Simple and Inexpensive Lysimeters for Monitoring Reference- and Crop-ET

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Abstract

Weighing lysimeters are standard tools for measuring evapotranspiration (ET). Planted with a grass crop, a weighing lysimeter can be used to verify or calibrate weather-based reference-ET estimates. Planted with an agronomic crop, a weighing lysimeter can be used to measure crop-water use or to develop crop coefficients for use with weather-based ET-estimation methods. Simple and inexpensive weighing lysimeters are being used to help schedule irrigation of cotton in Mississippi. The design, construction, installation, and operation of these instruments are presented.

Keywords. Lysimeter, evapotranspiration, reference ET, crop coefficient

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Weighing lysimeters have been used for many years to measure and study water use for a variety of crops. A weighing lysimeter measures the amount of water used in evaporation and transpiration by a vegetated area.

Knowledge of crop water use is important in irrigation scheduling, optimizing crop production, and modeling evapotranspiration and crop growth. The ability to estimate and predict evapotranspiration and crop water requirements can result in better satisfying the crop's water needs and improving water use efficiency.

Many studies of crop water use have been undertaken for a variety of crops in many different locations and growing environments. Water-use and crop-coefficient curves have been developed from these studies. The results from one environment, however, may not be readily transferable to another (Piccinni et al, 2002). Installing lysimeters and collecting water-use data for local crop varieties and environmental conditions will provide the information needed to develop curves suitable to the local area.

Lysimeters of many different designs, sizes, shapes, and methods of operation have been built. Howell et al. (1991) offer a history of lysimeter development and use. A variety of studies involving lysimeters by various authors can be found in Camp et al. (1996). Many other researchers have designed and constructed lysimeters to meet their specific needs and objectives.

The objective of this paper is to describe simple and inexpensive lysimeters used for measuring reference- and crop-ET. The construction, installation, and operation of the lysimeters is detailed, and data collected during their operation are presented.

Lysimeter Construction

In designing the lysimeters, ease of fabrication, simple installation, low maintenance requirements, and low cost were important considerations. Using readily available materials and components helped keep cost down, and a simple design allowed fabrication using common shop tools.

The lysimeter design was based on that of Allen (Allen and Fisher, 1990). The main components of the lysimeters were an outer tank, an inner tank, loadcell assemblies, and a drain system. The outer and inner tanks consisted of four side walls and a bottom plate. When installed in the field, the inner tank contained the drain system and a volume of soil and vegetation isolated from the field. The loadcell assemblies supported and monitored the weight of the inner tank. The outer tank isolated the inner tank from the field and supported the loadcell assemblies and inner tank.

Two different lysimeters were designed and constructed, the main difference being the dimensions of the lysimeter tanks. One lysimeter was designed for use in monitoring reference (grass) ET, and had surface-area dimensions of 1 m wide x 1 m long. The second lysimeter was designed for use in monitoring the ET from a row crop (mainly cotton). The surface-area dimensions of this lysimeter were 1 m wide x 1.5 m long. The dimension in the direction of the crop row was lengthened to allow more plants to be planted on the lysimeter. Both lysimeter designs had an inner tank that was 1.5 m deep. An assembly drawing with top and side views of the 1 m x 1.5 m surface-area lysimeter is shown in Figure 1.

The lysimeters were constructed of steel plate and steel U-shaped channel stock. The inner and outer tanks consisted of four side walls and a bottom plate made of standard 4.8-mm (3/16-

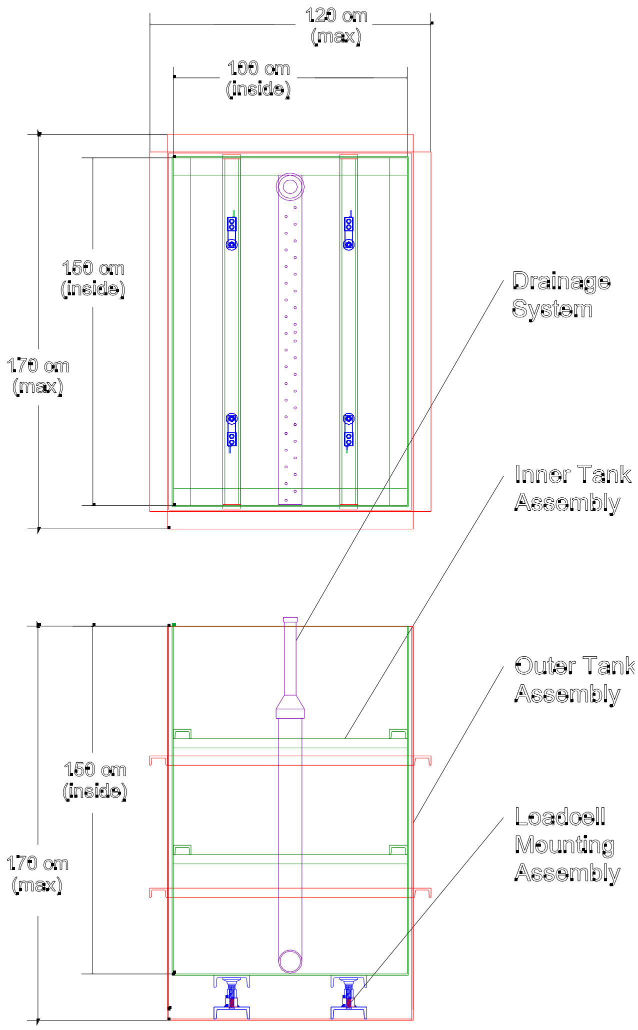

Figure 1. Top- and side-view drawings of the 1 m x 1.5 m surface-area lysimeter.

in) steel plate, and 76-mm (3-in) steel channel support members.

The support channels were welded to the side and bottom plates. The side and bottom plates were then welded together to form each tank. Each completed tank was painted with white enamel paint to protect against rust.

The loadcell assemblies consisted of stainless steel shear-beam loadcells bolted to steel channel supports on the bottom of the outer tanks. The loadcells used for both lysimeters were Sensortronics Single-Ended Shear-Beam, Model 65023[1]. Model 65023 loadcells with a 909-kg (2000-lb) capacity were specified for the 1 m x 1 m lysimeter, while loadcells with a 2272-kg (5000-lb) capacity were used for the 1 m x 1.5 m lysimeter.

The inner tank was supported by the loadcells via stainless steel leveling mounts threaded into the loadcells. The leveling mounts used were LEVEL-IT, Model 9T2LTM for the 1 m x 1 m lysimeter, and Model 19T2LTM for the 1 m x 1.5 m lysimeter, available from J.W. Winco, Inc. The height of the mounts could be adjusted to ensure that the inner tank was level and that there was an even distribution of weight on each loadcell. Views of the loadcell mounting assemblies are shown in Figure 2.

The drain assembly allowed excess water to be removed manually from the lysimeter. The drain assembly consisted of a 15-cm (6-in) diameter perforated PVC pipe connected to a 15-cm (6-in) diameter PVC standpipe. The standpipe was reduced to a 7.6-cm (3-in) diameter pipe near the surface so that it occupied less of the lysimeter's vegetated surface area.

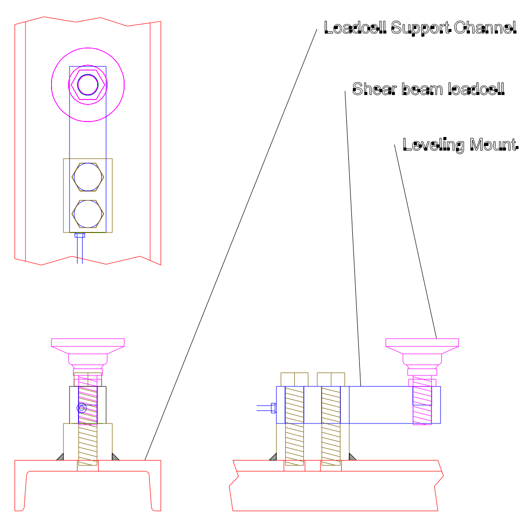

Figure 2. Top-, front-, and side-view drawings of the loadcell mounting assemblies.

[1] The mention of trade or manufacturer names is for information only and does not imply an endorsement, recommendation or exclusion by USDA-Agricultural Research Service.

The cost of the materials needed for each lysimeter, purchased in Mississippi, USA, in 2001, are shown in Table 1. The steel plates for the tank walls and bottoms were cut to size by the steel supplier, with cutting included in the price. The costs shown are for materials and delivery, and do not include labor or material costs of fabrication.

All fabrication was performed in-house by USDA ARS technicians. Fabrication consisted mainly of cutting the steel channels to the proper lengths, welding the plates and channels together, and cutting and assembling the PVC drain assembly. Each lysimeter required the efforts of two people and approximately 40 hours each to assemble and weld the components.

Lysimeter Installation

The lysimeters were installed in pairs in two different locations at the Application and Production Technology Research Unit's Mechanization Farm at the Jamie Whitten Delta States Research Center, Stoneville, Mississippi, USA. Two 1 m x 1.5 m surface-area lysimeters were installed in a field dedicated to row-crop (mainly cotton) research in the summer of 2002. Two 1 m x 1 m surface-area lysimeters were installed in a grass field in the fall of 2002.

Table 1. Cost of materials for each lysimeter

assembly	description	cost
inner tank	3/16-in thick steel plate	$750*
	3-in wide steel channel	
outer tank	3/16-in thick steel plate 3-in wide steel channel 6-in wide steel channel	
loadcell	2000-lb loadcells (1 m x 1 m lysimeter) 4 req'd	$205 ea
	5000-lb loadcells (1 m x 1.5 m lysimeter) 4 req'd	
	leveling mounts 4 req'd	$25 ea
drain	6-in diameter PVC pipe 4-in diameter PVC pipe	$30
total		$1700

*total cost of all steel for inner and outer tank.

Lysimeter installation was accomplished by two people using a backhoe, a forklift, hand shovels, and a few hand tools. Holes for each lysimeter were excavated using the backhoe. The outer and inner tanks were positioned and installed with the forklift. Soil was backfilled around the outer tanks and inside the inner tanks using hand shovels. Each pair of lysimeters required two days of work to complete the installation.

The procedure followed in installing the lysimeters is outlined in the following paragraphs. Photographs taken during and after lysimeter installation are shown in Figures 3 through 12.

1. *Choose a location*. A location with appropriate conditions for evapotranspiration measurement was chosen. Some factors to consider included; near the center of the field to provide adequate fetch; under healthy, maintained grass surface (for the grass lysimeters); under the center-pivot irrigation system (for the crop lysimeter).

2. *Prepare the site*. The location to excavate was marked. Plywood sheets were laid out around the area for the grass lysimeter to minimize damage to the existing grass field. This was not a concern in the row-cropped field since the field was tilled each season.

3. *Excavate the soil*. The soil was excavated in layers, with the soil from each layer placed in a separate pile (Figures 3 and 4). When the proper depth was reached, the bottom of the hole was leveled.

4. *Install the outer tank*. The outer tank was lowered into and centered in the hole. The tank was checked to ensure that it sat level on the bottom of the hole. Soil was backfilled around the outer tank to stabilize the tank (Figures 5 and 6).

Figure 3. Choose location and begin excavation.

Figure 4. Remove soil and ensure bottom is level.

Figure 5. Install outer tank in hole.

5. Install the loadcell assemblies. The loadcells were bolted to mounts located on the bottom of the outer tank. The leveling mounts

Figure 6. Backfill soil around outer tank.

Figure 7. Install loadcells in outer tank.

were threaded into the loadcells. The loadcell wires were routed to a common corner of the tank, brought out of the tank to the surface, and wired to a datalogger (Figure 7).

6. Install the inner tank. The inner tank was centered in the outer tank and lowered slowly until it rested on the loadcell assemblies. The output from each loadcell was checked to ensure that each loadcell was operating properly and that the weights supported by each loadcell were similar (Figure 8).

7. Install the drain system. The PVC drain system was placed on the bottom of the inner tank. The bottom of the tank and the perforated drain pipe were covered with a layer of gravel. The gravel was then covered with a layer of sand (Figure 9).

8. Backfill the inner tank with soil. The inner tank was backfilled with soil, returning the soil to the depth from which it was excavated. The soil was packed periodically in an attempt to return it to its original bulk density (Figure 10).

Figure 8. Install inner tank.

Figure 9. Install drain assembly, cover with gravel, sand.

Figure 10. Backfill soil in inner tank.

Figure 11. Crop lysimeters prior to planting, 2003.

Figure 12. Lysimeters with cotton crop, 2003.

The row-crop lysimeters after installation are shown in Figures 11 and 12. Figure 11 shows the lysimeters immediately prior to planting. The datalogger enclosure can be seen in between the two lysimeters. Figure 12 shows the same lysimeters with an actively growing cotton crop.

Lysimeter operation

Once installed in the field, the lysimeters were connected to an electronic datalogger (Campbell Scientific, Inc., Model CR21x). Each loadcell was connected to a separate input channel on the datalogger in order to monitor each loadcell independently. Each lysimeter pair was connected to one datalogger, resulting in the monitoring of eight loadcells with each datalogger. Data were stored in a storage module (Campbell Scientific, Inc., Model SM-

192), which provided long-term, non-volatile data backup.

The datalogger was programmed to collect loadcell measurements at 10-minute intervals. Every ten minutes, each loadcell was read 10 times, and the average of the 10 readings was stored. For each lysimeter, the four average loadcell measurements were totaled, and the total weight of the loadcell was recorded.

MAINTENANCE

Routine maintenance involved periodic visits to the lysimeter sites to check the condition of the vegetation on and around the lysimeters, and to check for excess water inside the outer and inner tanks. The grass on the grass lysimeters was periodically trimmed by hand and irrigated to maintain proper height and well-watered "reference ET" conditions. The row-crop lysimeter was occasionally tilled and sprayed by hand if the mechanized field equipment was not able to access the lysimeter.

Excess water inside the lysimeter tanks was removed periodically using a hand suction pump. After heavy rain events, the soil inside the inner tank could become saturated due to deep drainage being restricted by the tank's bottom plate. This water was removed by inserting the flexible tubing on the hand pump's inlet side into the vertical PVC standpipe on the drain system and pumping the water out. On several occasions, the rainfall was heavy enough to cause the inner tank to fill and overflow. The water flowed down between the inner and outer tanks and filled the space underneath the inner tank where the loadcells were located. The loadcells were not damaged, but the data were not usable during these periods. The water was removed by inserting the flexible tubing on the hand pump's inlet side into the space between the inner and outer tanks and pumping the water out.

One problem which resulted in loss of data and recurring problems involved damage to the loadcell wires. Initially, the loadcell wires were connected to the datalogger at a nearby weather station. The loadcell wires were buried in a shallow trench between the lysimeter tank and the weather station, then up alongside a metal pipe to the datalogger. During a visit to the site about six months after installation, the wires were found chewed through by some type of animal. The wires were spliced back together and loadcell measurements resumed. A conduit was then constructed of rigid PVC pipe and elbow fittings, and the loadcell wires were placed inside this to protect them.

LYSIMETER MEASUREMENTS

Lysimeter measurements consist of a time-series of absolute weights of the lysimeter's inner tank and its contents. The weights include the weight of the inner tank and drain system, and the weight of the vegetated soil inside the inner tank, which includes gravel, sand, soil, vegetation, and water.

Lysimeter measurements were collected automatically and continuously at 10-minute intervals. At each measurement interval, a series of 10 weight measurements were collected from each of the four loadcells. The 10 measurements from each loadcell were averaged, and the average weight was stored in the datalogger's memory. The four average weights were then added together to provide a measure of the total weight of the lysimeter.

Evapotranspiration rates and amounts were determined from changes in lysimeter weight which occurred over time. During daylight periods, weight decreases as water evaporates from plant and soil surfaces and transpires through plant tissues. The amount of water evaporated and/or transpired was determined by calculating the difference in weight from one time period to the next. The weight of water removed due to evapotranspiration, in kg, was then converted to an equivalent depth of water, in mm.

The lysimeters were also useful in measuring rainfall and irrigation amounts. Rainfall or irrigation water falling on the lysimeter caused an increase in lysimeter weight. Calculating the increase in weight from one time period to the next resulted in accurate determinations of rainfall and irrigation rates and amounts.

Examples of lysimeter weight data and calculated evapotranspiration and rainfall amounts are shown in Figures 13 through 15. The figures show absolute weights and calculated changes in weight, converted to equivalent depths of water, for a three-day period in May 2003. Weight measurements were collected at 10-minute intervals, with changes in weight/depth calculated as the difference in consecutive 10-minute weight measurements. The changes in water content are shown as cumulative totals, and were determined by resetting the cumulative total to 0 at midnight (0 hrs) and accumulating consecutive changes throughout the day.

The three-day series in Figures 13 through 15 shows data from the two grass lysimeters during two sunny days and one rainy day. The lysimeters are called E (East) and W (West), and in the figures, the weights and cumulative changes in water content are shown for 24-hr periods from midnight to the following midnight. In Figures 13 and 15, the cumulative change in water content (evapotranspiration) ranged from about 6.5 mm/day to 7.5 mm/day. In Figure 14, a rainfall event occurred around 0900, with approximately 2.5 mm of rain falling on the lysimeter. Evapotranspiration continued after

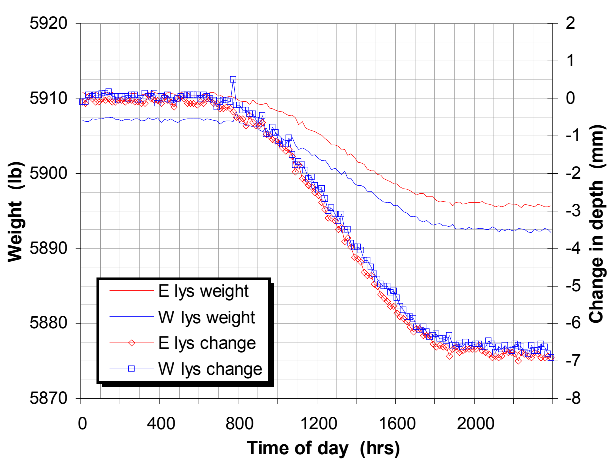

Figure 13. Lysimeter weights and cumulative changes in the depth of water over a 24-hr period, 24 May 2003.

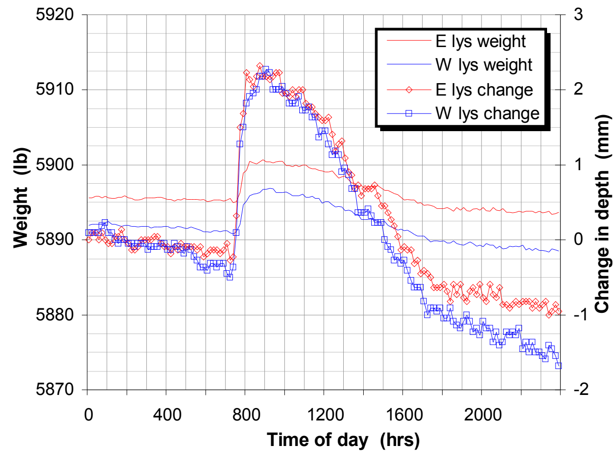

Figure 14. Lysimeter weights and cumulative changes in the depth of water over a 24-hr period, 25 May 2003.

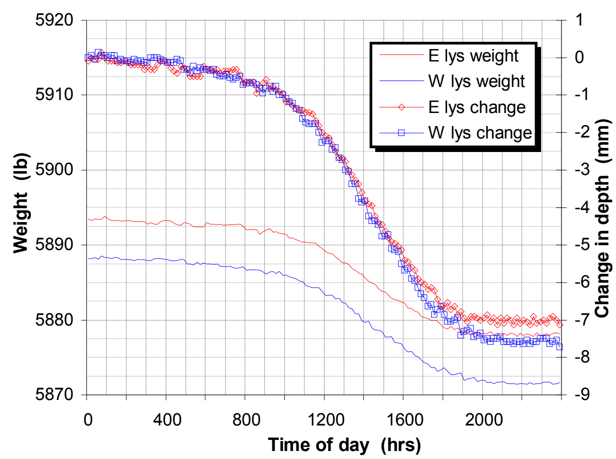

Figure 15. Lysimeter weights and cumulative changes in the depth of water over a 24-hr period, 26 May 2003.

the rain, with a cumulative change in water content of about 3.5 mm for that day. Lysimeter measurements were used to determine evapotranspiration values on a daily basis. The changes in water content from one day to the next were determined by calculating the difference in lysimeter weights at 0700 on consecutive days. The 0700 time period was chosen to coincide with the measurement interval of the weather station at the Stoneville research station.

Daily evapotranspiration values for the grass and crop (cotton) lysimeters for the 2003 growing season (April through September) are shown in Figures 16 and 17. Figure 16 shows grass (reference) ETo values from one lysimeter: the other grass lysimeter values were almost identical. Figure 17 shows crop (cotton) ETc values from one crop lysimeter: the cotton crop on the other lysimeter was noticeably stunted and in poor health throughout the growing season and the ETc values were not deemed representative of a typical cotton crop grown in the region.

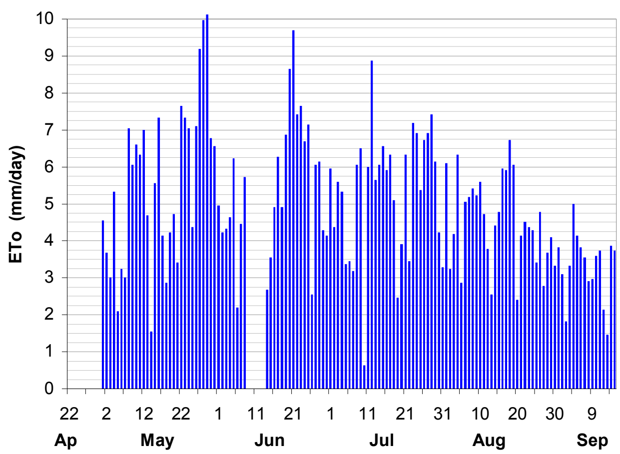

Figure 16. Daily ET values for grass measured during the 2003 growing season.

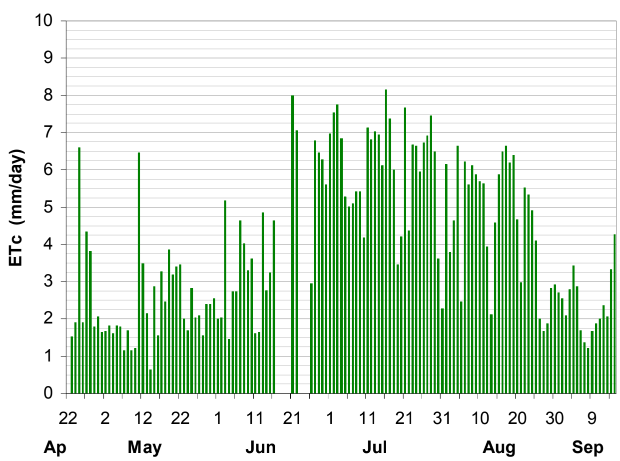

Figure 17. Daily ET values for cotton measured during the 2003 growing season.

Conclusions

Two pairs of electronic weighing lysimeters were constructed and installed. The lysimeter design was simple, consisting mainly of an inner tank, outer tank, and strain-gage loadcells. The cost of each lysimeter was approximately US$1700, excluding labor costs of construction.

Evapotranspiration data are being collected under reference (grass) and crop (cotton) covers on a daily and seasonal basis. The data will be used to quantify water use under local environmental conditions, evaluate weather-based reference-ET estimation methods, and develop crop coefficients.

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