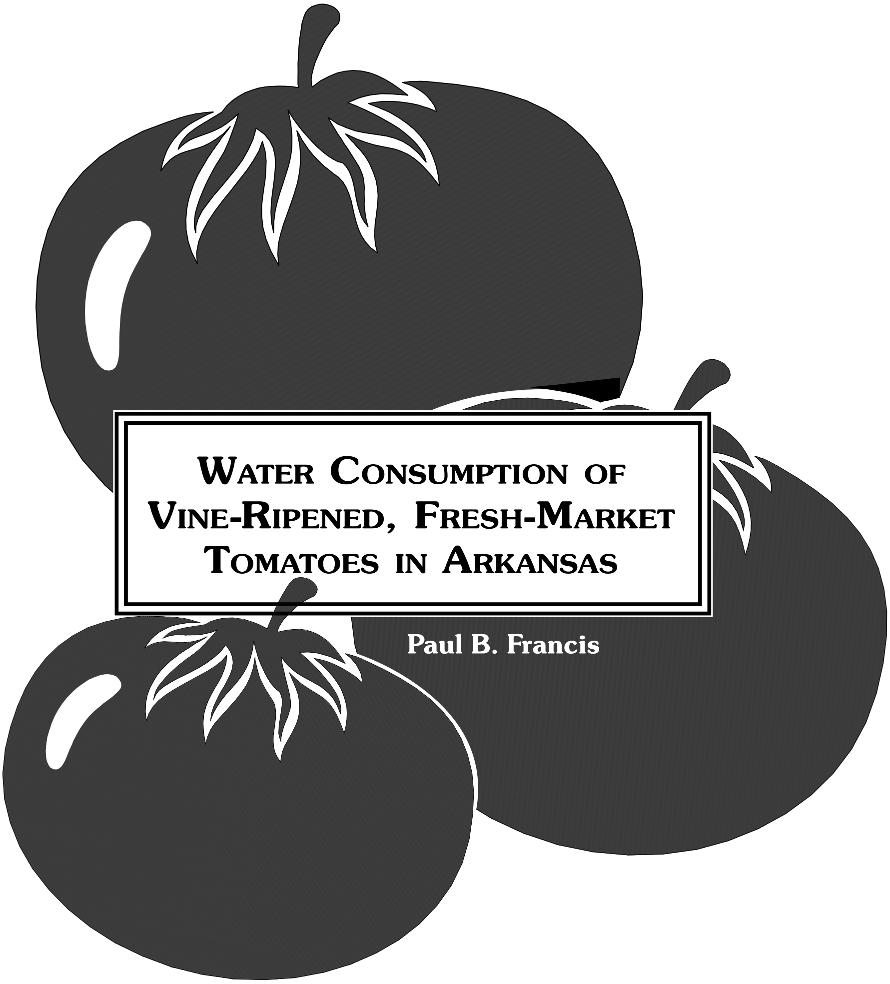

Water Consumption of Vine-Ripened, Fresh-Market Tomatoes in Arkansas

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WATER CONSUMPTION OF VINE-RIPENED, FRESH-MARKET TOMATOES IN ARKANSAS

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SUMMARY

Water consumption by tomato plants on a commercial farm in southern Arkansas was measured during three growing seasons. The growing conditions were typical of those found on commercial tomato farms in southern Arkansas.

The results indicate that water demand by vine-ripened tomatoes in southern Arkansas, under the conditions described, is greatest during June when plants have large numbers of developing fruit of 2 to 3 inches diameter.

The findings can be used by producers to help schedule irrigation management to assure that plants receive adequate water during periods of peak moisture demand.

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INTRODUCTION

Vine-ripened, fresh-market tomato production is a $10 million industry in Arkansas (Arkansas Agric. Stat., 1995). Most commercial production occurs on the Coastal Plains sediments of southern Arkansas, with some recent expansion to other regions of the state. Twenty-five years ago, production methods involved growing pink-fruited varieties on cultivated ground using fixed overhead sprinkler irrigation systems. Today, most producers are growing red-fruited varieties on raised, black-plastic-mulched beds with micro-irrigation (drip-lines) systems.

Irrigation efficiency of micro-irrigation systems is reported to be much higher than that of sprinkler irrigation (Schmueli and Goldberg, 1971; Sammis, 1980; Phene et al., 1987). A micro-irrigation system also allows a grower the option to inject nutrients, most notably nitrogen (N), into close contact with the actively growing root system, which increases fertilizer efficiency provided that rates are not excessive (Bresler, 1977; Miller et al., 1976). The rate and timing of irrigation applications with drip systems can affect overall fertilizer efficiency, fruit yields, fruit quality and fruit maturation (Clark et al., 1991; Bar-Yosef and Sagiv, 1982; Bar-Yosef et al., 1980; Karlen et al., 1985). Fruit yields and fertilizer efficiency can decrease with water shortages or surpluses.

Several strategies for scheduling irrigation applications include the use of ceramic-tipped tensiometers and a "target" level for watering, observations of pan evaporation losses, reference evapotranspiration rates derived from weather data or a combination of these methods (Smajstrla and Locascio, 1991; Clark et al., 1991; Pier and Doerge, 1995; Hartz, 1993). Shortcomings of these methods include variability from tensiometer cup size (Hendrickx et al., 1994), determining placement depth and number of sensors in heterogeneous soils (Or, 1995) and the cost and inconvenience associated with the necessary maintenance requirements of the tensiometers and weather instruments. In addition, most water use studies of tomatoes have been conducted primarily on sandy soils in semi-arid regions such as Israel, or the sandy soils of Florida for mature green harvests.

Most commercial tomato producers in Arkansas base their method of determining water needs and irrigation applications on experience and intuition. The primary objective of this study was to measure water consumption of plastic-mulched, vine-ripened tomatoes under Arkansas conditions and utilize this information to provide some guidelines for irrigation scheduling based on the observed water demand of the crop.

MATERIALS AND METHODS

This study was conducted on the Roger Pace farm near Monticello, Arkansas, during the 1995, 1996 and 1997 growing seasons. The soil was a Sacul loam, which has a loamy topsoil underlain by a clay to clay loam subsoil (Table 1). Soil texture and bulk density profiles were determined using the hydrometer method (Day, 1965) and core extraction with a 2-cm-diameter (0.75-in.) sampling tube, respectively. The phosphorus (P) and potassium (K) levels were higher and the pH more favorable for tomato growth in the 0- to 30-cm (0- to 12-in.) depths. The bulk density, clay content and soil acidity were higher in the 30- to 60-cm (12- to 24-in.) depths. The soil in the upper 30 cm of the raised plant bed had been tilled and was given the morphological designation Ap, and the soil in the 30- to 60-cm zone was given the designation of Bt1.

The method to measure water consumption involved placing a profile of ceramic-tipped tensiometers between plants in the raised bed at 8, 15, 30, 45 and 60 cm (3, 6, 12, 18 and 24 in). Four replications across were used, one placement per row across a 4 x 1 skip-row bed arrangement with 5-ft bed spacings. In 1997, tensiometers were spaced across the plant bed at the drip-line and 30 cm to either side at each depth. Volumetric soil water content was calculated from the observed tensiometer readings using regression equations derived from moisture retention curves from each horizon (Fig. 1).

Moisture retention curves were derived by placing oven-dried soil into 2000-ml plastic graduated containers and lightly tamping until the bulk density was equivalent to that of field conditions. It was necessary to add known amounts of water in 100-ml increments to the soil from the lower horizon in order to compact it equivalent to field conditions. The containers had holes drilled in the bottom for drainage with a filter paper lining to prevent soil from seeping out. A tensiometer was inserted so that the ceramic tip was in the center of the

Table 1. Study site soil characteristics in 1995.

Depth	pH	P	K	Ca	Mg	sand	silt	clay	Bulk density
cm		----------------ppm-----------------				-----------%-----------			g/cm^3
0 - 30	6.7	172	211	1367	84	56	32	12	1.12
30 - 60	4.9	28	150	1134	133	47	31	22	1.45

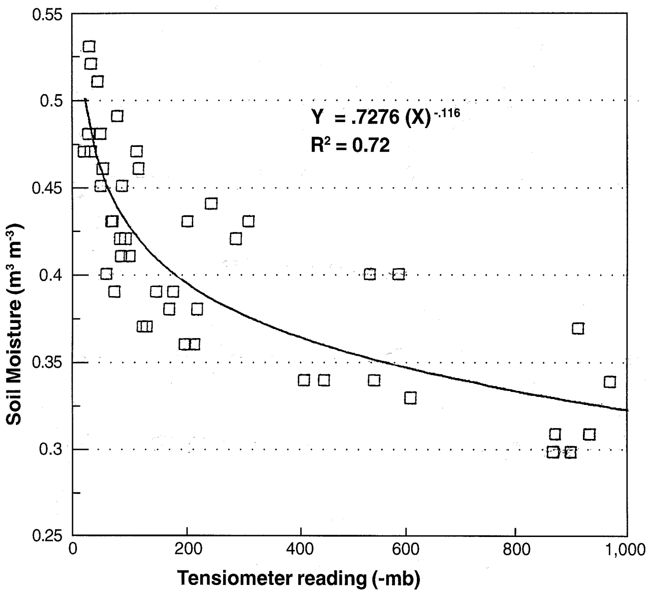

Fig. 1. Moisture retention curve of the Ap horizon.

container. The volume of the tensiometer in the container was determined by inserting it into a partially filled 100-ml graduated cylinder until the water level was at the soil insertion depth, and then observing the amount of water displaced. The tensiometers were constructed from PVC pipe with a septum-covered neck and a round-bottomed, 1-bar ceramic tip. The soil was wetted by capillary absorption for two days, followed by surface ponding/draining for another two days. As the soil dried, tensiometer readings (mbars) were recorded using a Tensimeter (Soil Measurements Systems[1]), and the container was weighed. Tensiometer readings continued until they approached -800 mbar. Assuming that the density of water is 1 g/cm^3, volumetric moisture (VM) at each reading was calculated from:

$$VM = \frac{WCW - WCD - WT}{VS - VT} \cdot \frac{1}{\rho w}, \quad (1)$$

where VM = Volumetric moisture content,
WCW = Weight of the container + wet soil (g),
WCD = Weight of the container + dry soil (g),
WT = Weight of the tensiometer (g),
VS = Volume of soil in the container (cm^3),
VT = Volume of the inserted portion of the tensiometer (cm^3),
ρw = density of water (1 g/cm^3).

[1]Mention of trade names for illustration purposes only.

Bulk density and moisture retention curves for the Ap and Bt1 horizons were measured at the beginning of the growing season each year of the study from five replications of each horizon and two rewettings.

Apparent evapotranspiration (ETa) was determined from:

$$ETa = SMi - SMf \qquad (2)$$

where SMi and SMf are the soil moisture content of the profile at initial and final measurements respectively. Soil moisture content of the profile was calculated from:

$$SM = (VM1 \times 7.6 \text{ cm}) + [15 \text{ cm} \times (VM2 + VM3 + VM4 + VM5)] \qquad (3)$$

where VM1, VM2, VM3, VM4 and VM5 are the volumetric moisture content at the 8-, 15-, 30-, 45- and 60-cm depths, respectively, as determined from the tensiometer readings. The measurements were taken over short intervals where no rainfall occurred; thus, the assumption was that runoff and drainage losses were negligible. On a typical day, the cooperating grower would irrigate from about 3 to 9 p.m., which emitted approximately 0.50-0.64 cm (0.20-0.25 in.) of water. Initial soil moisture was measured the next morning at 7 a.m., and final readings were taken at 2 p.m. before the next irrigation cycle. Thus, the apparent evapotranspiration rate determined was primarily the water loss between irrigation cycles. Measurements of water loss were made once or twice a week during the growing season. On several occasions, the data were abandoned due to rainfall or irrigation occurring between initial and final readings or due to failed tensiometers (usually the 8- and 15-cm tensiometers). It was found that the tensiometers needed to be inspected for soundness regularly during the growing season.

Additional information collected included the high and low air temperatures from a position in the inner canopy using an insulated thermometer and pan evaporation from a 46-cm (18-in.) zinc-treated metal pan filled with 5 cm (2 in.) water and placed between the second and third rows. Root density profiles from three locations were determined at the end of the 1997 growing season using the core method (Bohm, 1979), and fruit growth from 2-cm diameter to breaker growth stage was measured using calipers from 24 fruits selected at random across the plots.

RESULTS

Daily averages of water use from the 1995, 1996 and 1997 seasons were compared (Table 2). Peak water use appeared to be during the month of June and averaged 0.70 cm (0.27 in.). During June the vines have a considerable number of fruit above 5-cm (2-in.) diameter, which corresponds to a significant increase in water demand (Fig. 2). It took about 3 weeks for a 2-cm-diameter fruit to reach harvest size. The observed apparent evapotranspiration rates in June were considerably higher than water loss from pan evaporation, which averaged 0.40 cm (0.16 in.). However, pan placement was between the rows where it was shielded from direct sunlight and wind throughout most of the day. Pan evaporation losses may have been greater and nearer to observed

Table 2. Average apparent evapotranspiration, 1995-1997.

Date	ETa[†]	PAN	Hi	Lo	I1	I2	I3	Growth stage
mo/d/yr	--------cm------		------C------		----------------(-mb)---------------			
5/16/96	0.79	0.30	31	26	30	23	25	FS
5/20/96	.48	.40	37	22	856	843	342	FS
5/29/97	.84	.40	30	18	48	55	69	FS
6/1/95	.79	.40	32	27	42	204	178	FS
6/3/97	.89	.30	33	21	48	62	80	FS
6/4/96	.95	.20	29	27	48	51	85	FS
6/8/95	.44	.40	34	27	443	509	236	EH
6/11/97	.91	.30	31	18	48	53	52	EH
6/13/95	.62	.40	31	18	438	455	290	EH
6/20/95	.66	.50	33	23	66	805	355	EH
6/22/95	.30	.40	33	28	719	425	495	EH
7/1/97	.13	.40	33	26	153	97	248	LH
7/3/97	.33	.40	34	27	144	117	274	LH
7/11/96	.21	.40	34	28	849	746	575	LH

[†]ETa = apparent evapotranspiration; PAN = pan evaporation; Hi, Lo = high and low temperatures; I1, I2, I3 = initial tensiometer reading at 8-, 15- and 30-cm depths; FS, EH, LH = fruit set, early harvest and late harvest.

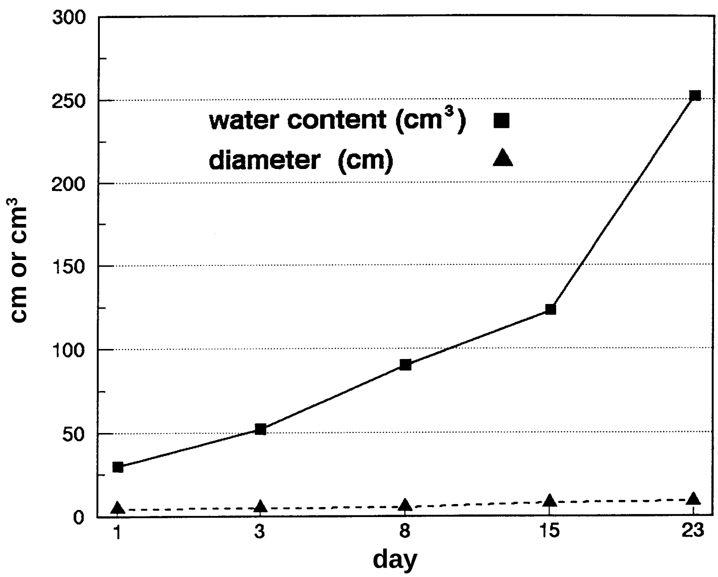

Fig. 2. Tomato fruit growth in relation to diameter and water content.

evapotranspiration if the pan had been placed in an open, mowed location. By late harvest in July, apparent evapotranspiration decreased and was generally equivalent to, or slightly less than, pan evaporation. By July, the vines were damaged from four to five weeks of hand harvesting every other day and had much less developing fruit than in mid-June.

A significant negative correlation between apparent evapotranspiration and tensiometer readings in the upper 30 cm existed (Table 3). For example, apparent evapotranspiration was reduced more than half between 20 and 22 June 1995, when the average tensiometer reading at the 8-cm depth went from -66 to -719 mb. These findings indicate that tomatoes will extract more soil-water if soil water level is held closer to saturation. This may or may not be conducive to higher fruit yields. Locascio and Smajstrla (1996) found a higher irrigation demand for tomatoes using a -100 mb tensiometer threshold at the 30-cm depth compared to irrigating at rates of 0.75x pan evaporation in a fine-sandy soil, but they noted similar fruit yields.

Root density profile measurements revealed that most of the roots were uniformly distributed in the upper 30 cm (Table 4). This was in contrast to observations of tomatoes grown in a sandy soil of a semi-arid region by Bar-Yosef et al. (1980) and a sandy soil in Florida by Ben-Asher and Silberbush (1992) where root proliferation occurred within a cylindrical pattern around the drip line. The implications of the root survey are that soil moisture is more uniformly distributed across the bed for loamy soils compared to sandy soils.

Table 3. Pearson correlation coefficients of selected variables, 1995-1997. The significance levels are given in parentheses.

	ET†	HI	LO	PAN	I1	I2	I3
ET	1.000 (.000)‡	-0.239 (.311)	-0.687 (.001)	0.421 (.065)	-0.723 (.001)	-0.549 (.012)	-0.750 (.001)
HI			0.375 (.104)	-0.009 (.971)	0.327 (.160)	0.263 (.262)	0.209 (.376)
LO				-0.303 (.195)	0.459 (.042)	0.378 (.101)	0.651 (.002)
PAN					-0.145 (.542)	0.230 (.329)	-0.269 (.252)
I1						0.719 (.001)	0.704 (.001)
I2							0.668 (.001)

†ET = water consumption; HI, LO = high and low inner canopy air temperatures; PAN = pan evaporation; I1, I2 and I3 = tensiometer reading at 8-, 15- and 30-cm.

‡Significance of probability of correlation, Pearson product-moment correlations.

Table 4. Root density profile, 1995.

	distance from row center (in.)							row
depth	38	25	13	0	13	25	38	ave.
cm	----------	----------	----------	cm/cm^3	----------	----------	----------	
				drip line location ▼				
5	-	9.9	3.9	7.9	4.6	4.1	-	6.1
10	8.3	4.6	4.4	5.2	3.4	5.1	4.4	5.1
15	4.1	4.1	5.4	3.6	3.3	2.9	3.3	3.8
20	5.4	3.9	4.3	2.9	3.9	3.2	3.6	3.3
25	3.2	5.0	3.0	1.5	2.1	3.9	1.5	2.9
30	2.1	3.2	2.8	1.2	1.8	1.4	2.6	2.2
35	2.2	2.2	1.2	0.7	0.8	0.8	1.6	1.4
40	1.8	1.4	2.1	0.8	1.1	0.6	1.0	1.2
45	0.6	1.4	0.8	0.7	1.1	1.0	0.8	0.9
50	0.3	1.0	1.2	0.6	0.7	0.7	1.2	0.8

Another factor that probably influenced root distribution at the study site was the low soil pH and high bulk density of the 30- to 60-cm depth, both of which would restrict root growth. High soil bulk density has been found to restrict tomato root growth (Oliveira et al., 1996), and low soil pH increases aluminum toxicity (Pierre et al., 1932). This also implies that soil fertility management for these conditions should be based on the fertility status in the upper 30 cm.

The findings indicate that moisture demand by vine-ripened tomatoes in southern Arkansas is greatest during June, at the peak of the harvest season. It is at this time that the vines contain a considerable number of developing fruit between 5 and 8 cm (2-3 in.), which have a high demand for water until reaching mature size. The month of June also corresponds to the greatest demand on the producer's time, when they are busy harvesting, grading, packing, shipping and marketing their crop. The results emphasize that irrigation management should also be a priority at this busy time of the season. At the end of the harvest season in early July, moisture demand of the crop decreases even though temperatures usually increase.

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