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REVIEW

A Review of Lysimeter Studies and Experiments by Considering Agricultural Production

Mohamad Hesam Shahrajabian#, and Wenli Sun*#

[1] National Key Laboratory of Agricultural Microbiology, Biotechnology Research Institute, Chinese Academy of Agricultural Sciences, Beijing, China

#These authors contributed equally to this research

*E-Mail: sunwenli@caas.cn

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Lysimeters have been used to obtain accurate information for developing calibrating, and validating crop evapotranspiration and crop coefficients for many plants and crops. Lysimeters are also an unique equipment for studying the transport of solutes when saline waters are used, and therefore, for assessing alkalization and salinization hazards. Three main types of lysimeters are used: constatnt water-table lysimeters, drainage lysimeters, and weighing lysimeters. The weighing lysimeters provide scientist the basic information for research related to the evapotranspiration, and they are commonly divided into two types, continuous weighing and intermittent weighing. Lysimeters are foremost devices, typically tanks or containers, that define a specific boundary to contain soil water and permit measurement of either the soil-water balance or the volume of water percolating vertically and its quality. The limitations are expense which depends on design, variable experimental conditions such as climatic/environmental factors which are usually not controlled, the spatial variability is normally less, they are not appropriate for every plant species and even every soil type. The main goal of lysimeter is defining the crop coefficient (Kc) which used to convert Etr to equivalent crop ET (Etc) values, and determining agronomical parameters of crops which are planted on the field of lysimeter. All weather data like air temperature, humidity, solar radiation, and potential evaporation should be obtained onsite, and the frequency and time of measurements should be at least daily. For crop products, the management such as fertilization, sowing tillage, seed bed preparation, and harvest of the lysimeter including its surrounding area is carried out on the basis of good agricultural practice. it may be required to complement natural precipitation by irrigation. The main purpose of this literature review is to give a brief summary about lysimeters, and survey the impacts of lysimeter studies and crops production. The information provides is obtained from randomized control experiments, review articles, and analytical studies and observations which were gathered from numerous literature sources such as Scopus, PubMed, Google Scholar,and Science Direct.

Key words: *Crop; Lysimeter, Weighing lysimeter, Leachate, Evapotranspiration, Crop coefficient*

The Purpose of the Lysimeter

A lysimeter is a piece of tool utilize to gather and measure any water that drains below the root zone from a agriculture field or pasture. It consists of a cylindrical tube, which is precisely inserted the soil so as not to disturb the soil core inside. The cylinder is then conscientiously extracted and a base with a thin layer of sand on top of its is then glue to the bottom of the pipe. When in position in the ground the lysimeter is not clear 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 induced to a collection vessel just a short distance downhill, which is the place any drainage water is held before collection (Kandrea *et al*., 2023). The system consists of supporting capsules and a pressure sensing device, and it needs not power, is not significantly influenced by temperature fluctuations and the design has the benefit of being readily adaptable to quite large loads (Berwick and Sumner, 1968; Dagg, 1970; Waggoner and Turner, 1972; Farrell *et al*., 1984; Meijer *et al*., 1985). The amount of drainage water collected is analyzed at set intervals and a sample of the leachate is taken for measurement for nitrogen content. One of the most appropriate and useful procedures a structure can emphasize to scholars in a beginning of soil physics course is the determination of the rate and direction of soil water movement which is manageable by lysimeter (Scott, 1974; Wherley *et al*., 2009; Abhiram *et al*., 2023). Unlu *et al.* (2010) considered lysimeters as the standard equipments for evapotranspiration (ET) measurements, is the solvent that moves many of chemicals (pesticides and nutrients) from agricultural fields to offsite regions. This offsite movement causes much concern in terms of consequences on the quality of water, even drinking one and the influence of agricultural practices on the environment. In order to determine and understand the optimal management possibilities, the water balance must be considered more than growing season which can be done by lysimeter station (Zupanc *et al*., 2005). In simple words, weighing lysimeter is the most accurate, sensitive and direct means of measuring evapotranspiration which can develop procedures of predicting water use, and shows soil-water-plant relations. One of the popular process is to record lysimeter weight either continuously or periodically to determine changes so that evapotranspiration rates can be measured (Voisey and Hobbs, 1972; Xu and Chen, 2005). Ramsbeck *et al*. (1997) noted that a significant measurement tool is the application of lysimeter stations to better understand the nitrate leaching. Effective planning and use of available water needs evaluation of all constituents in the water budget. Each component must be determined using the best available technique. Perhaps the most complicated portion of the water budget involves evaluation of vegetative water use or evapotranspiration, henceforth referred to as ET.

Lysimeter data are applied with climatic and environmental data to calibrate and evaluate different ET models. The lysimeter facility provides a wonderful tool for agronomists, botanists, and other plant scientists. By recording information such as soil moisture within the lysimeter and plant properties such as growth rates and maturation, it will be possible to more closely analyze and model the impacts of environment on plant growth (Sammis, 1981; Silver and Ritcey, 1985; Silver *et al*., 1985; Mugah and Stewart, 1986; Ruiter, 1987). The weighing lysimeter offers the best available technology for determining ET. The weighing lysimeter technique can provide the best direct estimate or water use by vegetation in experimental field, assess the accuracy of vegetative water use models, evaluate the function 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 via data obtained from non-weighing lysimeters, and perform joint studies involving plant scientists. These studies would involve both ET and plant growth factors (Allen and Fisher, 1990; Santikari *et al*., 2022). If the lysimeters weight is measured in certain time steps, precipitation and seepage water amount is recorded separately, actual evapotranspiration can be deduced from their weight change (Corwin and LeMert, 1994). Because of these characteristics, lysimeters are an unique tool to derive or calibrate water and solute transport models. Crop evapotranspiration (ET_c) determination is necessary to guide irrigation scheduling and to manage water resources. Lysimeters are the most reliable research equipment for direct measurement of ET_c (Green *et al*., 1984; Burman and Pochop, 1994; Young *et al*., 1996; Baghanam *et al*., 2022). 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 transpiration and evaporation (Martin *et al*., 2001).

By considering the change in water storage in the lysimeters, together with other components in the water balance (e.g., irrigation, precipitation, and drainage), the actual evapotranspiration rate can be found over the measurement interval. Resultant measurements can provide daily evapotranspiration values for grass to within 0.05 mm or 1% of accuracy (Von Unold and Fank, 2008), and to 0.43 mm per day over three growing seasons for shallow-rooted crops (Howell *et al*., 1985). Howell *et al*. (1985) showed that evapotranspiration accuracy is affected by the measurement duration, weighing mechanisms, lysimeter shape, and construction materials as well as site maintenance. Abdou and Flury (2004) concluded that lysimeters studies are considered to be an intermediate findings between field studies and small-scale laboratory trials. Lysimeters, after being exposed to the same environmental conditions, are more probable to mimic natural field soils that columns in the laboratory. These tools are commonly categorized according to their size, filling procedures, and the method for collecting drainage (Boll *et al*., 1992). With considering the way water is drained from the system, we can differentiate between two types of lysimeters: the free- drainage system, and the suction-controlled drainage system. In the free-drainage lysimeter, water is permitted to drain freely through the soil under gravity alone (Boll *et al*., 1992). 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 as it is sucked away via porous ceramic plates, or fiberglass wicks, or pipes (Boll *et al*., 1992). Suction-controlled lysimeters are costly and are difficult to install, particularly if they have large surface areas (Trajkovic, 2010). Another problem with suction-controlled lysimeters is that water and solutes can interact with the material utilized for the suction device with the probability of altering the matrix potential, streamlines, and the composition of the leachate (Jensen *et al*., 1990). Lysimeters classify according to drainage, packing of test material, and methods of measurement. Keypoints about different types of lysimeters are shown in Table 1.

Weighing lysimeters are usually divided in two kinds: continuous weighing and intermittent weighing (Allen *et al*., 1999). The latter are also called weighable lysimeters. The principle difference between them is the time interval between two consecutive weight measurements. Continuous weighing lysimeters, despite their precision and accuracy, are not extensively used because of the high installation costs and the skilled personnel required. For these lysimeters, the weighing mechanism and the lysimeter are always 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 (Calder, 1976). The time interval between two consecutive measurements is usually one day or longer (Aston, 1984). The basic goal of a lysimeter is to maintain a controlled environment while mimicking field conditions for the measurement of water into and out of the system (Seuntjens *et al*., 2001). This needs that soil-plant system inside the lysimeter be indistinguishable from the surrounding area in terms of soil moisture, plant height, nutrient availability, root density, etc. (Farrell *et al*., 1984; Hall, 1985). On the basis the literature, hydraulic and mechanical weighing lysimeters, which use electronic load cells, are considered the most precise equipment to directly assess reference evapotranspiration an crop Evapotranspirtion (Arrusa Junior *et al*., 2023). Agronomic usages of weighing lysimeters are many. Among them, comparisons and analyses of various 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 numerous cultivars, analyses and validation of models separating evaporation (E) and transpiration (T), determination of basal crop coefficients 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 lysimeter, and lastly, correlation between canopy light interception and crop coefficients (K_c) in trees (Dong and Hansen, 2023). Weighing lysimeters and soil physical methodologies represent the key set of evaporation measurement approaches, and such methods utilize the major of soil water balance to determine evaporation, and soil physical methods include an in situ study of soil profile; furthermore, by obtaining the gain terms (irrigation, precipitation, and capillary rise), the loss terms (runoff and drainage), and the change in soil water content, the rate of evaporation can be evaluated (Baalousha *et al*., 2022). The lysimeter 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 needed if water quality measurement are necessary. The key to a successful weighing lysimeter is to design a system capable of detecting an alteration 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 keeping 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 includes 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 (Holdsworth and Roberts, 1982; Butler *et al*., 1999; Thevenot *et al*., 2008). The capability to analyze and predict evapotranspiration and crop water requirements can result in better satisfying the crop 's water needs and promoting water use efficiency. Installing lysimeters and collecting water-use data for local varieties and environmental conditions will provide the information requested to develop irrigation scheduling to the local area (Albers *et al*., 2020; Summer *et al*., 2020; Tremosa *et al*., 2020). The common concept of a weighing lysimeter needs four principle elements. These include the container to hold the soil, water and vegetation; a rigid foundation; the force analyzing or weighing system; and the data acquisition and evaluation system. Accessory instrumentation is also requested to measure and record climatic data. In designing the lysimeters, simple and accurate installation, ease of fabrication, low maintenance requirements, and low cost were important considerations. The major components of the lysimeters were an outer tank, load-cell assemblies, an inner tank, 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 load-cell 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 connected with the types of specialized equipment and the labor and materials used in the lysimeter construction (Bergstrom, 1990; Goyne *et al*., 2000). In considering the design of the lysimeters, two key points were of paramount importance: the lysimeters had to be large enough to show all conditions, yet small enough not to require expensive tools for lifting and weighing. The lysimeter construction is categorized 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 distinguishes all additions and subtractions of water in the lysimeter box. Crop Etc is the major subtraction of water from the lysimeter, and is recorded continuously. Any irrigation, rainfall, or drainage is also measured by the weighing scale. The point is that the lysimeter is managed the same way as the surrounding field with the aim 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 required to keep a similar thermal regime between the lysimeter and surrounding field. Soil profile depth, siting, drainage, and wind 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 (Schrader *et al*., 2013; Hagenau *et al*., 2015; Kohfahl *et al*., 2019; Montoro *et al*., 2020; Morvan *et al*., 2020). Merits and some limitations of lysimeter studies are mentioned in Table 2.

The duration of a lysimeter study should be determined by the objective of the study, but for various plants and crops, it should commonly 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 obtained from information grained for example, from results on adsorption and degradation rates and from application pattern. It may also be suitable to modify the duration according to the results obtained during the study. Matching the soil and water conditions inside the lysimeter to those in the field is not easy. To manage 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 commonly 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, sowing tillage, seed bed preparation, and harvest of the lysimeter including its surrounding area is carried out on the basis of 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 suggested 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 able of detecting a change in weight to an equal to a millimetre of water when the lysimeter itself weighs several tons. 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, humidity, solar radiation, 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 (Lopez-Urrea *et al*., 2020; Gong *et al*., 2021; Takahashi *et al*., 2022).

Routine maintenance involved periodic visits to the lysimeter sites to monitor the condition of the vegetation on and around the lysimeter, and to check for excess water inside the outer and inner tanks. Excess water inside the lysimeters tanks was removed periodically using hand suction. The load-cell wires should linked to the datalogger at a nearby weather station. The relative sophistication of a weighing lysimeter is such that it needs 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 (Brown *et al*., 2021). Lysimeter measurements consist of a time-serious absolute weights of the lysimeter 's inner tank and its components. 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 vegetation, soil, 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 gathered from each of the load-cells. The measurements from each load-cell were averaged, and the average weight was stored in the datalogger 's memory. The lysimeters were also appropriate 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 tool which will contribute to the educational and research programs. In addition to providing required research data, it will serve to show the best available equipment for measuring vegetative water use. The lysimeter facility provides a unique facility 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 (Li *et al*., 2022; Liu *et al*., 2022).

Table 1: The main points of different kinds of lysimeter.

Different types of lysimeter		**Key points**
According to Drainage	1 Zero-tension lysimeter	It is a lysimeter with freely drainage leachate.
	2 Zero-tension lysimeter equilibrium tension lysimeter	It is a lysimeter designed to keep equilibrium between the suction applied to the leachate collection system and soil matrix potential thus the suction applied may varies.
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 adjacnt soil)	Leachates can be collecyed with or without suction.
	3 Filled-in lysimeter method.	1 The test material is collected and potentially pretreated, for example by homogenization, before being filled into the lysimeter container. 2 Leachates can be collected with or without applying suction.
According to methods of measuring water content	1 Weighing lysimeter	The lysimeter is either placed directly on weighing equipment or can be moved and places 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.

Table 2: Advantages and limitations of the lysimeter.

Advantages and Disadvantages	Key points
Advantages	They are closer to field environmental conditions, there is no significant disturbances of the subsurface soil (below the top 25-30 cm plough layer).
	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.
	Mass fluxes can be determined.
	Provide the best direct estimate of water use by vegetation in the area.
	Evaluate the accuracy of vegetative water use models.
	Evaluate the role of rainfall in meeting plant water requirements.
	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.
	More accurate calculations of replacement water required for depletion from well.
	Better crop coefficients for ET-based irrigation scheduling.
	Better Etc calculations for future administration of water rights.
	Using a weighing lysimeter in combination with other meteorological and hydrological instrumentation in long-term measurements allows to assess the water balance in detail.
Limitations	Expense which depends on design.
	Another problem certain limitation is variable experimental conditions such as environmental/climatic parameters (temperature, rainfall, light and wind) which are normally not controlled.
	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.
	The spatial variability is normally less, particularly when compared to field plots.
	They are not suitable for every plant species.
	They are not suitable for every soil type.

Table 3: Selected lysimeter studies in the context of duration, purpose, and specifications.

Lysimeter Specification	Duration	Aim of the Study	Reference
The container with a length of 1 m, width of 1m, and height of 1.6 m	5 months	Analyzes antimony (Sb) distribution, solubility, and mobility into natural soils of China	Hou *et al*. (2013)
Three cylindrical lysimeter having an outer diameter of 1.98 m and inner diameter (ID of 1.48 m, with a height of 3.35 m)	6 weeks	Analyzes the characteristics of leachate in pilot scale landfill and organic compounds as well as metal and heavy metal concentrations against their operational conditions based on statistical tool through statistical package for social science (SPSS) software	Ahsan *et al*. (2014)
Three lysimeters with a volume of 151	239 days	The investigation of the effects of waste aeration on the dynamics of the aerobic degradation processes in lysimeter	Slezak *et al*. (2015)
Height 75 cm, inner diameter 18 cm, a compression plate (perforated stainless-steel plate with ID less than 18 cm)	223 days	The performance of simulated landfills with different biogas collection practices, including upward biogas collection only and both upward and downward biogas collection	Xu et al. (2019)
Landfill test cells with the dimensions of 20 m × 40 m × 5 m	450 days	Leachate recirculation and the impact of aeration on the waste decomposition rate by means of leachate quality and quantity in field-scale landfill test cells.	Top et al. (2019)
1 m height, inner diameter of 40 cm	100 days	To investigate the effect of inverse conditions of landfilling.	Grossule and Lavagnolo (2020)
1 m height, inner diameter of 40 cm	6 months, divided into two subsequent phases	To investigate the performance of semi-aerobic landfill under tropical dry-wet climate conditions and to assess the potential benefits afforded by appropriate management of water input when operating the landfill by overlaying a new layer of waste in each climate season.	Grossule and Lavagnolo (2020)
1.8 m × 1.8 m × 1.1 m	1 year	To evaluate the water balance performance of Evapotranspirative Landfill Biocovers (ET-LBCs) under Canadian cold-climate conditions.	Jalilzadeh *et al*. (2020)
1 m^3 polyethylene box set upon a 0.3 m tall wooden bench	2 years	To investigate the ability of poplar and willow grown in mesocosm to withstand and remove specific pollutants.	(Eicosky *et al*., 1983; Guidi Nissim *et al*., 2021)

New findings on lysimeter studies and its different applications

The lysimeter is a extensively used tool to study the movement of agrochemicals via the vadose zone and to estimate the evapotranspiration of crops, and the basic types of lysimeter are pant lysimeter, suction cup lysimeter, drainage lysimeter and capillary-wick lysimeter or flux meters (Shahrajabian and Sun, 2023a,b,c,d,e,f). The lysimeter experiments involved with collecting greenhouse gases are momentarily capped using a chamber, but this is not used for controlling the microclimate of plants, and a lysimeter with permanent capping permits the climate changes to be manipulated, in a small confined space, so that it can be more effective when compared to a large space in a greenhouse (Shahrajabian and Sun, 2023g,h,i,j,k). Evapotranspiration (ET) from bioretention systems could be measured by weighing lysimeters or estimated by ET models, weighing lysimeters measure ET based on the water balance principle, which is considered the best available means for measuring ET, however the weighing lysimeters are usually very expensive in construction and maintenance, and models are considered to be a feasible method for ET estimation, and the potential evapotranspiration (PET) models, such as FAO Penman-Monteith, Priestley-Taylor, Hargreaves, Penman, and Blaney-Criddle, have been widely applied in agriculture (e.g., farmland and grassland) (McFarland *et al*., 1983; Howell *et al.*, 1991; Zhang *et al*., 2023). Dong and Hansen (2023) reported that weighing lysimeters are used to measure and understand the crop water uptake over time, and weighing lysimeters can estimate crop evapotranspiration by recording the change in weight of a plant, soil, and water, and the change in weight can be converted to the change in volume of water lost through evaporation from the soil and transpiration through the plant. Shu et al. (2023) has done a field-based lysimeter study evaluated the effect of three rates of alkaline treated biosolids on the leaching potential of naproxen, ibuprofen, and ketoprofen over 34 days in a sandy loam textured soil, and they reported that application of alkaline treated biosolids significantly increased soil pH and organic matter content of the soil but did not impact retention of the compounds in the soil profile. In one experiment, soil water contents and fluxes, electrical conductivity of the soil saturation paste extract (EC_e), and the actual crop evapotranspiration ($ET_{c\ act}$) were measured using water table lysimeter, and the HYDRUS-1D model successfully simulated lysimeter data during two seasons, the water table depth influenced the effectiveness of autumn irrigation leaching, the leaching efficiency only increased by improving soil drainage conditions, and reducing autumn irrigation depth (<200 mm) promoted soil salinization (Sun *et al*., 2022; Ramos *et al*., 2023; Sun and Shahrajabian, 2023). Baghanam *et al*. (2022) showed that the moisture of the lysimeters made a significant contribution to the Electrical Conductivity (EC) value prediction, and it is worth mentioning that among Artificial Neural Network (ANN), Neuro-Fuzzy Inference System (ANFIS), and Emotional ANN (EANN,) and EANN model yielded more precise results in EC estimation, which the average DC above 0.80 and 0.90 for individual and assembled modelling in both the training and verification phases, respectively. Per- and polyfluoroalkyl substances (PFAS) measurable in soil porewater authoritatively represent the mobile mass fraction critical to accurate assessment of leaching from source zones, and because of the complexity of soil PFAS retention, field-collected soil porewater samples from lysimeters has been argued as the authoritative measure of the mobile mass fractions, and the data validate the use of suction lysimeters for short-term site characterization deployments and emphasize the importance of in situ porewater samples for interrogating PFAS transport within source zones (Schneider *et al*., 1998; Lorite *et al*., 2012; Shahrajabian and Soleymani, 2017; Shahrajabian *et al*., 2017a,b). Santikari et al. (2022) have done field lysimeters tests examined leaching of technetium-99 (^{99}Tc) from two types of cementitious waste forms and found that the presence of blast furnance slag reduced the overall leaching of ^{99}Tc from the waste form, flow and transport modelling has verified that oxygen diffusion into the waste form led to oxidative leaching of technetium, leached technetium moved downward in soil due to transport by infiltrating rainwater, and upward movement of leached technetium occurred during soil drying due to evaporation from soil surface. The soil moisture is of big importance for many ecological process, and for the investigations of soil water balance and as a basis for soil water management, ΔS plays a particular role in the lysimeter studies (Dietrich and Steidl, 2021). In one experiment cattle slurry applied on lysimeters coinciding with the British closed period, storm even leachate was collected and analysed for steroids and total phosphorus, the treatment had no significant effect on tracer concentrations, through time did, and there was a weak correlations between steroids and phosphorus (Manley *et al*., 2022). In the UAE, a simple weighing lysimeter to measure directly the water-use lettuce, capsicum, tomato, cucumber and zucchini grown in the field is designed, as well as in a shadehouse and a cooled greenhouse for capsicum, cucumber and tomato, the yields in the greenhouse were the highest, and the crop water-use efficiency was three fold higher in the greenhouse than in the shadehouse of field, however, when the water used to cool evaporatively the greenhouse was accounted for in the water productivity, there were no differences between the filed, shadehouse and greenhouse (Tamimi *et al*., 2022).

Long-term lysimeter experiments to study the weathering of different waste rocks in two different mine sites in Finland, and the experimental results were quantitatively interpreted with multi-phase and multi-component reactive transport modeling, which allowed capturing the complex dynamic trends and the concentration levels observed in the effluents of the different pilot-scale lysimeters (Muniruzzaman *et al*., 2021). Liu et al. (2022) reported that the weighing lysimeter use in other regions, similarly to the China studies, also primarily refers to assess the actual crop evapotranspiration ($ET_{c\ act}$) and to estimate the terms of the SWB, as well as to estimate $ET_{c\ act}$ and crop coefficients, and there are related requirements for accuracy of estimates of the $ET_{c\ act}$ values, including (I) lysimeters; (ii) the use of eddy covariance energy balance systems; (iii) the Bowen Ratio Energy Balance; (iv) scintillometers; (v) sap flow methods; (vi) remote sensing techniques; and (vii) the monitoring of changes in soil water content measurements over a period of time. It has been reported that ET is an important aspect of hydrologic cycle on all terrestrial landscapes, lysimeters are used to measure ET as losses of water from a container of growing plants, calibrated load cells are important components of modern lysimeter to improve accuracy of ET, design and performance of lysimeters is dependent on statistical treatment of calibration data (Misra *et al*., 2011; Virtanen *et al*., 2013; Herbrich *et al*., 2017).

In weighing lysimeter, the measurement system may be selected according to the technical data supplied by the manufacturer; however, periodic calibration of the effective measuring range is necessary to verify and compensate for systematic errors, which are accentuated during the operation time (Valtanen *et al*., 2017; Amaral *et al*., 2018; Widmoser and Wohlfahrt, 2018). Phogat et al. (2013) reported that timing of water and fertilizer applications to an orange crop can be better regulated to enhance the efficiency of applied inputs under lysimeter conditions. Nicolas-Cuevas et al. (2020) present a weighing lysimeter prototype (1000 × 600 mm and 350 mm depth) designed to be used in agricultural farming of horticultural crops, and the design details described includes east of assembly, carriage and minimum soil alteration, structural design results and construction process are also provided showing their performance under different tractors scenarios, the measurements accuracy results show the outcomes of the prototype after being testes, and in comparison, the prototype designed is an accurate and reliable device which reduces the surface and depth of the current weighing lysimeters. Avila-Davila et al. (2021) and Dabrowska et al. (2021) also confirmed that the weighing lysimeter can be used in experiments under different conditions (crop variety, ground composition, atmospheric conditions, and irrigation events) and to extrapolate the behavior to great land extensions and optimize the hydric resources, and these devices have been used to quantify precipitation, condensation, and determine crop evapotranspiration, and they could be used to characterize the contribution of groundwater and determine the percentage of leachate for a crop in real-time. McCauely and Nackley (2022) reported that mini-lysimeter sensors have the potential to be an effective instrument for automatic irrigation scheduling, and on the basis of results mini-lysimeter controlled irrigation system can produce plants of equal size to traditional irrigation methods while using 26% less water on average, and the technology provides a novel approach to improving water efficiency in container nurseries. Sagar et al. (2022) concluded that the developed smart lysimeter system has unique applications due to its real-time measurement, portable attribute, and ability to produce accurate results for determining crop water use and crop coefficient for greenhouse chrysanthemum crops. Soler-Mendez et al. (2021) observed that the validation over seven irrigation events established that the structural system achieved in Spain allows precise monitoring of the water exchanges produced in the cultivation tank, so this portable weighing lysimeter can be useful for the efficient management of fertigation. Alataway et al. (2019) noted that the accumulated values of the measured crop evapotranspiration of potato derived from the lysimeters were 574, 554, 592, and 570 mm, while the accumulated values of the predicted crop evapotranspiration from Penman-Monteith equation based on FAO were 651, 632, 672, and 647 mm for the Qassiem, Riyagh, Al-Jouf, and Eastern regions, respectively. Large weighing lysimeters can have sufficient depth and surface area as to not impede crop and root growth; however, shallower or smaller lysimeters may cause restrictions on plant development in addition to affecting drainage and soil water dynamics, and these issues can cause discrepancies between the field surrounding the lysimeters or between different lysimeters (Hashem *et al*., 2020). It should be noted that lysimeter studies for municipal waste can be a perfect complement to the methods of predictive models, geophysical tests, an isotopic multi-tracer approach, or even to analyse of data from groundwater monitoring to assess the vulnerability of groundwater to pollution in the area of pollution sources (Dabrowska *et al*., 2022). Some of the most important studies from published articles about purpose, duration and specification of lysimeter studies have been shown in Table 3.

CONCLUSION

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 divides 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, continuous 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 costly 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 determining agronomical characteristics of crops which are planted in the field of lysimeter. The duration of a lysimeter study 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 evaporation should be obtained onsite, and the frequency and time of measurements should be at least daily.

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CONFLICTS OF INTEREST

The authors declare that they have no potential conflicts of interest.

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