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Research Article

Design and Development of a Load-Cell Based Cost Effective Mini-Lysimeter

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ABSTRACT

Mini-lysimeters are generally used to quantify accurate and minor changes in amount of soil moisture content, drainage water, evapotranspiration, and other water balance components within a soil monolith. A study has been carried out to develop a mini-lysimeter for quantification of water balance components in field under an arid environment at ICAR-Central Arid Zone Research Institute, Jodhpur. The mini-lysimeter has been designed and fabricated based on electronic single load cell with a dimension of 0.50 m × 0.50 m × 0.55 m, and then installed in the experimental field. The cost for fabrication of a single mini-lysimeter was ₹ 14,500 (~234.5 US \$). It has been observed that fabrication of mini-lysimeters based on single load cell is less expensive as compared to conventional tank lysimeter, therefore, can be economically replicated and easily installed. The developed mini-lysimeter was tested in field during *kharif* season of 2014 and found effective to measure different water balance components with a resolution of 0.2 mm.

Key words: Fabrication, Mini-lysimeter, Single load cell, Water balance, Weighing accuracy

Introduction

Lysimeters are most commonly used to determine the water balance components in field and more specifically the crop evapotranspiration or crop coefficients (k_0) for different crops. For this purpose, weighing type lysimeters have been commonly used at different parts of the world with variable costs, for example Storlie and Eck (2006) reported a cost of \$1475 for constructing a lysimeter to measure evapotranspiration of young high bush blue berries (*Vaccinium corymbosum* L.), whereas Allen and Fisher (1990) reported a cost of \$ 5550 per unit. Recently, Fisher (2012) reported an electronic weighing type lysimeter consisting of a steel outer tank and an inner tank, electronic load cell assemblies, and a PVC drain system, which costs about \$1700.

The cost of lysimeter can be minimised by using single load cell, although the accuracy of measured water balance components can be marginally lower as compared to commonly available lysimeter (Storlie and Eck, 2006).

In hot arid regions, surface energy balance is crucial for monitoring crop water use and evaluating daily and seasonal water budgets (French *et al.*, 2012). Shortage in water availability has further highlighted the importance of water resource for agricultural production in arid regions (Payero and Irmak, 2008). The exchange process of water between soil surface and the atmosphere plays an important role in arid regions especially during long dry spells (Malek *et al.*, 1999). Loss of applied water in agricultural field through evapotranspiration process can be either directly measured or estimated by various technologies such as

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lysimeter, soil moisture depletion method, eddy correlation technique, water balance component analysis, energy-mass exchange, crop coefficient method etc. Among these technologies, lysimeter or mini-lysimeter is generally used for direct measurement of crop evapotranspiration and water balance components (Parisi *et al.*, 2009; Igbadun, 2012). Mini-lysimeters have the advantages that they permit the measurement of the evaporative flux from smaller areas; create less disturbance to the environment of inters during installation; and are considerably cheaper to construct, install and maintain (Igbadun, 2012). Analysis of the costs of the mini-lysimeter system reported in literatures indicates that evapotranspiration can be measured economically at a reasonable accuracy and sufficient resolution with robust method of load-cell calibration. Keeping in view of the above, an initiative was taken to develop a mini-lysimeter for field measurements of water balance components, and is presented in this paper.

Materials and Methods

Study area

The present study was carried out at experimental research farm of the ICAR-Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan (26.3°N, 73.02°E; 224 m above mean sea level). The climate of the region is arid, characterized by high diurnal and seasonal temperature variations and annual and inter-annual irregular rainfall with long dry seasons associated with strong winds. Mean monthly maximum and minimum temperature during the year ranges from 24.9 °C to 41.1 °C and 10.6 °C to 28.1 °C, respectively. The mean annual rainfall is 379.2 mm with a coefficient of variation 46% (Singh *et al.*, 2011). Soils of the experimental

plots were originated from rhyolite and subsequently modified through alluvial and aeolian processes. Taxonomically, the soil may be defined as coarse loamy mixed hyperthermic of camborthids. Soil organic C is very low (1.6 g kg⁻¹). Soil physical properties of the experimental area are shown in Table 1.

Design of mini-lysimeter

The mini-lysimeter (ML) with load-cell based measurement system was designed for quantifying actual measurement of water balance components in the field. Design parameters of the ML were first identified after considering the characteristics of soil-plant-atmosphere continuum. A major requirement of this is its resemblance with field rhizosphere. A minimum depth of 50 cm was considered, up to which root growth of most field crop restricts (Fig. 1). Width of 50 cm was considered for the ML so that at least one row of a selected crop can be grown inside the lysimeter. Capacity of the load-cell was decided based on weight of ML tank and the weight of soil to be filled in the tank. Field bulk density of 1.45 Mg m⁻³ was considered in order to calculate the weight of the soil to be filled inside the ML. Thus, the designed ML was comprised of three main components (i) tank, (ii) concrete underground chamber and (iii) single load cell based weighing system.

Load-cell characteristics

Load cell with digital display (Fig. 1) is the most important part of a ML. A single point parallel beam based on load cell (Make-ADI Company India; regular 410) was selected. High tool steel platform of the load cell makes it rugged for shock loads and is suitable in harsh applications. The general load cell working

Table 1. Characterisation of soil physical properties

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Field capacity (%)	Permanent wilting point (%)
0-10	7.5	10.8	81.7	8.98	3.44
10-20	8.3	6.7	85.0	8.59	3.48
20-30	9.6	7.5	82.9	9.76	3.87

principle is not discussed in detail here. Briefly, it works on the wheat stone bridge principle and gives milli-volt output in response to change in weight, which is further calibrated with known weight. The calibration chart between mV reading and weight in kg may be found in the product brochure. The load cell with maximum weighing capacity of 750 kg and resolution of 0.05 kg was selected after considering the weight of soil, weight of crop biomass to be grown and weight of ML tank. Calculation of weight of fully saturated soil in the lysimeter was found about 237 kg (181 kg dry soil + 56 kg pore-filled water). Root and shoot biomass was considered negligible as it was < 5 kg. Weight of ML tank was 80 kg. It was fabricated according to study requirement within platform size 0.50 m × 0.50 m × 0.27 m. The platform was made of 4 mm mild steel (MS) iron and MS angle for supporting legs. The single load cell was fixed in an upright orientation in the centre of platform bottom (Fig. 2). The platform was supported to the ML tank for measuring weight of the tank.

The required power to operate the load cell digital display system was supplied through establishing an AC power supply line. Otherwise the load cell system has a power backup with a 6 V, 4.5 AH lead acid battery, which helps to operate the digital display system in case of supply power failure. It is to be noted here that any interruption in power supply leads to loss of

memory and thus, continuous measurement of weight cannot be done. The backup period of the in-built battery is 12-18 hours; therefore it is ascertained in the field condition for weighing the lysimeter tank continuously. The display indicator of the load cell was covered with a plastic box for avoiding moisture, rain water, dust, wind and direct sunlight etc. because of its sensitivity.

Fabrication and installation in field

The ML tanks were fabricated with iron material as Hot Rolled Steel sheet (4 mm) and MS angle (40 mm × 40 mm × 6 mm) at fabrication workshop at the Institute. The tanks were designed to quantify actual water balance components from the tanks after irrigation and rainfall event. The tank dimension was 0.50 m × 0.50 m × 0.55 m, including 0.05 m of drainage chamber height, with 10 cm height supporting legs. The tank was comprised of a ML tank, drainage plate, drainage collator tank, drainage hole, legs and handle. The drainage plate dimension was 0.49 m × 0.49 m with a thickness of 4 mm, kept inside the ML tank with support of 0.05 m height angles in the corners. It was also made of HR sheet with 49 holes (6 mm diameter of each hole) (Fig. 1). Water drained through these holes from the tank and was collected in the drainage collector tank. The drainage collector tank dimension was 0.50 m × 0.50 m × 0.05 m, in

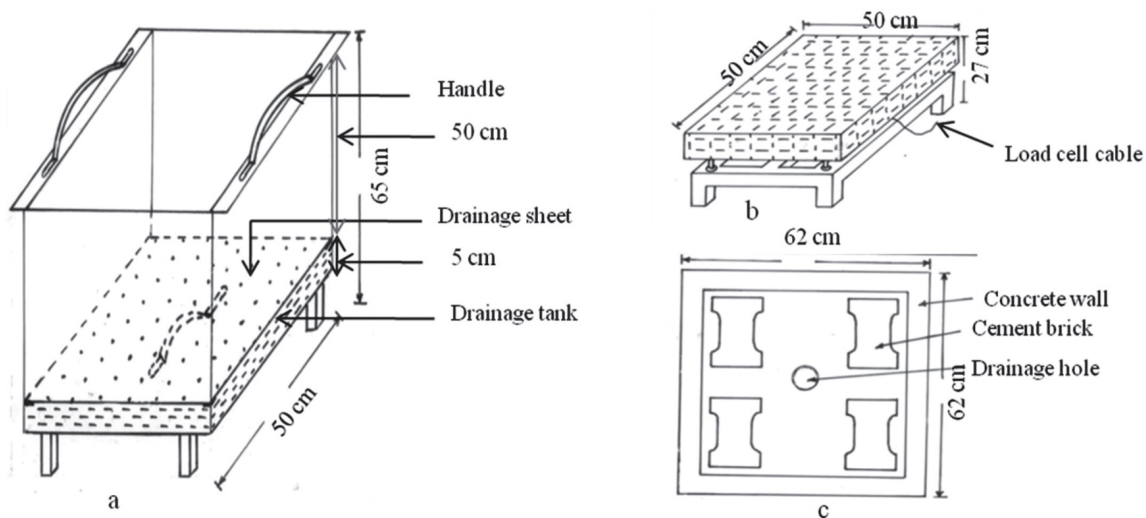


Fig. 1. Design of mini-lysimeter; (a) mini-lysimeter tank, (b) electronic weighing system based on single load cell along with platform and (c) concrete chamber for placing the mini-lysimeter inside

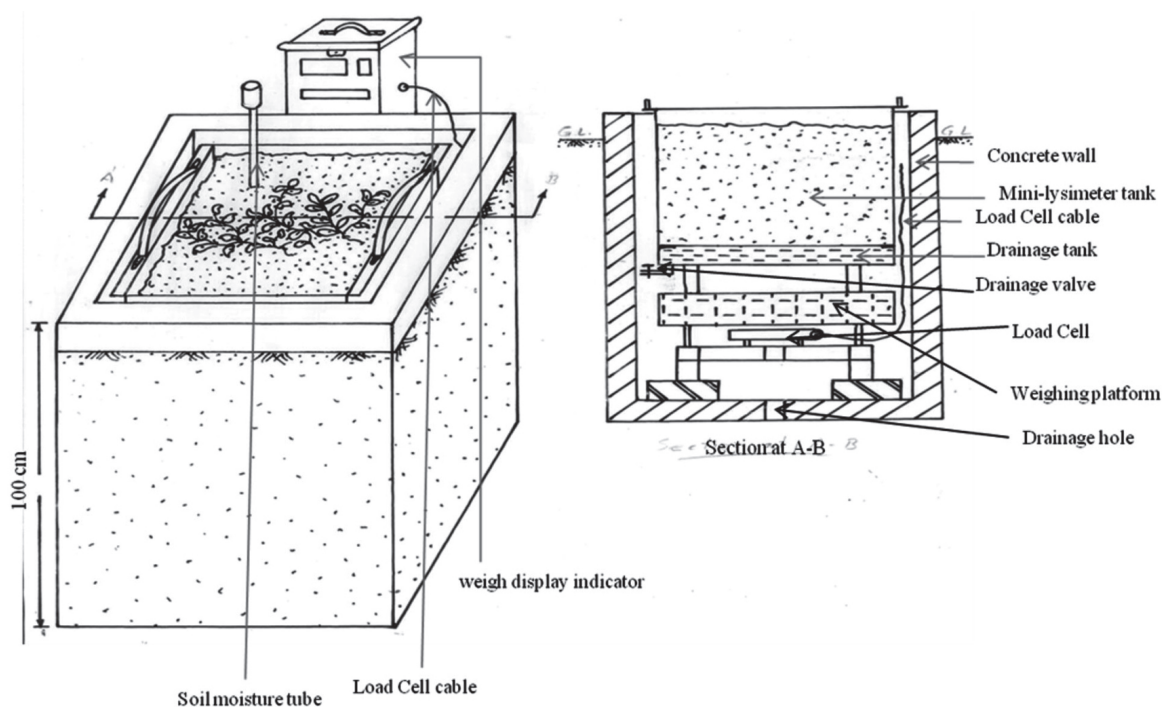


Fig. 2. view of mini-lysimeter and cross section view of the system

the bottom of this tank, having a hole of 12 mm diameter and the hole was connected with GI pipe along with control valve to drain out the water from the drainage collector tank. Two handles were attached to the top of the tank in two opposite sides to slide up and down during the installation.

The developed ML was installed in the field on 30th August, 2014. Earth pit was dug with dimension of 1m×1m×1m and after development of plain concrete cement, the final dimension of constructed pits was 0.62 m × 0.62 m×1.0 m from 10 cm above the ground level (Fig. 1a). The bottom was made with cement concrete up to 10 cm height and a hole of 10 cm diameter was kept for drainage water from the chamber. In the corners of the bottom of the pits cement bricks were kept for supporting the load cell platform legs up to 8 cm height. The walls of the pits were constructed with brick and cement of about 10 cm width. All the components were assembled to operate electronic weighing ML based on the single load cell (Fig. 2). Soil up to 50 cm profile from the ground level was excavated from the experimental plot to fill the ML. Tank filled-in soil layer was alternatively saturated and drained

until the bulk density inside the ML was maintained at about 1.45 Mg m⁻³, which was the average bulk density of nearby field site. The mini-lysimeter along with assembly is presented as Plate 1.

Results and Discussion

Calibration of mini-lysimeter

The lysimeter was calibrated after installation in the field on the same day. The area of each one was 0.25 m², and therefore a change of ML by 1 kg will be equivalent to 4 mm of water after consideration of density of water as 1000 kg m⁻³. A known quantity of water was added in each ML and corresponding weight change was recorded, which was then converted to the amount of water added using conversion factor of 1 kg = 4 mm. Measured amount of water by ML was compared with the known amount of water added and a good match has been observed. The least count or resolution of the load cell used in the ML was 0.05 kg, and thus the least count of ML measurement would be 0.2 mm. Hence, the ML was calibrated in the field with a conversion factor of 1 kg = 4 mm with resolution of 0.2 mm.

Table 2. Validation of load cell during rainfall events on different occasions

Date (dd-mm-yyyy)	Mini-lysimeter weight (kg)			Net change of mini-lysimeter (kg)			Rainfall (mm)	Drainage (mm)
	1	2	3	1	2	3		
07-09-2014	192.60	18.45	18.75	-	-	-	0	0
08-09-2014	190.85	16.70	17.25	-1.75	-1.75	-1.50	0	0
09-09-2014	189.05	15.00	15.55	-1.80	-1.70	-1.70	0	0
10-09-2014	193.90	19.80	20.30	+4.85	+4.80	+4.75	23.8	2.73*

*drainage component represents average of three mini-lysimeters

Field validation of mini-lysimeter

Further the installed lysimeters were validated during a 4-day period from September 7 to 10, 2014 during which a rainfall event of 23.8 mm occurred (on September 9, 2014). Prior to this period, heavy rainfall events occurred during September 2-4 with a total amount of 130 mm. Daily recordings of each mini lysimeter during the period from September 4 to 7, 2014 are presented in Table 2. It was observed that during 7th and 8th September, the average net change of mini-lysimeter was about -1.70 kg d^{-1} , which was equivalent to -6.8 mm . Since, there was no rainfall event during this period and no drainage amount was observed, the change of ML was due to evapotranspiration. Increase in plant biomass for a single day was ignored. Subsequently, a net average change of $+4.80 \text{ kg}$ of the lysimeter was observed during rainy day (9th September) with a rainfall and drainage of $+23.8 \text{ mm}$ and -2.73 mm ,

respectively. Therefore, effective rainfall of 21.07 mm could contribute to increase in soil moisture storage and evapotranspiration loss. Increase in soil moisture storage was calculated from a net change of lysimeter as 19.02 mm after multiplying with the conversion factor. Thus, the estimated amount of evapotranspiration was 2.05 mm during 9th September morning to 10th September morning, which was again a rainy day.

Conclusions

An low cost mini-lysimeter was designed, fabricated and developed at ICAR-Central Arid Zone Research Institute. The lysimeter was calibrated in the field and successfully field-tested and validated to estimate water balance components. Because of its simplicity in operation and handling, it may be an affordable instrument for monitoring water balance components in most of the agro-meteorological experiments.

Acknowledgements

We express our sincere thanks to Dr. M.M. Roy, Director ICAR-CAZRI, Jodhpur for providing continuous encouragement, necessary facilities and support to carry out the present work. Our sincere thanks are also extended to Fabrication workshop team, CAZRI for fabrication of the mini-lysimeter.

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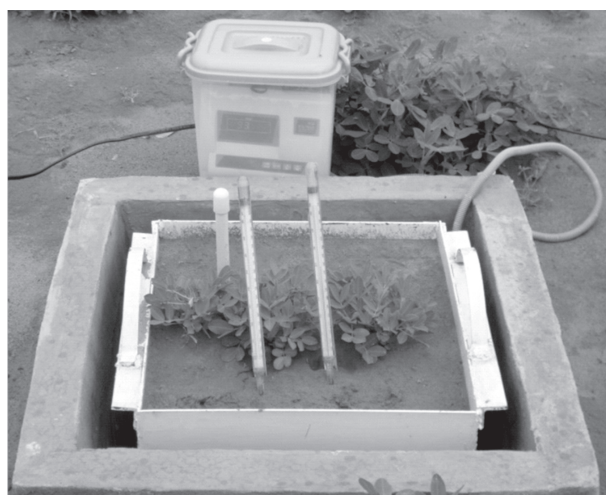


Plate 1. Complete mini-lysimeter system along with assemblies

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- Received: February 16, 2015; Accepted: June 25, 2015