A Weighing Lysimeter Facility at Roodeplaat for Crop Evapotranspiration Studies

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Abstract

The design features of four recording lysimeters installed at Roodeplaat, near Pretoria, are described. Each lysimeter consists of a 2 m x 2 m x 1 m steel tank supported on a counterbalanced lever system, water content changes being monitored by means of an electronic load beam. Calibration data indicate that hourly evapotranspiration to about 0,1 mm water can be measured. Evapotranspiration and other environmental parameters are monitored and recorded by a data logging system.

Introduction

A means of obtaining precise evapotranspiration data is indispensable when studying soil-water-plant relations and developing methods of predicting water use. The most sensitive and direct means of measuring evapotranspiration is by using weighing lysimeters. It was decided to construct lysimeters capable of measuring hourly evapotranspiration of field crops, in support of the irrigation research programme at Roodeplaat, approximately 30 km north of Pretoria. Facilities now include four weighing lysimeters, an intensive irrigation network which can be used for sprinkler, drip or micro-spray irrigation, and a monitoring and data logging system. The design, construction and performance of the lysimeters are described in this paper.

A weighing lysimeter consists of a tank containing soil and a crop, level with and representative of the surrounding area, and supported by a weighing mechanism for detecting water content changes. Design criteria are discussed by Van Bavel (1961). Commonly used weighing methods are floating tanks (King, Tanner & Suomi, 1956), hydraulic systems incorporating manometers or pressure transducers (Glover & Forsgate, 1962; Black, Thurtell & Tanner, 1968), mechanical balances (Pruitt & Angus, 1960; McIlroy & Sumner, 1961), load cells (Green, Burger & Conradie, 1974) and a combination of the last two (Van Bavel & Myers, 1962; Ritchie & Burnett, 1968; Armijo, Twitchell, Burman & Nunn, 1972). The choice of system depends upon the desired sensitivity, frequency of measurement, ease of recording and the cost involved.

In South Africa, evapotranspiration of sugar cane was studied at Chaka's Kraal, Natal, using hydraulic lysimeters and by means of mechanical weighbridge lysimeters at Pongola (Thompson and Boyce, 1967 & 1971). Mottram and De Jager (1973) described a lysimeter installation in Pietermaritzburg for shallow-rooted crops using a platform scale and electronic load beam; a similar system was used at the Makatini Research Station for a few years (Hellman, 1976). Green, *et al.* (1974) measured evapotranspiration in a citrus orchard at Addo in the Eastern Cape using a lysimeter supported on load cells. This installation has since been expanded and improved (Green & Bruwer, 1979).

Lysimeter Design

A mechanical lever/load beam combination was chosen for Roodeplaat because this system provides the accuracy and sensitivity required as well as ease of recording. The various components of the lysimeter system are illustrated in Fig. 1.

Site

The lysimeters are installed in pairs on 4 ha of land, the distance between each in a pair being 20 m and the pairs 108 m apart. The pairs are situated on soils of the Shorrocks and Glendale series (MacVicar, *et al*, 1977) or Rhodic Paleustalf and Typic

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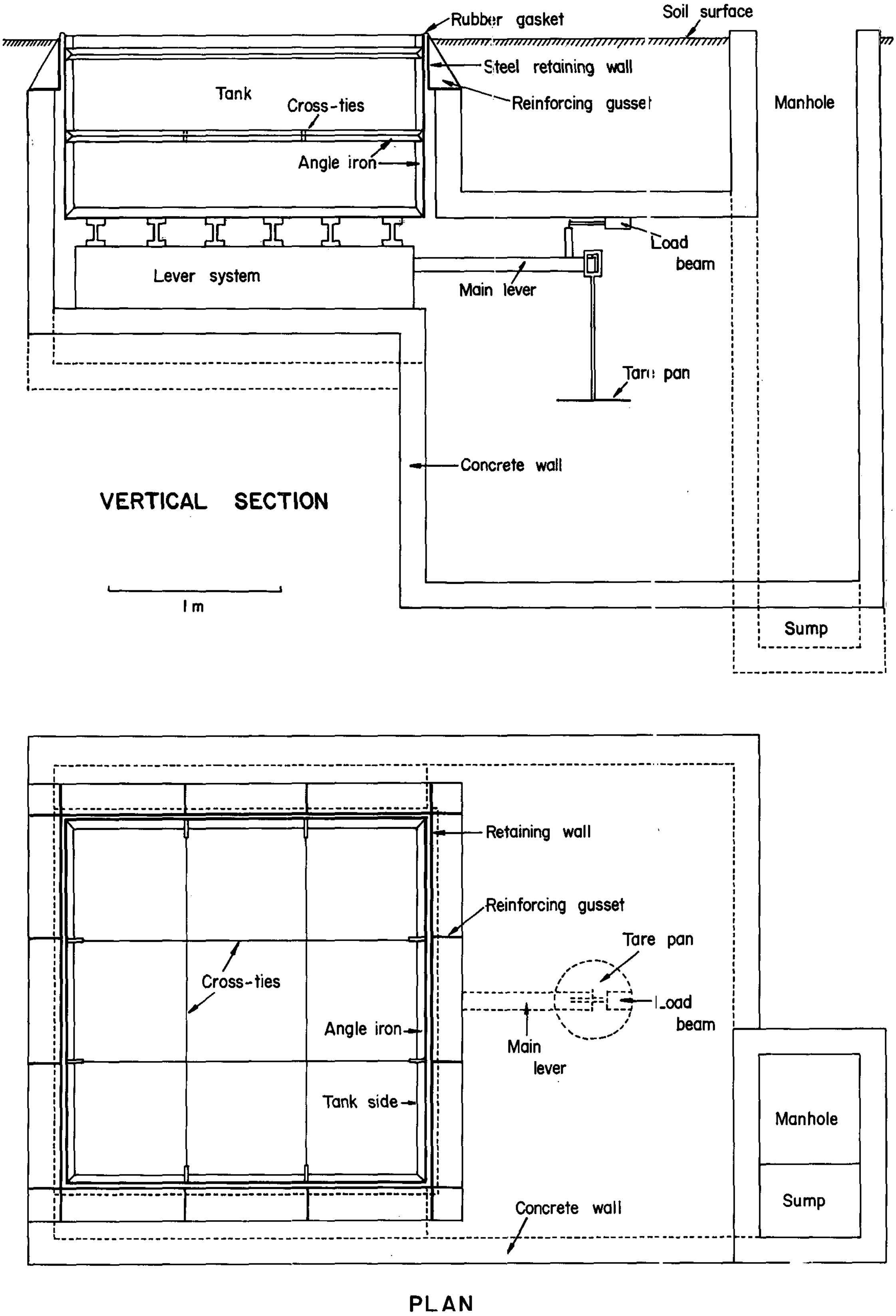

Figure 1
Diagram of lysimeter system

Ustropept according to the USDA system (Soil Survey Staff, 1960). The experimental area can be divided into 12 m x 12 m plots capable of being irrigated independently. The lysimeters are situated at the centres of four of these plots.

Foundations

The lysimeter foundations and retaining walls are of reinforced concrete, with the exception of a steel retaining wall surrounding the upper 300 mm of the tank. A sump facilitates removal of storm water although thorough waterproofing and tight-fitting manhole covers have virtually eliminated leaks into the foundations.

Tanks

The lysimeter tanks measure 2 m x 2 m and are 1 m deep. Square rather than round tanks were preferred because of the ease of accommodating row crops. The tanks were constructed of 6 mm steel plate reinforced with horizontal 50 mm x 50 mm x 5 mm angle iron strips. Adjustable cross-ties were fastened in the half height position to prevent distortion of the sides. The 20 mm gap between the tank sides and the steel retaining wall is sealed at the surface with flexible, ultra-violet resistant, synthetic rubber sheeting. All steel surfaces were cleaned and coated with epoxy primer and several coats of epoxy paint.

The drainage system at the bottom of each tank consists of 25 mm diameter black plastic pipes, laid 100 mm apart and having slots 1,5 mm wide and 20 mm long, cut at intervals of 70 mm across the pipes. Soil is prevented from entering the pipes by a covering of glass fibre surface tissue. The pipes are embedded in a 100 mm layer of washed sand separated from the overlying soil by a sheet of glass fibre tissue. The drainage pipes are connected to two transverse pipes which feed into drainage collection bottles fastened to the tank support beams. Drainage losses are thus not registered by the weighing system until the bottles are emptied. The vacuum in the drainage system is maintained by an aquarium aerator in which the air flow direction is reversed. The aerator can operate continuously, maintaining a pressure about 10 kPa below atmospheric pressure.

Soil

Soil for the tanks was obtained by isolating a 2 m x 2 m by 1 m deep monolith of soil in the vicinity of each lysimeter. The monoliths were separated into 100 mm horizontal layers which were packed in the tanks in the correct order and compacted to the original depth. This ensured that the bulk density of the soil within the lysimeters was similar to that in the field.

Weighing and data logging system

The lysimeter tank support platform, consisting of six rigid "I" beams, rests upon a weighbridge scale which was manufactured to match the tank size. The tank and dry soil are tared mechanically by means of a sliding counterpoise or by placing lead balance pieces in a pan suspended from a knife edge on the main lever of the scale. The mechanical advantage of the lever system is about 80:1. The force exerted at the end of the main lever is measured using a 200 N capacity load beam, which can cover a water content range equivalent to 400 mm. This is approximately the difference between saturation and air dry water content so it is not necessary to change the tare over the possible soil water content range.

The excitation voltage of the load beams is 10 V, supplied from mains through a DC power supply and voltage reference. The nominal load beam output is 1 mV/V at rated maximum load.

The data logger was designed to satisfy requirements at Roodeplaat. It consists of three units, each recording onto separate tape cassettes. Scanning intervals and the number of channels scanned can be set for each unit. A crystal clock provides an accurate time base. One unit handles input signals of -3 to $+7$ mV, recording to 1 μV. Output from the load beams is monitored by this unit. A second unit monitors transducers having outputs up to 10 V and in addition has 12 integrator channels in the millivolt range. The third unit consists of pulse counting channels.

The data logger is powered by two 12 V batteries in series, charged by a mains-fed charging unit. This system ensures that the time base, scanning and recording are maintained during power cuts, even though some transducers, including the lysimeter load beams, may not be operating at such times.

Tape cassettes from the data logger are read into a desk computer for further data processing. At present all channels are scanned at ten-minute intervals. Hourly averages are calculated from the ten-minute data and stored on computer tape cassettes. In addition to the lysimeter load beams a wide variety of transducers for monitoring the soil-atmosphere environment can be accommodated.

The data logger, load beams and other transducers may easily be damaged by lightning. Protective measures have been implemented (Van Niekerk & Eriksson, 1977). Briefly, these involved improving the earthing system, protecting the data logger power supply from surges and ensuring that all data input lines and transducers are suitably protected.

Calibration

Potential resolution and accuracy of the lysimeter system may be assessed by examining the nature and specifications of the various components.

Load beams The guaranteed accuracy of 0,05 % represents 10 N or 0,2 mm of water. This takes into account maximum deviations from linearity, thermal and hysteresis effects and power supply fluctuations (1 mV in 10 V) over the whole range of operating conditions. Since normal day-to-day operation takes place under comparatively static thermal and load conditions, daily weight changes will be detected with much greater accuracy than this. The load beams are infinite resolution transducers, so limitations to the resolution of the system must be sought elsewhere.

Mechanical lever system Frictional forces can introduce resolution difficulties, but these are minimised since almost all movement of the lever system is arrested by the load beam. Nevertheless, frictional forces both within the lever system and external to it (e.g. from cables entering the tank and the rubber seal between tank and retaining wall) are responsible for the greatest inaccuracies of the system as a whole.

Measuring system Resolution of the measuring system is 1 μV, equivalent to about 0,04 mm of water. Electronic noise is however a variable factor which is at times negligible but at other times capable of introducing an error of ± 3 μV ($=0,12$

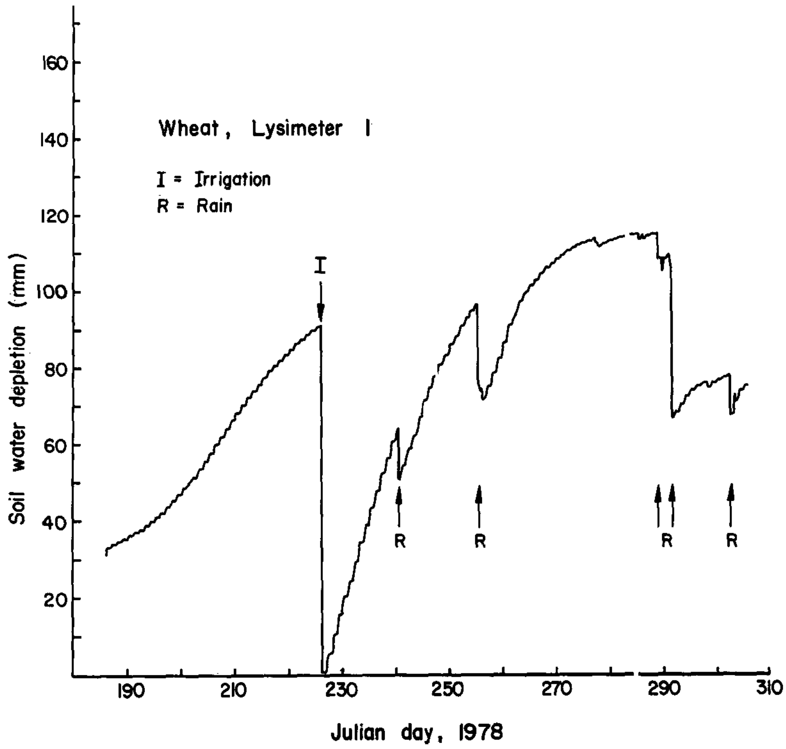

Figure 2
Water balance of a wheat crop

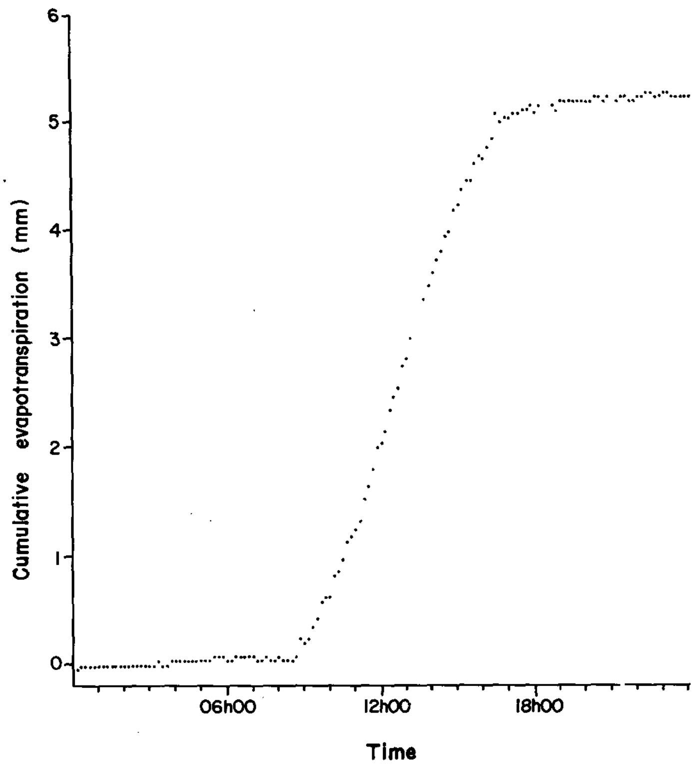

Figure 3
Cumulative ten-minute evapotranspiration data (78/08/18, lysimeter 2)

TABLE 1
LYSIMETER CALIBRATION DATA

	Lysimeter 1	2	3	4
Date: 78/04/18				
Range (mV)	0,67 – 1,43	0,96 – 1,73	0,17 – 0,95	0,43 – 1,20
Data logger response (μV/5 mm water)				
Adding	127,2 ± 2,5	128,2 ± 1,5	130,2 ± 2,5	128,2 ± 4,3
Subtracting	127,0 ± 2,2	127,0 ± 0,6	129,7 ± 2,9	130,7 ± 2,2
Overall	127,1 ± 2,2	127,6 ± 1,3	129,9 ± 2,6	129,4 ± 3,5
Calibration (μV/mm)	25,4	25,5	26,0	25,9
Date: 78/11/29				
Range (mV)	4,26 – 6,18	2,81 – 4,79	2,91 – 4,79	3,62 – 5,61
Data logger response (μV/5 mm water)				
Subtracting	127,8 ± 2,1	127,9 ± 1,1	125,5 ± 5,0	129,6 ± 3,2
Calibration (μV/mm)	25,6	25,4	25,1	25,9

mm of water). Wind effects are indistinguishable from electronic noise and of the same order of magnitude under all but abnormally windy conditions. Noise and wind errors are to some extent suppressed over an hour by the adopted procedure of averaging six ten-minute values.

The nominal calibration constant of the lysimeters is 25 μV per mm of water assuming a load beam excitation of 10 V, output of 1 mV/V at maximum rated load and a mechanical advantage of 80:1 on the lever system. None of the above values is exact so calibration constants were obtained using assized mass pieces.

Calibration constants for each lysimeter were obtained at two different times and over different parts of the measuring range.

Successive 20 kg mass pieces placed on the tanks represent 5 mm increments of water. The response of the data logger to the addition and removal of a series of mass pieces, and the calculated calibration constants (Table 1) show that the response of the lysimeters is linear and stable over a period of time. Resolutions of 0,1 mm (about 2,5 μV) are feasible, especially if a number of readings are averaged. Calibration constants will be checked periodically.

Field Performance

For the purpose of the current experiment a crop rotation of wheat *(Triticum aestivum* L) in summer and soya beans *(Glycine max)* in winter is followed. Various water application cycles have been used to study the effect of stress on plant physiological response (Meyer & Green, 1980 a & b). To illustrate the type of data obtainable from the lysimeters, hourly average water balance of wheat during a growing season is plotted (Fig. 2). Fig. 3 shows cumulative evapotranspiration values for a 24 h period.

Conclusion

The lysimeters described in this paper are capable of continuously recording water content changes of 0,1 mm while requiring no tare changes over the full range of soil water content. Two years of continuous operation have shown the system to be accurate and reliable. In conjunction with the other monitoring facilities available at Roodeplaat, they should prove valuable tools in increasing our knowledge of the interaction between soil, plant, water and atmosphere.

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