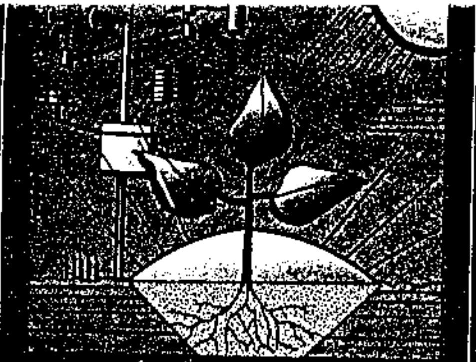

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A Weighing Lysimeter For Developing Countries

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ABSTRACT

Weighing lysimeters, designed for both monolithic and repacked soils and adaptable to both developing and industrialized countries, were installed and tested at Bushland, TX, USA, and Ismailia, EGYPT. At Bushland, a monolithic lysimeter was required for measuring grass reference evapotranspiration (ET) because the dense subsoil and calcic horizon of the clay loam soil cannot be reconstructed. The fine sand at Ismailia allowed the use of a repacked lysimeter to measure alfalfa reference ET and the ET of field crops. The soil and enclosure tanks are of welded steel construction, the scale is a factory-assembled load cell, deck-type, and the lysimeter sets on a simple, reinforced concrete pad. Field construction was minimized by shop fabricating the steel tanks, by the ease of constructing the foundation and by using commercially-available scales. Field calibration, of one lysimeter at Bushland and two lysimeters at Ismailia, resulted in standard errors $s_{y/x} \le 0.1$ mm and coefficients of determination $r^2 \ge 0.9999$. In initial tests, the Bushland lysimeter provided data suitable for verification of hourly calculations of Penman type ET equations.

Keywords. Lysimeter, Weighing, Evapotranspiration, Crop Coefficient, Design

INTRODUCTION

Although weighing lysimeters provide the best available measurements of evapotranspiration, the construction and operation of weighing lysimeters is expensive and requires specially trained personnel. Each lysimeter must be designed to fit the unique combination of crop, soil and climate at the location. An engineering design, specialized equipment and skilled construction workers are usually required to construct the lysimeter. Operation of the lysimeter requires specially trained personnel to grow the crops and to collect, report and interpret the data. Equipment, instrumentation and data collection require continual monitoring with timely repairs and adjustments as needed.

This paper summarizes the design, installation and use of a simplified weighing lysimeter suitable for both monolithic and reconstructed soils and adaptable to both developing and industrialized countries. The simplified lysimeters are being used at Bushland, Texas, USA, (35° N. Lat., 102° W. Long., 1069 m Elev.) and Ismailia, EGYPT (31° N. Lat., 32° E. Long., 25 m Elev.).

LYSIMETER DESIGN

The lysimeters were designed for the crops and soils at Bushland, TX, and Ismailia, EGYPT. The Bushland lysimeter was designed to measure grass reference ET, and the Ismailia lysimeters were designed to measure either alfalfa reference ET or ET of field crops. At Bushland, the

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Pullman clay loam soil is classified as a fine, mixed, thermic Torrertic Paleustoll and has a dense B2t horizon from about 0.15 to 0.6 m and a calcic horizon from 1.1 to 2 m. Disturbing either the subsoil or calcic horizon causes long-term changes in the hydraulic properties of the soil (Allen et al., 1995), so a monolithic lysimeter was required. At Ismailia, the deep, fine desert sand is without layering or structure, and a repacked lysimeter was satisfactory. Both soils are well-drained so a high water table was not a consideration in the design. The 2.3 m depth for the Bushland lysimeter matches the depth of four weighing lysimeters installed earlier (Marek et al., 1988).

The basic components of the lysimeter are illustrated in Fig. 1. The soil tank sets on a factory-assembled, load cell deck scale, and the enclosure consists of three components — the cover, tank and base. A concrete pad foundation, with a single grid of reinforcing steel, supports the deck scale and enclosure. The enclosure base is set in the concrete foundation at the time the

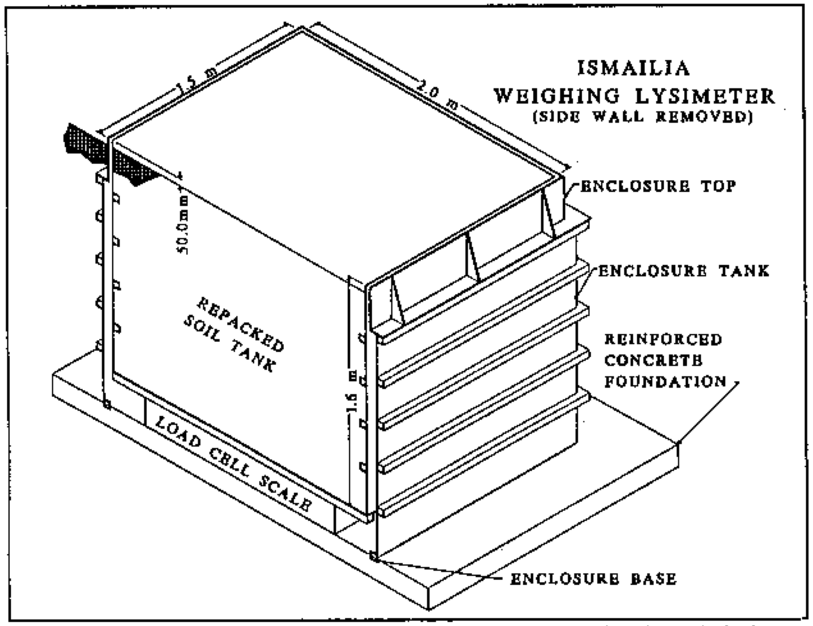

Figure 1. Isometric view of one of the Ismailia lysimeters illustrating the main lysimeter components.

concrete is poured. Then, the enclosure tank is field welded to the base to provide a simple watertight connection. To allow adjustment of the air gap between the soil tank and cover, the enclosure cover is field drilled and bolted to the main tank

Details of both the monolithic lysimeter installed at Bushland and the repacked soil lysimeters installed at Ismailia are illustrated in Fig. 2. The Bushland soil tank is 1.5 m square by 2.44 m deep, and the Ismailia soil tanks are 1.5 m x 2.0 m by 1.6 m deep. The soil and enclosure tanks are of all-welded steel construction with ASTM A36 steel for the Bushland tanks and DIN 1024 steel for the Ismailia tanks. The soil and enclosure tanks at Bushland were externally reinforced with 12.7 x 76-mm bars (Fig. 2), and the external reinforcing allowed the monolith to be collected as a large soil core. The internal, anti-seep collar reinforced the upper section of the soil tank and allowed the narrow air gap along the upper 0.61 m of the soil tank. The Ismailia tanks were reinforced with U50x50x6 beams, with the enclosure tank having external reinforcing and the soil tank having internal reinforcing plus a large gusset at the center of each wall. Reinforcing for the

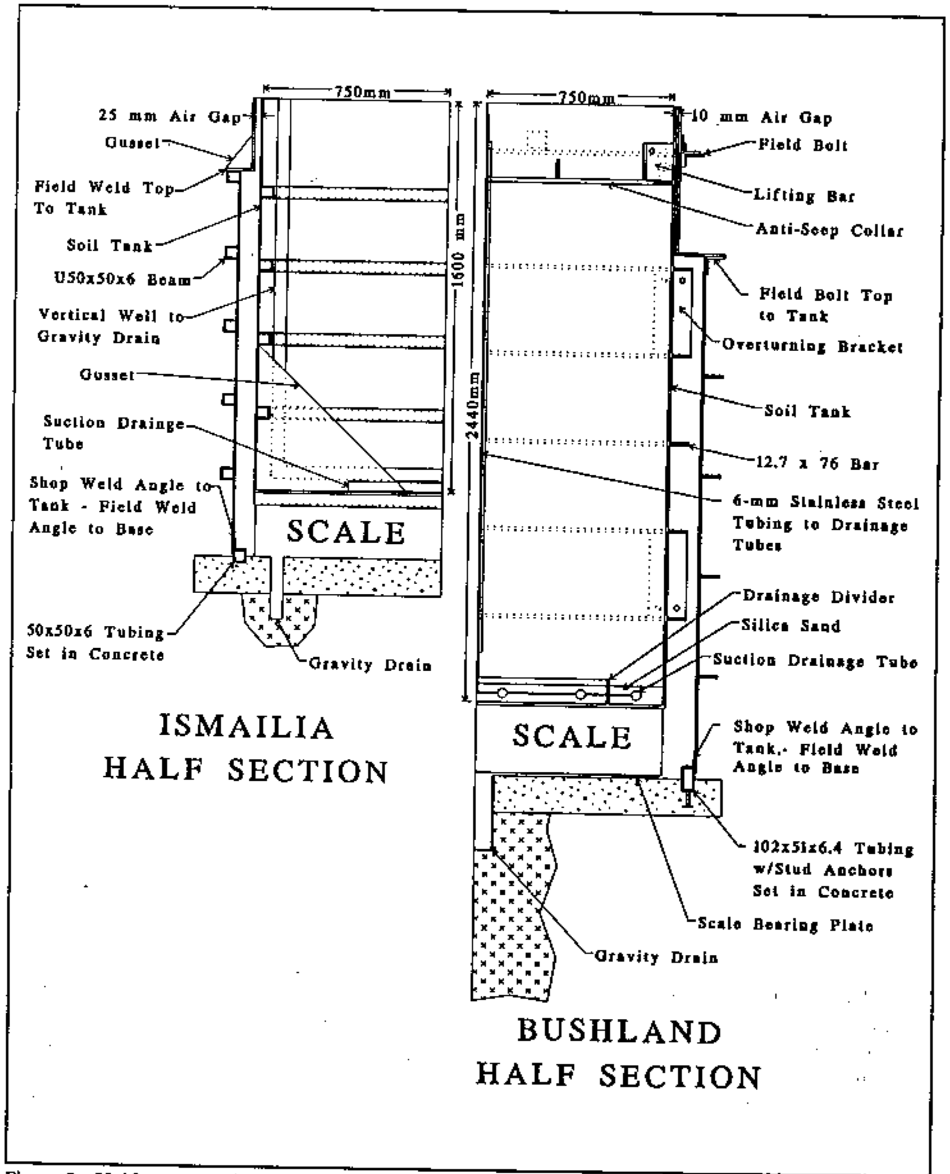

Figure 2. Half cross sections of the Bushland and Ismailia lysimeters illustrating design details.

concrete foundations was 19-mm bars on a 200-mm grid for the Bushland lysimeter and 13-mm bars on a 250-mm spacing for the Ismailia lysimeters.

The lysimeters at both locations had sintered, stainless steel suction drainage tubes, and the Ismailia lysimeters also had gravity drains (Fig. 2). The drainage tubes were 38 mm diameter by 762 mm long, and the tube walls were of 0.5-µm particles that produced a bubbling pressure of 12 kPa. A 6-mm stainless steel tube was run from each drain tube to a central location on the tank bottom and then vertically to the soil surface for attaching an external vacuum pump. The gravity drains of the Ismailia lysimeters were fiberglass wrapped, 50 mm, slotted PVC pipe that could be pumped through a 50-mm vertical well. The monolithic soil tank was turned upside down to install the drainage system, and the drainage systems for the repacked soil tanks were installed before repacking the soil.

The monolithic soil tank had additional features for lifting and overturning the monolith and for placing the soil tank on the deck scale. Two pairs of brackets on the tank were designed for temporarily attaching two vertical W200x31 beams. When the monolith was lifted with a crane from either end of these beams, the center of gravity was vertically above the lower corner of the monolith. By resting the lower corner of the tank on the ground, the tank could be easily rolled with the crane to lie on either its end or its side. A lifting bar in each corner of the monolithic tank allowed the tank to be lifted in a true vertical position. With this feature, the deck scale could be uniformly loaded as the soil tank was placed on it.

A square, Weigh-tronix, Inc.** deck scale with a chain-link suspension and flexure load cell in each corner was used for all lysimeters. The Bushland scale was a Model DS 606030 with a design capacity of 13.6 Mg, and the Ismailia scales were Model DS 606020 with a design capacity of 9.1 Mg. Surface dimensions of the scales were 1.52 x 1.52 m, and the heights were 279 mm for the Bushland scale and 203 mm for the Ismailia scales. Installing the factory-assembled scales required only a suitable foundation and wiring to the data logger.

The flexure type load cells of the Weigh-tronix deck scales are wired in parallel and require a DC excitation voltage and a high resolution voltage recorder. Campbell Scientific, Inc. Model CR7 data loggers provided the excitation voltage and recorded the output signal. The load cell signal was measured every 2 to 5 s, and the average and standard deviation of the measurements were calculated and stored for intervals of 5 to 30 min. After initial scale calibrations, we selected an excitation voltage of 1.00 VDC to keep current low and to operate within the CR7 specifications. In addition, we used an offset voltage of -1.5 V in the data logger instructions to keep recorded voltage as near zero as possible and make the 5-digit number recorded by the data logger as precise as possible. A 6-wire bridge configuration compensated for changes in excitation and output voltages due to temperature changes in the wiring between the scales and data loggers located in instrument shelters about 40 m away.

LYSIMETER INSTALLATION

Lysimeter installation generally followed accepted procedures such as those presented by Aboukhaled et al. (1982), Howell et al. (1991) and Schneider and Howell (1991). The installation is only briefly described except for new procedures. Commercial contractors at both locations fabricated the steel tanks, and at Ismailia, the contractor also did the field construction except for installing the drainage system and repacking the soil tank. At Bushland, the research staff or contractors (supervised by the research staff) did the field construction. The research staffs at both locations calibrated the lysimeters.

The Bushland monolith was collected with the hydraulic pulldown procedure presented by Schneider et al. (1988) with several innovations to prevent bending the tank walls and to speed undercutting of the monolith (Schneider et al., 1993). With the hydraulic pulldown procedure, anchors are installed at the four corners of the monolith tank, and the tank is pulled into the soil with hydraulic jacks connected to the anchors. A pulldown frame uniformly distributes the force

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

from the jacking assemblies to the monolith tank and protects the top edges of the tank. As the tank is jacked down, soil is excavated around the outside of the tank to provide space for the external reinforcing. To prevent warping of the tank walls, the bottom edges of the tank were temporarily reinforced with 152x152x9.5 steel angles, and 51-mm diameter pipe columns transferred the force from the pulldown frame to the angles which were welded to the tank. After the monolith tank was fully pulled down, it was undercut with two steel wedges approximately 600 mm long along each wall. The wedges were fabricated from structural T-beams and were driven into the soil with a 3-kg sledge hammer. A temporary top of 12.7-mm steel plate was fitted over the top of the monolith tank, and the wedges and top were chained to the tank to contain the monolith within the tank. The monolith was then lifted from the ground with a 27-Mg capacity crane and overturned for installation of the suction drainage system and steel bottom.

At Bushland, the soil monolith was collected about 30 m from the lysimeter site so that soil compaction and disturbance from the construction machinery would not affect soil conditions around the lysimeter. At the lysimeter site, construction traffic was controlled and the smallest practical, vertical-walled pit was excavated for the enclosure. The concrete foundation was constructed at the bottom of the excavated pit with the gravity drain, enclosure base and scale bearing plates set in the concrete. Then, the enclosure tank was welded to the base and the scale was installed. The crane used initially to lift and overturn the monolith was used to set the monolith on the scale, the enclosure cover was installed, and the narrow space around the enclosure tank was backfilled.

Excavation for the Ismailia lysimeters followed the traditional procedure of removing and storing 0.25-m layers of soil and then placing them in the soil tank. After the hand excavation was completed, the foundation, enclosure and scale were installed similar to the Bushland lysimeter. The suction and gravity drains were installed prior to placing the soil tanks on the scales. Then, the soil tank was filled in 0.25-m layers and packed by saturating and then gravity draining the tank.

The Bushland lysimeter was field calibrated with 60 hermetically sealed gravel containers each having a mass of 7 to 8 kg and weighed to an accuracy of 0.1 g on a laboratory scale calibrated to NITS standards. To prevent mass changes due to evaporation, the lysimeter was covered with a thick rubber tarpaulin held in place by metal weights. The four load cells on the scale were wired in parallel, and the resulting single differential bridge measurement was made with the Campbell CR7 data logger. The data logger was programmed to read every 1 s using the high resolution mode and an input range of +/- 5 mV (precision of 166 nV), and to output the average reading and standard deviation for 1-min intervals. Initially, 15+ averages were measured with the lysimeter covered but unloaded. Then, five averages were measured after groups of 10 calibration masses were placed on the lysimeter. When all masses were loaded, 15+ averages were measured with the maximum load of 480.9 kg (213.7 mm water equivalent). The measurement procedure was repeated as groups of 10 masses were removed until the lysimeter was completely unloaded. Data, for which standard deviations were high, were omitted leaving 97 observations for the calibration. Linear regression of water depth vs. load cell output resulted in a highly significant relationship with standard error $s_{y/x}$ = 0.1 mm and coefficient of determination r^2 = 0.9999.

The Ismailia lysimeters were field calibrated using a procedure similar to that used at Bushland but with a smaller ET range because of the smaller lysimeter depth and soil water holding capacity. In the laboratory, two calibration masses were weighed to each represent approximately 40 mm of ET. In the field, 10+ load cell averages were measured with the lysimeter unloaded, with the masses incrementally loaded and unloaded and again with the lysimeter unloaded. The north lysimeter was representative of both Ismailia lysimeters, and linear regression of water depth vs. load cell output resulted in $s_{y/x}$ = 0.02 mm and r^2 = 0.9999.

RESULTS AND DISCUSSION

At Bushland, lysimeter ET measurements were compared with computed ET using the REF-ET (v. 2.14) (Allen, 1990) program for the Penman Monteith (PM), Kimberly-Penman (KPEN) equations and 1963 Penman equations for nine selected days during the summer of 1995. Of all the equations in REF-ET, the 1963 version of the Penman equation (Penman, 1963) had the closest agreement with the lysimeter data. Figure 3 illustrates hourly values of lysimeter ET, solar radiation and Penman (1963) calculated ET for DOY 180. With the default ratio of 1.25 for alfalfa to grass ET, the KPEN equation overestimated grass ET slightly. Conversely, the PM equation underestimated grass ET for 6 of the 9 days.

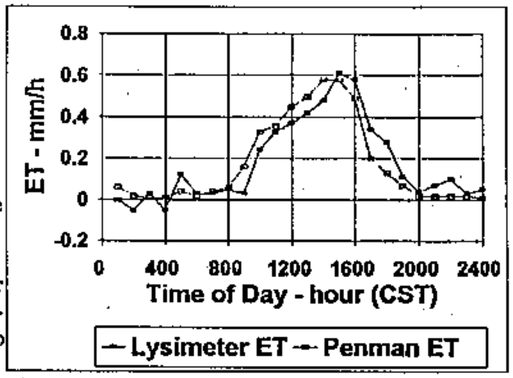

Figure 3. Hourly lysimeter ET compared with ET calculated with the 1963 Penman equation for DOY 180 in 1995.

The two lysimeter installations presented here used essentially the same design for greatly different soils and environments. The prefabricated steel tank construction, simple concrete foundation, and factory-assembled scale were easily adapted to the two environments. Coordination of equipment suppliers, research workers, and contractors was essential for cost-effective and timely lysimeter construction. Although cranes were used during the installation of all the lysimeters, the repacked lysimeters could be installed without a crane. The enclosure tanks for the repacked lysimeters could be skidded down the sloped walls of the pit and onto the tank bases. Then, the pits could be partially backfilled to allow the use of an A-frame for lowering the scales and soil tanks.

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