

Design, installation and calibration of a weighing lysimeter for crop evapotranspiration studies

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Abstract: Lysimeters are tanks filled with soil commonly used in studies of crop ET and movement of water and chemicals in the soil profile. The objective of this work is to describe the procedures for construction, installation and calibration of a precision weighing lysimeter for water demand studies of Sumatra type tobacco (*Nicotiana tabacum* L.) in Bahia, Brazil. The lysimeter was 1.60 m long, 1.10 m wide and 0.60 deep, with an internal soil surface of 1.76 m². The lysimeter was installed in an area covered by a 30% shading screen used specifically for production of this type of tobacco. The inner box of the lysimeter was made of steel plates and the outer box was built on site with burnt-clay bricks bonded with cement mass. The weighing platform comprised four 1,000 kg capacity load cells placed underneath the inner tank and a datalogger for data recording. The lysimeter was calibrated in the field using standard loads of known mass. Five cycles of loading and unloading were performed (47 points) in the range of 0 to 110 kg (62.5 mm). The system showed a strong linear relationship between standard mass and load cells output ($r^2 > 0.99$ and $S_{y/x} = 0.033$ mm). The load cell accuracy, which combines the effects of hysteresis, linearity and repeatability errors, was found to be of the order of ± 0.06 mm and the datalogger was found to be able to resolve mass changes less than 0.1 mm. These uncertainty parameters combined with the ability of the lysimeter to respond to relatively small mass changes suggest that the weighing lysimeter herein described is adequate to measure tobacco ET over time periods of one hour or longer. The investment was around US\$ 5,100.00, including hardware and field work for installation.

Key words: lysimetry, crop water demand, tobacco, *Nicotiana tabacum*

Projeto, instalação e calibração de um lisímetro de pesagem para estudos de evapotranspiração de culturas agrícolas

Resumo: Lisímetros são tanques preenchidos com solo comumente utilizados em estudos de ET das culturas e movimento da água e solutos no perfil do solo. O objetivo deste trabalho é descrever os procedimentos de construção, instalação e calibração de um lisímetro de pesagem para estudo da demanda de água do fumo (*Nicotiana tabacum* L.) tipo Sumatra, na Bahia, Brasil. O lisímetro, com área interna de 1,76 m², tinha 1,10 m de largura, 1,60 m de comprimento e 0,60 m de profundidade e foi instalado em área comercial de fumo coberta com tela de sombreamento de 30%. A caixa interna era feita de chapas de aço e a caixa externa de alvenaria construída no campo. A plataforma de pesagem continha quatro células de carga com capacidade de 1.000 kg e um datalogger para armazenamento dos dados. O lisímetro foi calibrado no campo por meio de pesos-padrão no intervalo de 0 a 110 kg (62,5 mm). O procedimento de calibração incluiu cinco ciclos de incremento e decremento (47 pontos) do peso total do lisímetro. Como esperado, o sistema mostrou forte relação linear ($r^2 > 0,99$ e $S_{y/x} = 0,033$ mm) entre os pesos-padrões e o sinal das células de carga. A acurácia das células de carga, que combina os erros de histerese, linearidade e repetibilidade, foi em torno de $\pm 0,06$ mm. A resolução do datalogger foi inferior a 0,1 mm. Estes dados de desempenho combinados à sensibilidade do lisímetro a pequenas variações de massa sugerem que o lisímetro de pesagem aqui descrito é adequado para medição da ET do fumo em intervalos de tempo iguais ou superiores a uma hora. O custo total do sistema foi da ordem de US\$ 5.000,00, incluindo equipamento e mão de obra para instalação.

Palavras-chave: lisimetria, necessidade hídrica de culturas, fumo, *Nicotiana tabacum*

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Introduction

Evapotranspiration (ET), which combines the processes of evaporation and transpiration in the return of surface moisture to the atmosphere, is one of the most important hydrological and meteorological components of the water cycle in nature. ET simultaneously involves flux of mass and energy as latent heat. Therefore, mass balance methods such as lysimeters and energy balance methods such as Bowen ratio can be used to quantify ET from fields of agronomic crops or natural vegetation.

As water becomes a critical resource for agriculture, supplying the right amount is essential for healthy plants and optimum productivity (Johnson et al., 2005). Precision weighing lysimeters are the most reliable method to measure water use by crops as long as they are properly designed, installed, and managed (Burman & Pochop, 1994; Johnson et al., 2005). Many studies have reported the use of such lysimeters in ET studies (Pruitt & Angus, 1960; Howell et al., 1985; Allen & Fisher, 1990; Howell et al., 1995; Marek et al., 2006; Payero & Irmak, 2008). Due to the high accuracy that can be obtained with weighing lysimeters for measuring ET over short periods of time, this method has been taken as the standard for derivation of crop coefficient (Kc) and calibration of reference ET equations (Allen et al., 1998).

Weighing lysimeters measure crop water used by measuring the change in mass of an isolated volume of soil (Payero & Irmak, 2008). While irrigation and precipitation add water and increase the weight of the soil volume, drainage and ET subtracted water therefore decreasing lysimeter mass. Mass variations are usually sensed by load cells whose signals are recorded and stored in electronic recording devices (datalogger).

Irrigation and precipitation add water to the lysimeter increasing its mass while drainage removes water from the lysimeter causing its total mass to decrease. Since weighing lysimeters measure crop ET by measuring the change in mass of an isolated volume of soil (Martin et al., 2002; Payero & Irmak, 2008), adjustments should be done in lysimeter mass variation to account for the effects of these water balance components, before ET (mm) is computed. For example, over a given period of time, the amount of water collected by the drainage system must be subtracted from mass variation. Therefore, care must be taken in lysimeter management

and data analysis in order to minimize problems of under or overestimation of crop ET and avoid reporting inconsistent ET data (Allen et al., 2011). Strong precipitation events, especially in tropical regions, and wind gusts are of concern when analyzing lysimeter mass changes (Pereira et al., 2002; Faria et al., 2006). Recently, Allen et al. (2011) reviewed the advantages and disadvantages of lysimeters for crop ET studies, with emphasis in the requirements for consistency and data representativeness.

The purpose of this paper is to describe the characteristics, calibration and field performance of a precision weighing lysimeter with a reconstructed soil profile designed and installed to measure water used by the Sumatra type tobacco (*Nicotiana tabacum* L.) grown under shade in Bahia, Brazil.

Material and Methods

Design and construction

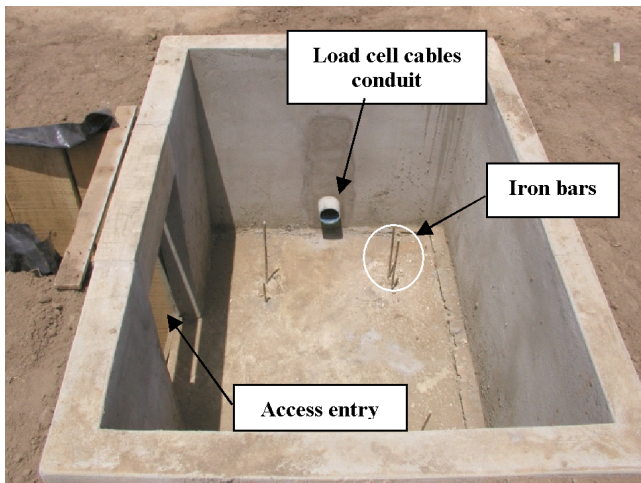
The weighing lysimeter described in this study was part of a lysimetry facility with two others, a drainage lysimeter and a constant water table lysimeter. The weighing lysimeter comprised of an outer box, an inner box with drainage system, and a weighing mechanism based on load cells connected to a data recording device. The lysimeter was designed, constructed and installed to measure the water use of Sumatra tobacco during the 2006/2007 growing season (December to April) in Bahia, Brazil.

The outer lysimeter box

Different of the inner box that was manufactured indoors, the outer box (Figure 1) required masonry work and was built directly in the field. A rectangular design was preferred over a round box for ease of construction. Inside, the outer box was 1.66 m long x 1.16 m wide x 1.00 m deep, slightly larger than the inner box to leave a gap of 3 cm between the two boxes and allow free up and down movements of the inner box.

At the selected site for lysimeter installation, a pit sufficiently larger and deeper than the lysimeter outer box was dug by hand. During excavation the soil was carefully removed in layers of 10 cm increments and placed aside in separate piles on plastic sheet for backfilling. With room enough to work easily in the pit, a mason built the walls of the outer box with burnt-clay bricks. Mortar was used to bond together the bricks and to evenly cover the walls in both sides and on the top to reinforce the

A.



B.



Figure 1. Outer box in the field showing the lateral access entry (A) and the same box with the four concrete cylinders at the bottom (B) to support the weighing mechanism platform here positioned for testing

tank and limit water infiltration into it. The final width of the walls was about 0.12 m and on all sides they were raised rigorously perpendicular to the bottom and to each other.

The next step was to pour a layer of gravel into the bottom of the outer box and then pack it by hand with a cylinder-shaped piece of timber. Then a layer of concrete was poured on the top of the packed gravel and left to dry. While the concrete was drying, in the corner of the outer box 1/4-inch construction iron bars were inserted vertically as shown in Figure 1A. Centered in these bars four small cylinder-shaped columns (20 cm tall x 15 cm diameter) made from PVC pipe encased concrete were built (Figure 1B) to support the weighing platform and the inner box. The walls of the outer box were not painted. A lateral entry (tunnel) (Figure 1) was left in one of the largest walls to allow easy access to the space underneath the inner box for (a) verification of integrity and functioning of the load cells and weighing platform during

lysimeter operation and (b) collecting drainage water manually. As shown in Figure 1, the load cell cables were routed below the soil surface inside a PVC pipe to prevent damage caused by rodents and moisture.

The outer box was designed and constructed so that two rows of tobacco plants in the inner box would be aligned with the rows in the field. For this purpose, the larger sides of the outer box had to be perpendicular to plant rows. Once the work was done, the pit around the outside of the outer box was backfilled with part of the soil that was originally taken out of the pit.

The lysimeter inner box

The inner box measuring 1.60 m long x 1.10 m wide x 0.60 m deep with an internal area of 1.76 m² was manufactured indoors from 2 mm thick steel plates (Figure 2). Following the orientation of the outer box in the field and according to the planting spacing, the inner box could have a total

A.



B.

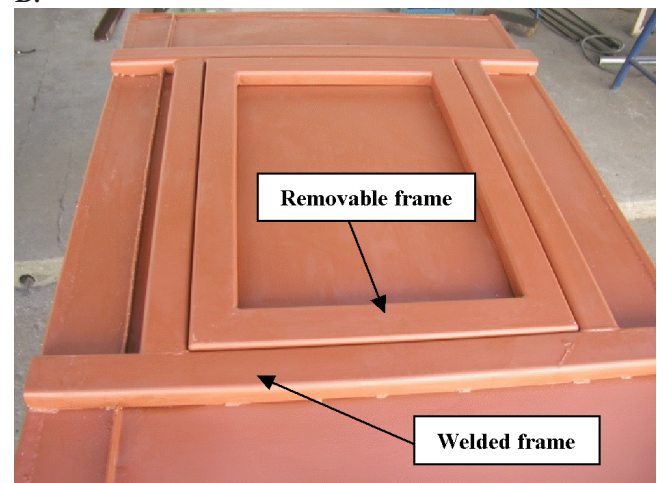


Figure 2. Inner tank assembled in the shop (A) and the same tank upside down (B) showing the rectangular frame welded to reinforce the tank and to fit a removable frame that later became part of the weighing platform

of six plants in two rows of three plants each. The crop spacing was 0.36 m along the planting row and 1 m between rows, leaving 0.30 m distance from the row to the border of the inner box on both sides. Some authors (Howell et al., 1991; Payero & Irmak, 2008) have recommended the sides of rectangular lysimeters to be an integer multiple of crop spacing. In this study, this recommendation was matched relative to the shorter sides of the lysimeter.

Observations made in previous seasons with trenches showed that roots of Sumatra tobacco in the cultivated area can be found up to 2 m below the surface (Schmidt, 2008) but with the bulk of water extracting roots restricted to the 0.40 m top layer. Further evaluation of crop growth in the lysimeter (Schmidt, 2008) confirmed that the 0.60 m depth was not a significant limitation to normal root development and soil water extraction.

To the outside face of the bottom plate a rectangular frame made of 150 mm wide U-shaped steel channels was welded (Figure 2B). The objectives were (a) to reinforce the box to prevent any bending during lysimeter installation and (b) to allow a perfect fitting and centering of the weighing platform. Therefore, the internal dimensions of the frame (0.79 m long x 0.55 m width) set the size of the weighing platform. Lysimeter inner boxes, especially the deepest ones, are usually reinforced inside with steel channels welded horizontally (Payero & Irmak, 2008). That was not the case for this study and no problem occurred that could have affected the lysimeter operation in the field. The inner box inside and outside was spray-coated with anti-corrosion paint.

The weighing platform and data acquisition system

In order to automatically weigh the mass of the lysimeter (inner box) at regular intervals a weighing mechanism with four load cells were designed and constructed (Figure 3A). The dimensions were such that the weighing platform could easily fit the external frame welded at the bottom of the inner box, as shown in Figure 3B. In Figure 1B the platform rests on the top of the supporting columns inside the outer box.

In each corner between the frames a temperature compensated load cell (model Z-1T, Alfa Instrumentos Eletrônicos, São Paulo, Brazil) was bolted (Figure 3A) making the weighing platform a single piece. A load cell converts force into a measurable output, therefore allowing

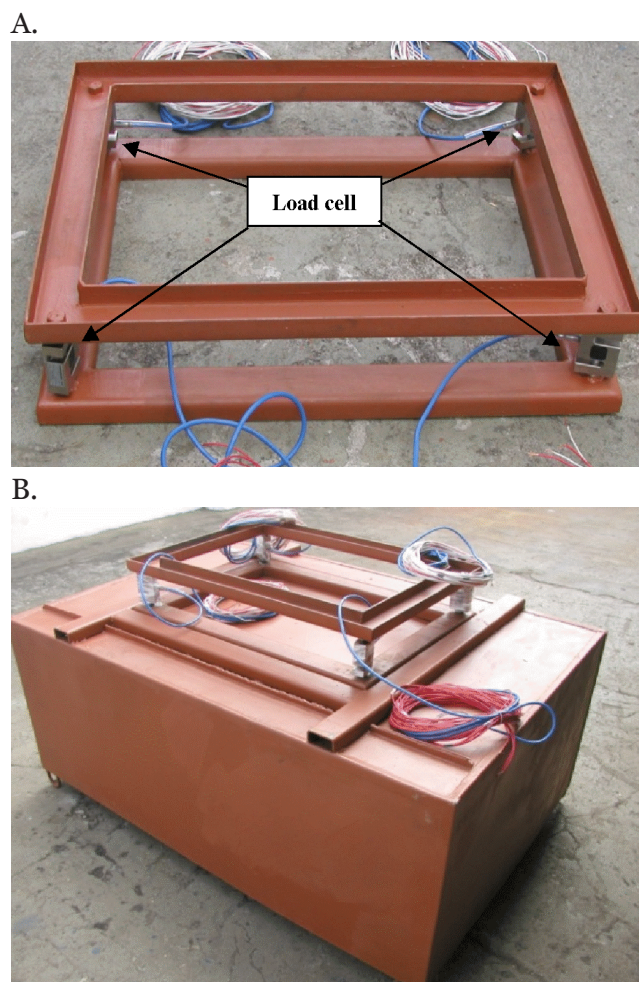


Figure 3. Weighing platform with the four S-beam load cells (A) and the same platform on the top of the inner tank upside down (B)

weights to be measured accurately (Wheeler & Ganji, 1996). Detailed specifications of the load cell type are shown in Table 1. The capacity and number of load cells were more than enough to support the distributed weight of the lysimeter inner box estimated at 1,800 kg with soil at saturation.

The electronic signals from the load cells were transmitted to a datalogger (model CR10X, Campbell Scientific Inc. Logan, Utah, USA) for processing and storage. This hardware was housed in an enclosure for protection against humidity and direct incidence of sunlight. The outputs of the load cells were sampled every 3 seconds and stored in averages of 10 minutes during the tobacco ET study. The cables from the load cells to the datalogger were buried about 1 m below the surface as shown in Figure 1B. A solar panel in series with a charge regulator and a lead acid battery powered the datalogger. Like as Allen & Fisher (1990), the load cells in this study were excited by the CR10X datalogger individually rather than as a group in parallel. The advantage

Table 1. Factory specifications for the Z-1T model load cell by Alfa Instrumentos Eletrônicos, São Paulo, Brazil

Parameter	Value
Type (Direction of loading)	S-type (tension/compression)
Material	Carbon steel (Cr/Ni/Mo)
Size	86 mm in height 60 mm in width 30 mm in thickness
Capacity	1,000 kg
Sensitivity	2 mV/V \pm 0.1%
Operating temperature range	-5 °C to 60 °C
Compensated temperature range	0 to 50 °C
Safe overload	150% of rated capacity
Ultimate overload	300% of rated capacity
Input resistance	400 \pm 10 Ω
Output resistance	350 \pm 1 Ω
Insulation resistance	> 5,000 M Ω @ 50 Vdc
Excitation	15 Vac or Vdc (maximum) 10 Vac or Vdc (recommended)
Maximum deflection	< 0,3 mm @ rated capacity
Zero balance	\pm 1% FSO
Creep	< 0,03 %FSO (20 minutes) < 0,05 %FSO (8 hours)
Combined error	< 0,03 %FSO
Protection level (IEC 529)	IP67

of this option is to enable surveillance of individual load cell performance and stability. The individual outputs were collected and summed to provide the total output of the load cells.

Field work

Site description

The lysimeter was constructed, installed, and calibrated from October to December 2006. The lysimeter was intended to determine the water use by a cropped field of Sumatra tobacco (*Nicotiana tabacum* L.) grown under shading. This type of tobacco is commercially cultivated by Danco Comércio e Indústria de Fumo Ltda a company dedicated to produce and export tobacco leaves. The lysimeter was installed in their farm located in the municipality of Governador Mangabeira, State of Bahia, Brazil. (12°37' S, 39°03' W, 220 m asl). The leaves of the plant are specifically used to wrap cigars and the crop has been traditionally cultivated in the region for more than 50 years. The soil of the experimental site is a deep Yellow Latosol in a relatively flat topography. In general, the climate characteristics fit the Am type according to the Köppen system, with 1,150 mm of average annual rainfall and mean air temperature around 25°C (Schmidt, 2008).

The total area for growing tobacco in the farm was 130 ha in 2006 divided in many sectors all irrigated by drip systems. A sector can have several fields individually covered by a black screen (15 mesh/inch, model 1003, Equipesca, Campinas,

SP) that provides 30% of shade. The screen on rests top of a 10 m x 10 m grid of wood fence posts, is positioned 3 m above the soil surface during the growing season. Covering the plants the entire season is necessary to protect them against direct exposure to sunlight and reduce the impact of winds that can affect plant growth.

The lysimeter was installed near the center of a 2 ha (132 m x 150 m) field, which provided at least 60 m of fetch in the upwind direction and 30 to 50 m of fetch in the other directions. Additional fetch was provided by other tobacco fields in the surroundings, which contributed for the representativeness of the lysimeter. Howell et al. (1991) suggested the lysimeter site to have an upwind fetch distance greater than 50 m and field area of 1 ha.

Lysimeter installation

Following the installation of the outer box, the next step was to center the weighing platform on the top of the four concrete columns as shown in Figure 1B. Before lowering the inner box, the weighing platform was checked to make sure was on level in both directions. The inner box was lowered carefully inside the outer box and was set in place making sure that: (a) the sides of the two boxes were not touching, (b) an adequate gap was left on all sides, and (c) the weighing platform fitted correctly the frame welded below the inner box (Figure 3B). Any adjustment in the fitting of both pieces, inner box and weighing platform, was monitored from outside through the lateral access entry that was left in the outer box (Figure 1). Aligned to this entry a pit was excavated large and deep enough (0.71 m x 0.77 m x 2.10 m) to work as a tunnel from which a person could reach the 0.39-m clearance between the bottoms of both lysimeter boxes.

The lysimeter was not equipped with vacuum drains which are frequently reported (Martin et al., 2001; Payero & Irmak, 2008) to remove the excess water that accumulates at the bottom of the inner tank. Instead, only drainage under saturated soil conditions could be performed. For that, a 32 mm diameter hole was opened in the bottom plate of the inner box aligned with the tunnel outside the outer box from which a person could easily open a PVC valve to collect the drainage water. The valve was then closed and the water weighed on an electronic scale. The mass changes in the lysimeter caused by the collected drainage water has to be accounted for in the adjustment of the calculated crop evapotranspiration (ET).

The accumulation of the drainage water at the bottom of the lysimeter was facilitated by a 10 cm layer of pea gravel covered with coarse sand. The gravel would provide storage of excess water at the bottom of the inner box and would allow free movement of water to the gravity drain. To monitor the fluctuation of the water table inside the lysimeter a vertical PVC pipe was inserted extending from the bottom of the inner box to just above the soil surface. The lower end of the pipe was perforated with a 3/8-inch driver-drill and covered with a nylon screen as filtering material. This filtering material was also used to cover the entry of the drain. The remaining depth of the inner box (50 cm) was backfilled with the soil taken out of the pit.

The lysimeter was filled with repacked soil. Backfilling the inner box with a shovel started with the soil of the last layer removed in an attempt to approximate the soil profile. Additionally, the soil of each layer was slightly compacted in an effort to try and mimic the soil density in the lysimeter to match that in the field (Martin et al., 2001; Payero & Irmak, 2008). It is believed that such procedures contributed for the lysimeter representativeness since plants inside the lysimeter showed similar growth and development to the ones in the field.

Completing the lysimeter installation, pressure transducer tensiometers were installed inside and outside the lysimeter at 0.10 m, 0.20 m, and 0.30 m depths for monitoring soil water content in the crop root zone. Other instruments nearby the experimental area were two automatic weather stations (AWS), one in the area covered by the shading screen and the other outside in an open field. Both AWS could measure all variables needed to calculate reference ET (ET_0), such as solar radiation, maximum and minimum air temperature, relative humidity, and wind speed.

Calibration procedure

The field calibration of the lysimeter was performed in November 2006 and followed the methodology suggested by Wheeler & Ganji (1996) in which known weights are loaded and unloaded and the outputs recorded. The data are then used for uncertainty analysis and overall accuracy assessment. Other authors (Dugas et al., 1985; Schneider et al., 1998; Martin et al., 2001; Payero & Irmak, 2008) have described similar procedures to calibrate load cell-based weighing lysimeters of varying shapes and sizes.

The calibration consisted in measuring the

load cell outputs that resulted from loading and unloading the lysimeter with plastic bags filled with dry sand. These sand bags were taken as standard weights that were measured on a 1.5 kg capacity electronic scale to the nearest 0.01 g resolution. The standard weights included 108 bags of 1 kg each, three bags of 0.5 kg each, and five bags of 0.1 kg each for a total mass of 110 kg corresponding to a 62.5 mm water depth. The smaller weights were considered in this study for sensitivity analysis of the weighing system. A plastic sheet was used to cover the lysimeter during calibration to minimize water evaporation (Dugas et al., 1985; Allen & Fisher, 1990; Marek et al., 2006). Additionally, the calibration was performed early in the morning under low wind conditions to minimize the effects of wind shear on the lysimeter.

Five cycles of loading and unloading were performed. In the loading cycles, the 1 kg bags were initially added as nine packs of 10 kg each (90 kg) one at a time and then as three packs of 5 kg each (15 kg). From this point, the remaining standard weights were added individually starting with three bags of 1 kg (3 kg) followed by the three 0.5 kg bags (1.5 kg) and finally by the five 0.1 kg bags (0.5 kg). Unloading followed the reverse order. Each loading/unloading cycle consisted of 47 pairs of calibration weights (independent variable) and voltage output (dependent variable).

Voltage outputs from the load cells were read with a precision of 0.0001 mV by means of a portable display (model CR10KD, Campbell Scientific Inc., Logan, Utah, USA) connected to the data logger. Taking any reading required stabilization of the voltage value shown in the display. Once finished the five loading/unloading cycles, the mean voltage was calculated and used to derive the calibration curve of the lysimeter and to evaluate parameters as linearity, hysteresis, and overall accuracy of the weighing and data recording system.

Results and Discussion

Calibration results and uncertainty analysis

Environmental conditions during the calibration tests are shown in Table 2. All data were collected by an AWS located nearby the lysimeter in the same area covered by the screen. The wind speed was less than 1 m s⁻¹ during the tests due to both the protection offered by the

screen and because the calibration was done early in the morning. In open fields, the negative effects of wind on the performance of weighing lysimeters have been largely reported. Campeche et al. (2002) reported serious problems to calibrate a weighing lysimeter under wind speed higher than 1.5 m s^{-1} . Marek et al. (2006) chose days with light wind conditions to calibrate weighing lysimeters in Texas to prevent noise on the scale.

Table 2. Mean hourly values of selected weather variables measured within the tobacco field below the shading screen, during calibration of the weighing lysimeter

Time (h)	Air temperature ($^{\circ}\text{C}$)	Relative humidity (%)	Wind speed (m s^{-1})
0400	24.0	92.0	0.0
0500	23.9	92.5	0.0
0600	24.2	88.5	0.0
0700	24.0	88.0	0.4
0800	26.6	71.0	0.5
0900	27.7	64.5	0.7

The calibration curve is shown in Figure 4. Linear regression of standard weight versus load cell output resulted in a highly significant relationship with standard error of estimate ($S_{y/x}$) around 0.033 mm and $r^2 > 0.99$ for all three cases (loading, unloading and all data). The slope of the all-data calibration curve (503.2 kg mV^{-1} or 0.002 mV kg^{-1}) indicates the sensitivity of the weighing and data logger system.

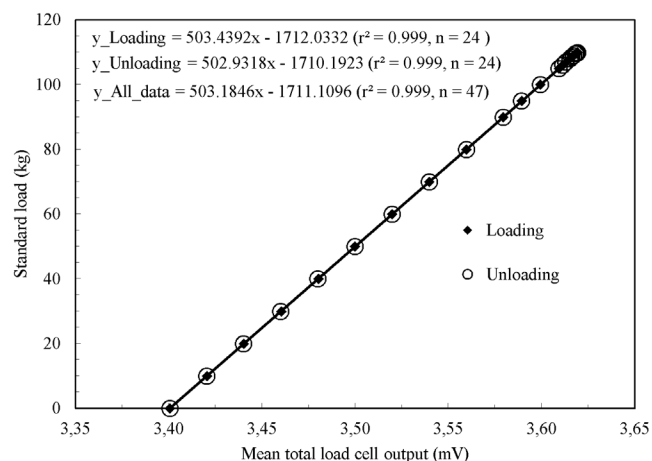


Figure 4. Cumulative standard mass vs measured mean total output from the load cells during lysimeter calibration test

The calibration data provided assessment to linearity and hysteresis errors of the scale and data logger combination. The calibration data revealed that both the linearity and lack of hysteresis was excellent. Some hysteresis in the calibration data of a weighing lysimeter in Nebraska was reported by Payero & Irmak (2008). The authors linked the hysteresis to

mass changes due to evaporation since the lysimeter surface was not covered during the 1 h calibration period.

Plotting the residuals of the linear regressions from Figure 4 gives assessment of the overall accuracy of the weighing system. Wheeler and Ganji (1996) defined accuracy as the closeness of agreement between a measured value and the true value and as an uncertainty specification it typically integrates the error components due to hysteresis, linearity, and repeatability. Figure 5 shows the accuracy limits considering both the loading and unloading data over the 110 kg range (equivalent to 62.5 mm soil moisture change). Errors were generally within $\pm 0.1 \text{ kg}$, corresponding to $\pm 0.06 \text{ mm}$ of water depth. Allen & Fisher (1990) found similar errors in the range of $\pm 0.05 \text{ mm}$ for two weighing lysimeters in Logan, UT.

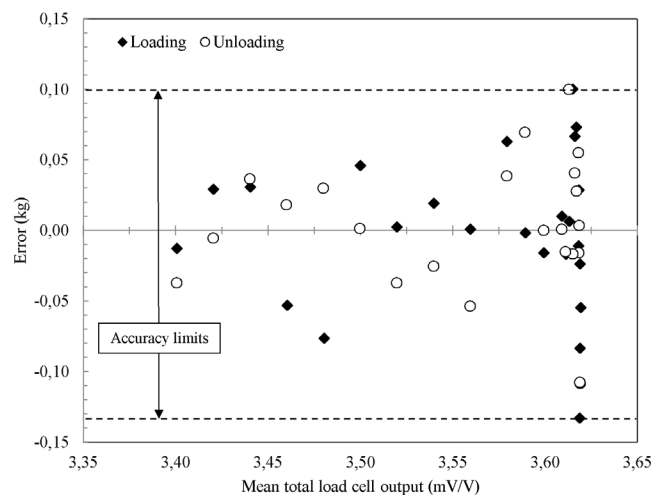


Figure 5. Errors between standard load and measured mean total output from the load cells during the lysimeter calibration test

In computer-based data acquisition systems where electrical signals travels through several components from the measuring devices to digital data displays, each component can add some unavoidable bias and precision errors so that the system output combines the effects of all error sources (Wheeler & Ganji, 1996). Allen & Fisher (1990) pointed out that inaccuracies in the calibration weights (standard loads), which are cumulative during the loading/unloading cycles (Howell et al., 1995), can also contribute to the overall accuracy limits in lysimeter calibration tests.

Performance under field conditions

The lysimeter responded to small variations in mass compared to its total mass. Figure 6 shows the mass variation during the period from February 17 (DOY 48) to February 21 (DOY 52)

where data are displayed in 10 min intervals. Over this period several events (drainage, precipitation, and irrigation) that altered the lysimeter mass occurred and are indicated by vertical arrows. The graph clearly shows that higher variation of lysimeter mass occurred daytime and the gradual decrease of mass reflected crop evapotranspiration (ET). As expected, crop ET was negligible during nighttime, when lysimeter mass remains nearly constant in the absence of precipitation or irrigation.

During the five day period in Figure 6, crop ET varied from day to day with a peak of 9.1 mm on DOY 50. The accumulated crop ET was 34 mm with an average of 6.8 mm day⁻¹. With a R_s/R_{s0} ratio of 0.72, February 19 (DOY 50) can be considered a clear day, which can help to explain the high crop water demand. Atmospheric conditions outside the covered area were 30.4°C for maximum temperature, 22.8°C for minimum temperature, 91% for maximum RH, 56% for minimum RH, and 3.3 m/s mean wind speed. Tobacco plants grow fast and on DOY 50 (56 days after transplanting) the plants was 2.5 m tall, on average, with some inflorescences almost touching the shading screen positioned 3 m above the ground. At this growth stage and time of year and shading tobacco ET can easily be higher than 5 mm per day.

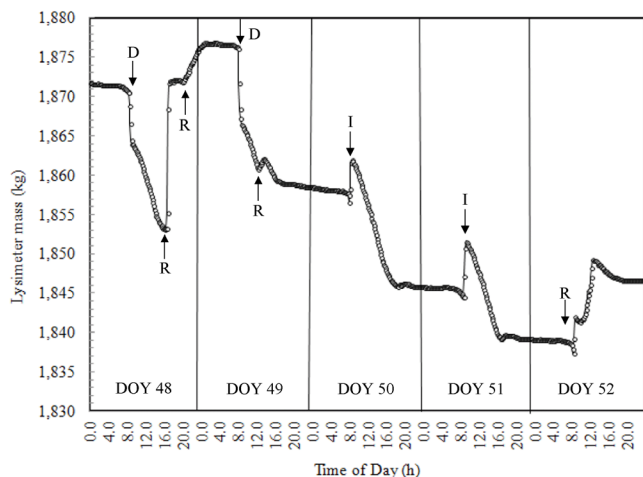


Figure 6. Mass variation of the lysimeter during a 5-day period (February 17–21, 2007 – DOY 48 to 52) planted with Sumatra tobacco (plant height = 2.5 m). Each point is a 10 min average of lysimeter mass sampled at 3 s interval. Space between vertical lines represent one day. (D = drainage, R = rainfall, and I = irrigation)

Practical information regarding the lysimeter operation under field conditions for ET determination is how much water has to evaporate or be added to the lysimeter to cause a detectable mass change. This amount of water calls for the resolution of the lysimeter. Resolution therefore is the last significant definable increment of

the measurement (Howell et al., 1991). In the weighing system here presented, the CR10X read the load cell with a resolution of 0.33 μ V or 0.00033 mV, corresponding to 0.133 kg or 0.07 mm in evaporation equivalent. This means that the datalogger was able to resolve mass changes less than 0.1 mm, which is sufficient for measuring tobacco crop ET over hourly and daily periods during the growing season of irrigated tobacco in Bahia. This period comprises spring and summer months from October to February, when the incident solar radiation reaches high levels with elevated air temperature and low relative humidity. Under such conditions, evapotranspiration from adequately irrigated fields can be significant, which makes the lysimeter here described a reliable equipment for measuring tobacco ET under shading over periods of time as short as 1 hours.

Costs for lysimeter construction and installation, including rental of equipment, was around US\$ 5,100. The datalogger with keyboard display was the only equipment rented. Material for building the outer and inner tank was easily found in local retail stores. The 1,000 kg capacity load cells were purchased in the national market at a cost US\$ 300 each. The total cost of this lysimeter could have been higher if a suction type drainage system was used. For the Payero & Irmak (2008) weighing lysimeters, such drainage system was 15% of the total cost.

Conclusions

1. The design and characteristics of the lysimeter in terms of area and depth combined with the load cell based weighing platform and electronic data recorder make the lysimeter here described adequate for crop ET studies. The primary purpose was for tobacco ET measurement, but the lysimeter can be used with other annual crops as well.

2. The use of a tunnel that allowed access to the space underneath the inner tank is highly recommended not only for collecting drainage water but also for inspection of weighing platform integrity and maintenance.

3. The overall accuracy of load cells and datalogger resolution were both below 0.1 mm, which makes the lysimeter suitable for measuring ET of Sumatra tobacco grown under shade in Bahia, Brazil, over periods of one hour or longer.

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