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A Lysimster Study, a Unique Tool for Botanists, Agronomists and Other Plant Scientists

Mohamad Hesam Shahrajabian[1*] and Ali Soleymani[1]

[1]*Department of Agronomy and Plant Breeding, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran.*

Authors' contributions

This work was carried out in collaboration between both authors. Author MHS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MHS and AS managed the analyses of the study. Author MHS managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

A lysimeter is an equipment used to collect and measure soil water that drains below the root zone from a pasture or agriculture field. According to methods of measuring water content, lysimeter devides into weighing lysimeter and non-weighing lysimeter. The weighing lysimeters provide scientists the basic information for research related to evapotranspiration, and they are commonly divided into two types, continous weighing and intermittent weighing. Compared to laboratory experiments, out-door lysimeter studies have advantages like being closer to field environment conditions, it is possible to grow plants and therefore to study the fate of chemicals in soil/plant systems, transformations and leaching. The limitations are costy which depend on design, variable experimental conditions such as environmental/climatic parameters which are normally not controlled, the soil spatial variability is normally less, they are not suitable for every plant species and even every soil type. The objective of lysimeter is defining the crop coefficient (Kc) which used to convert ETr into equivalent crop evapotranpiration (ETc) values, and determing agronomical characteristics of crops which are planted in the field of lysimeter. The duration of a lysimeter study

**Corresponding author: E-mail: hesamshahrajabian@gmail.com;*

is determined by the objective of the study, but for different crops, it should normally be at least two years. Precipitation should be recorded daily at the lysimeter site. All weather data like air temperature, solar radiation, humidity and potential evporation should be obtained onsite, and the frequency and time of measurements should be at least daily.

Keywords: Weighing lysimeter; evapotranspiration; crop coefficient; precipitation.

1. INTRODUCTION

1.1 The Purpose of the Lysimeter

A lysimeter is a piece of equipment use to collect and measure any water that drains below the root zone from a pasture or agriculture field. It consists of a cylindrical tube, which is carefully inserted the soil so as not to disturb the soil core inside. The cylinder is then carefully extracted and a base with a thin layer of sand on top of it is then glue to the bottom of the pipe. When in position in the ground the lysimeter is not obviously visible, as the surface of the pipe is just at ground level. The base of the pipe is then fitted to a hose, which is buried in the ground and lead to a collection vessel just a short distance downhill, which is the place any drainage water is held before collection. The amount of drainage water collected is measured at set intervals and a sample of the leachate is taken for analysis for nitrogen content. One of the most useful and meaningful procedures an instructor can emphasize to researchers in a beginning of soil physics course is the determination of the rate and direction of soil water movement which is possible by lysimeter [1,2]. Unlu et al. [3] considered lysimeters as the standard tools for evapotranspiration (ET) measurements, is the solvent that moves many of chemicals (nutrients and pesticides) from agricultural fields to offsite locations. This offsite movement causes much concern in terms of consequences on the quality of water, even drinking one and the impact of agricultural practices on the environment. In order to understand and determine the optimal management possibilities, the water balance must be considered more than growing season which can be done by lysimeter station [4]. In another word, weighing lysimeter is the most sensitive and direct means of measuring evapotranspiration which can develop methods of predicting water use, and shows soil-water-plant relations. One of the popular technique is to record lysimeter weight either periodically or continuously to determine changes so that evapotranspiration rates can be computed [5,6]. Ramsbeck et al. [7] noted that a valuable measurement instrument is the use of lysimeter stations to better understand the nitrate leaching. Efficient planning and use of available water requires evaluation of all components in the water budget. Each component must be determined using the best available technology. Perhaps the most complex portion of the water budget involves evaluation of vegetative water use or evapotranspiration, henceforth referred to as ET. Lysimeter data are used with environmental and climatic data to calibrate and evaluate various ET models. The lysimeter facility provides a unique tool for botanists, agronomists, and other plant scientists. By recording information such as soil moisture within the lysimeter and plant characteristics such as growth rates and maturation, it will be possible to more closely evaluate and model the influences of environment on plant growth. The weighing lysimeter represents the best available technology for determining ET. The weighing lysimeter research can provide the best direct estimate or water use by vegetation in experimental field, evaluate the accuracy of vegetative water use models, evaluate the role of rainfall in meeting plant water requirements, provide comparative data to evaluate the accuracy of non-weighing lysimeters. These results will be used to correct errors or bias introduced into vegetative water use models through data obtained from non-weighing lysimeters, and perform joint studies involving plant scientists. These studies would involve both ET and plant growth factors [8,9]. If the lysimeters weight is recorded in certain time steps, precipitation and seepage water amount is measured separately, actual evapotranspiration can be deduced from their weight change [10]. Due to these characteristics, lysimeters are an excellent tool to derive or calibrate water and solute transport models [11]. Crop evapotranspiration (ET_c) determination is important to guide irrigation scheduling and to manage water resources. Lysimeters are the most reliable research tool for direct measurement of ET_c [12,13,14,15,16]. For ET_c research, a lysimeter is a tank containing a soil profile and plants of interest. More specifically, lysimeters are tanks filled with soil in which crops are grown under natural conditions to measure the amount of water lost by evaporation and transpiration [17]. By monitoring the change in water storage in the lysimeters, along with other components in the water balance (e.g., precipitation, irrigation, and drainage), the actual evapotranspiration rate can be obtained over the measurement interval. Resultant measurements can provide daily evapotranspiration values for grass to within 0.05 mm or 1% of accuracy [18], and to 0.43 mm per day over three growing seasons for shallow-rooted crops [19]. Howell et al. [19] indicated that evapotranspiration accuracy is influenced by the measurement duration, lysimeter shape, weighing mechanisms, and construction materials as well as site maintenance. Abdou and Flury [20] concluded that lysimeters studies are considered to be an intermediate approach between field studies and small-scale laboratory experiments. Lysimeters, after being exposed to the same environmental conditions, are more likely to mimic natural field soils that columns in the laboratory. These tools are usually classified according to their size, filling procedures, and the method for collecting drainage [21]. With respect to the way water is drained from the system, we can distinguish between two types of lysimeters: the free-drainage system, and the suction-controlled drainage system. In the free-drainage lysimeter, water is allowed to drain freely through the soil under gravity alone [21]. A free-drainage lysimeter is easy to install and is cheaper than the suction-controlled lysimeter. In suction-controlled lysimeters, water does not accumulate at the lower boundary because it is sucked away through porous ceramic plates, pipes, or fiberglass wicks [21]. Suction-controlled lysimeters are expensive and are difficult to install, especially if they have large surface areas [22]. Another problem with suction-controlled lysimeters is that water and solutes can interact with the material used for the suction device with the possibility of altering the matric potential, streamlines, and the composition of the leachate [23].

Lysimeters classify according to drainage, packing of test material, and methods of measuring water content.

1.2 According to Drainage

1- Zero-tension Lysimeter, which is a lysimeter with freely drainage leachate.
2- Zero-tension Lysimeter Equilibrium Tension Lysimeter, which is a lysimeter designed to maintain equilibrium between the suction applied to the leachate collection system and soil matrix potential thus the suction applied may varies.

1.3 According to Packing of Test Material

1- Block lysimeter= An undisturbed soil core is excavated and a casing is constructed around the block. Leachates can be collected with or without applying suction.
2- Ebermayer lysimeter (In situ lysimeter with no side walls separating a definitive soil block from adjacent soil) = Leachates can be collected with or without suction.
3- Filled-in lysimeter method = The test material is collected and potentially pre-treated, for example by homogenization, before being filled into the lysimeter container. Leachates can be collected with or without applying suction.

1.4 According to Methods of Measuring Water Content

1- Weighing lysimeter = The lysimeter is either placed directly on weighing equipment or can be moved and placed on weighing equipment periodically. This means that the lysimeter can be weighed constantly or periodically.
2- Non-weighing lysimeter = Lysimeters without weighing equipment available. This category falls potentially under any other category described in the table except from weighing lysimeter.

Weighing lysimeters are commonly divided in two types: continuous weighing and intermittent weighing [24]. The latter are also called weighable lysimeters. The main difference between them is the time interval between two consecutive weight measurements (Martin et al., 2001). Continuous weighing lysimeters, despite their accuracy and precision (Howell et al., 1985), are not widely used due to the high installation costs and the skilled personnel required. For these lysimeters, the weighing mechanism and the lysimeter are permanently installed in the field, and readings are taken at intervals as short as one minute. For weighable lysimeters every time it has to be weighed [14]. The time interval between two consecutive measurements is generally one day or longer [25]. The main objective of a lysimeter is to maintain a controlled environment while mimicking field conditions for the measurement of water into and out of the system [26]. This requires that soil-plant system inside the lysimeter be indistinguishable from the surrounding area in terms of soil moisture, nutrient availability, plant height, root density, etc [8,19]. Agronomic applications of weighing lysimeters have been numerous. Among them, comparisons and analyses of different evapotranspiration estimation methods, verification of the reliability of the ET_c estimates by means of the most recent updates of the FAO method, measurement and comparison of ET_c in different cultivars, analyses and validation of models separating evaporation (E) and transpiration (T), determination of basal crop coefificients and water requirements for specific irrigated crops, evaluation of methods to determine ET_o, analysis of the relationship between evapotranspiration and soil water content, deficit irrigation studies in trees, analysis of the energy balance components, integration of Time-Domain Reflectometer (TDR) measurements and lysimetry, and finally, correlation between canopy light interception and crop coefficients (K_c) in trees [27].

1.5 Specific Details for the Design of the Lysimeter

The lysimster may be constructed by excavating directly into the existing waste rock profile to a minimum depth of 1.5 m. The design should not interfere with runoff over the final surface of the cover. Further special consideration will be required if water quality measurement are necessary. The key to a successful weighing lysimeter is to design a system capable of detecting a change in weight equal to a millimeter of water when the lysimeter itself weights several tons. The lysimeter weighing system should be sensitive. This can be accomplished by making the top area of the lysimeter large relative to its depth, by maintaining the water table depth precisely and by using modern high technology sensors on the weighing system and a computer controlled data acquisition system. 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. Knowledge of crop water use which obtained from we weighing lysimeter measurements 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. Installing lysimeters and collecting water-use data for local varieties and environmental conditions will provide the information needed to develop irrigation scheduling to the local area.

Within a lysimeter, assuming no over-topping, the water balance may be written:

$$D_a + D_p - D_{ET} - D_{re} = D_{\Delta S}$$

Where D is the depth of water and the subscripts a, P, ET, re, ΔS signify applied, precipitated, evapotranspirated, removed, and change in stored water. For a precipitation event, assuming no additional applications during the event, the depth of water removed (D_{re}) is due to deep percolation out of the root zone. The effective rainfall is then equal to D_p-D_{re}, without taking surface runoff into account.

1.6 Construction of Lysimeter System

The general concept of a weighing lysimeter requires four major elements. These include the container to hold the soil, water and vegetation; a rigid foundation; the force measuring or weighing system; and the data acquisition and analysis system. Accessory instrumentation is also required to measure and record climatic data. In designing the lysimeters, ease of fabrication, simple and accurate installation, low maintenance requirements, and low cost were important considerations. 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. The size of a lysimeter is one of the main determinants of its cost. Cost is also associated with the types of specialized equipment and the labor and materials used in the lysimeter construction [28]. So, how

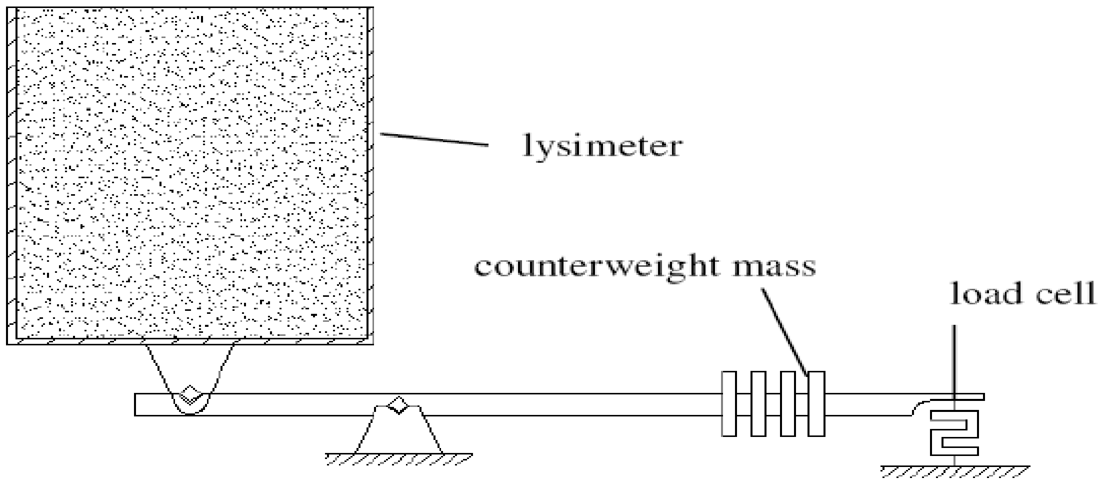

Fig. 1. The schematic diagram of the weighing lysimeter

well a lysimeter represents the surrounding environment is dependent on a compromise between costs and management under field conditions. In considering the design of the lysimeters, two points were of paramount importance: the lysimeters had to be large enough to represent conditions, yet small enough not to require expensive equipment for lifting and weighing. The lysimeter construction is grouped into three stages: foundation construction, lysimeter tank fabrication, and tank installation and instrumentation. The on-site construction of lysimeter foundation began with soil excavation from the experimental site. The weighing scale detects all additions and subtractions of water in the lysimeter box. Crop Etc is the main subtraction of water from the lysimeter, and is recorded continuously. Any irrigation, rainfall, or drainage is also detected by the weighing scale. The point is that the lysimeter is managed the same way as the surrounding field with the goal of having crop growth in the lysimeter that is very similar to the surrounding field. Large surface area to depth ratios are necessary in order to maximize sensitivity. Minimization of unnatural surface area is necessary to maintain a similar thermal regime between the lysimeter and surrounding field. Soil profile depth, siting, wind and drainage are also important consideration. Soil and vegetation were places in the cylinder to duplicate as closely as possible natural conditions surrounding the site. Subsoil in the site originally selected was gravelly sandy loam and thus it was not possible to obtain a completely undisturbed soil profile in the lysimeter.

1.7 Advantages and Limitations of the Lysimeter

Compared to laboratory experiments, out-door lysimeter studies have the following advantages:

1- They are closer to field environmental conditions, there is no significant disturbance of the subsurface soil (below the top 25-30 cm plough layer).
2- It is possible to grow plants and therefore to study the fate of chemicals in soil/plant systems, transformation and leaching, which are normally measured separately in laboratory experiments, remain integrated processes.
3- Mass fluxes can be determined.

And the limitations are:

1- Expense which depends on design.
2- Another problem certain limitation is variable experimental conditions such as environmental/climatic parameters (temperature, rainfall, light and wind) which are normally not controlled.
3- The bottom boundary between the soil block and the container influences the water flow and thus can affect the amount of chemical leached from a lysimeter.
4- The spatial variability is normally less, particularly when compared to field plots.
5- They are not suitable for every plant species.
6- They are not suitable for every soil type.

2. PROJECT OBJECTIVES

More accurately represent consumptive water use of major irrigated crops in the field, by defining the crop coefficients (Kc) used to convert ETr to equivalent crop ET (Etc) values. Determining agronomical characteristics of crops which are planted on the field of lysimeter.

2.1 Project Benefits

1- Provide the best direct estimate of water use by vegetation in the area.
2- Evaluate the accuracy of vegetative water use models.
3- Evaluate the role of rainfall in meeting plant water requirements.
4- Determine crop growth rates such as CGR, RGR and changes in total dry matter and LAI for each crops in each small lysimeters. This performance is called joint studies involving plant scientists and botanist. Those researchers would involve both ET and plant growth factors.
5- More accurate calculations of replacement water required for depletions from well.
6- Better crop coefficients for ET-based irrigation scheduling.
7- Better Etc calculations for future administration of water rights.
8- Using a weighing lysimeter in combination with other meteorological and hydrological instrumentation in long-term measurements allows to assess the water balance in detail.

2.2 Duration of the Study

The duration of a lysimeter study should be determined by the objective of the study, but for different crops, it should normally be at least two years. In some cases, it may be appropriate to extend this period to three years. The expected study duration could be derived from information grained for example, from results on adsorption and degradation rates and from application pattern. It may also be appropriate to modify the duration according to the results obtained during the study.

3. MANAGEMENT

Matching the soil and water conditions inside the lysimeter to those in the field is difficult. To minimize this problem, care must be taken at all steps from lysimeter design and construction to installation and management in the field. For any plants grown in a container, the volume of soil available may limit a normal rooting profile. Moreover, lysimeters usually have more moisture at the bottom of their soil profile compared to the same depth in the field, unless a drainage system efficiency removes the excess water. For crop products, the management such as fertilization, seed bed preparation, sowing tillage and harvest of the lysimeter including its surrounding area is carried out according to good agricultural practice. Special attention has to be paid to the depth of soil tillage which should only be done in the top 25-30 cm (plough layer). In the case of testing general chemicals, management practices will depend on the purpose of the study. Outdoor experiments are subject to natural climatic variations. Therefore, it may be necessary to complement natural precipitation by irrigation. Whenever this is needed, water with a quality comparable to rain water (e.g. rain, tap or well water) should be supplied to allow for plant growth. It is recommended that the pH and ionic strength of the irrigation water should be determined. Deionised water can destroy the soil structure and therefore must not be used. The key to a successful weighing lysimeter is to design a system capable of detecting a change in weight to a equal to a millimeter of water when the lysimeter itself weighs several tons.

3.1 Environmental Conditions

Precipitation should be recorded daily at the lysimeter site. Also, soil temperature and soil moisture should be measured. The measurements should be done in a separate lysimeter, in case the probes are installed vertically from the lysimeter surface. All weather data like air temperature, solar radiation, humidity, and potential evaporation should be obtained onsite or at a nearby meteorological station. Frequency and time of these measurements should be compatible with standard meteorological procedures (at least daily) as many estimation models or unknown parameters (e.g. evapotranspiration) rely on these standard data.

3.2 Maintenance

Routine maintenance involved periodic visits to the lysimeter sites to check the condition of the vegetation on and around the lysimeter, and to check for excess water inside the outer and inner tanks. 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 lysimeters tanks was removed periodically using hand suction. The loadcell wires should connected to the datalogger at a nearby weather station. The relative sophistication of a weighing lysimeter is such that it requires more attention and greater technical expertise for satisfactory operation than does a non-weighing lysimeter. This could be present a serious problem because the time and effort required would be prohibitive if the lysimeter was installed in a remote area.

3.3 Lysimeter Measurements

Lysimeter measurements consist of a time-serious absolute weights of the lysimeter 's inner tank and its contents. The weights include the weight of 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 soil, vegetation, and water. Lysimeter measurements were collected automatically and continuously at 10-minute or 5-minute intervals. At each measurement interval, a series of weight measurements were collected from each of the loadcells. The measurements from each loadcell were averaged, and the average weight was stored in the datalogger 's memory. 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. The weighing lysimeter is a permanent research facility which will contribute to the educational and research programs. In addition to providing needed research data, it will serve to demonstrate the best available technology for measuring vegetative water use. The lysimeter facility provides a unique tool for botanists, agronomists and other plant scientists on campus. By recording information such as soil moisture conditions within the lysimeter and plant characteristics such as growth rates and maturation, it will be possible to more closely evaluate and model the influences of environment on plant growth.

4. CONCLUSION

The weighing lysimeters provide scientist the basic information for research related to the evapotranspiration, and they are commonly divided into two types, continous weighing and intermittent weighing. Compared to laboratory experiments, out-door lysimeter studies have the following advantages like they are closer to field environment conditions, it is possible to grow plants and therefore to study the fate of chemicals in soil/plant systems, transformation and leaching. The limitations are expense which depends on design, variable experimental conditions such as environmental/climatic parameters which are normally not controlled, the spatial variability is normally less, they are not suitable for every plant species and even every soil type. The objective of lysimeter is defining the crop coefficient (Kc) which used to convert Etr to equivalent crop ET (Etc) values, and determing agronomical characteristics of crops which are planted on the field of lysimeter. The duration of a lysimeter study should be determined by the objective of the study, but for different crops, it should normally be at least two years. Precipitation should be recorded daily at the lysimeter site. All wather data like air temperature, solar radiation, humidity and potential evporation should be obtained onsite, and the frequency and time of measurements should be at least daily. For crop products, the management such as fertilization, seed bed preparation, sowing tillage and harvest of the lysimeter including its surrounding area is carried out according to good agricultural practice. it may be necessary to complement natural precipitation by irrigation. Whenever this is needed, water with a quality comparable to rain water (e.g. rain, tap or well water) should be supplied to allow for plant growth. The key to a successful weighing lysimeter is to design a system capable of detecting a change in weight to a equal to a millimeter of water when the lysimeter itself weighs several tons.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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