison, van Hylckama (*10*) measured summertime ET rates of 17 to 21 millimeters per day (.67-.83 inch/day) for established saltcedar in Arizona.

In New Mexico, we found saltcedar ET on a summer day varied from 5 to 11 millimeters per day (.2-.43 inch/day), depending upon stand density. Interestingly, on one June day, when the average ET rate in four saltcedar lysimeters of varying density was 7.8 millimeters per day (.3 inch/day), Gay (*7*) found (from micrometeorological measurements and energy budget analysis) that ET in the surrounding natural stand of saltcedar averaged 8.1 millimeters per day (.32 inch/day).

Under conditions of adequate water supply, summertime saltcedar ET rates can vary considerably, not only with weather conditions, but also with stand density and water availability. Consideration must thus be given to variations in ET rate with time of year, site and climatic conditions, and duration of adequate soil water availability when extrapolating daily ET rates for phreatophytes in other areas to determine the water lost annually and irrecoverably to the atmosphere.

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