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CONSIDERING SOIL WATER CONTENT, NUTRIENTS MOVEMENT, PHENOLOGY AND PLANT GROWTH WITH REFERENCE TO DEVELOPMENT OF FUNCTIONAL FOODS IN A LYSIMETER STUDY

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ABSTRACT. Lysimeter is equipped with mechanisms for weighing by load cells enable automated measurements, and the signals resulting from weight changes in the system due to evaporation that are generally recorded in a data acquisition system. According to methods of measuring water content, lysimeters may be divided 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. Weighing lysimeters have been used to quantify precipitation (P) not only in the form of rain or snow, but also dew, fog and rime, and also to determine actual evapotranspiration (ET). 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

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study is determined by the objective of the study, but for different crops, it should normally be at least two years. Weighing lysimeters using load cells have the advantage of measuring the water balance in the soil over a short time and with good accuracy. 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; super foods.

INTRODUCTION

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. 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. Ünlü *et al.* (2010) 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. 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 (Zupanc *et al.*, 2005). 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. Ramsbeck *et al.* (1997) 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 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 (Allen and Fisher, 1990; Corwin and LeMert, 1994). 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 (Young *et al.,* 1996). Due to these characteristics, lysimeters are an excellent tool to derive or calibrate water and solute transport models (Wriedt, 1994).

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 Etc. For ETc 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 (Jensen *et al.,* 1990).

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 (Allen *et al.,* 1990), and to 0.43 mm per day over three growing seasons for shallow-rooted crops. Howell *et al.* (1985) 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 (2004) 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 (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 because it is sucked away through porous ceramic plates, pipes, or fiberglass wicks (Bergström, 1990). Suction-controlled lysimeters are expensive and are difficult to install, especially if they have large surface areas (Goyne *et al.,* 2000).

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 (Goyne *et al.,* 2000). Lysimeters classify according to drainage, packing of test material, and methods of measuring water content. *Table 1* has shown different classification of lysimeter on the basis of drainage, packing of test materials and measuring methods.

Table 1 - Lysimeter classification according to drainage, packing of test materials and measuring methods

According to Drainage	According to Packing of Test Material	According to Methods of Measuring (Water content)
Zero-tension Lysimeter, which is a lysimeter with freely drainage leachate.	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.	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.
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.	Ebermayerlysimeter (*In situ* lysimeter with no side walls separating a definitive soil block from adjacent soil) = Leachates can be collected with or without suction.	Non-weighing lysimeter = Lysimeters without weighing equipment available. This category falls potentially under any other category described in the table except from weighing lysimeter.
	Filled-in lysimeter method = The test material is collected and potentially pretreated, for example by homogenization, before being filled into the lysimeter container. Leachates can be collected with or without applying suction.	

Weighing lysimeters are commonly divided in two types: continuous weighing and intermittent weighing (Howell *et al.*, 1991). The latter are also called weighable lysimeters. The main difference between them is the time interval between two consecutive weight measurements. Continuous weighing lysimeters, despite their accuracy and precision, 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. The time interval between two consecutive measurements is generally one day or longer (Oliveira, 1998). 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 (McFarland *et al.,* 1983).

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. Agronomic applications of weighing lysimeters have been numerous. Among them, comparisons and analyses of different evapotranspiration estimation methods, verification of the reliability of the ETc estimates by means of the most recent updates of the FAO method, measurement and comparison of ETc in different 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 ETo, 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 (Kc) in trees (Lorite *et al.,* 2012).

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; 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, load cell 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 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 load cell 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 (Schneider *et al.,* 1998). So, how 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. The most important advantages and limitations of the lysimeter is indicated in *Table 2*.

Table 2 - The most important advantages and limitations of the lysimeter

They are closer to field environmental conditions, there is no significant disturbance 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 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.
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.

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. The most important benefits of projects of lysimeter is presented in *Table 3*.

Lysimeter, study, management, environmental conditions, measurements and maintenance

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. 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.

Table 3 - The most important benefits of lysimeter project

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 depletions 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.

It is recommended that the pH and ionic strength of the irrigation water should be determined. Deionized 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 an equal to a millimeter 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, 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.

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 load cell wires should connected to the data logger 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. Lysimeter measurements consist of a timeserious 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 min or 5 min intervals. At each measurement interval, a series of weight measurements were collected from each of the load cells. The measurements from each load cell were averaged, and the average weight was stored in the data logger'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.

Lysimeter experiments in different countries

Crop water productivity is one the most important aspects of water use of crop, most especially where water is a limiting factor (Amini *et al.,* 2012; Soleymani and Shahrajabian, 2012; Ogbaji *et al.,* 2013; Shahrajabian *et al.,* 2017; Shahrajabian *et al.,* 2019a,b,c,d; Sun *et al.,* 2019a,b). Weighing lysimeters are considered to be the best means for a precise measurement of water fluxes at the interface between the soil-pant system and the atomosphere (Skaggs *et al.,* 2012). Any decrease of the net mass of the lysimeter can be interpreted as evapotranspiration (ET), any increase as precipitation (P) (Peters *et al.,* 2017). The measurement system in lysimeter experiments may be selected according to the technical data supplied by the manufacture; however, periodic calibrations in the effective measuring range are necessary to verify and compensate for the systematic errors, which are accentuated during the operation time (Amaral *et al.,* 2018).

Lysimeters are also widely used for closing water balances by monitoring drainage amount and water storage in the soil profile, and also used as management tools for fertigation scheduling (Raj *et al.,* 2018). Quinn *et al.* (2018) reported the field results from the lysimeters are simulated adequately by a water balance model based on FAO 56 with an additional components to represent both the difference between the variable saturation with depth, which occurs in practice, and the assumption in standard water balance models of a sudden change from dry to fully-saturated conditions at the water table.

Klammler and Fank (2014) concluded that the technical lysimeter design has different roles: 1) high-resolution weighing cells; 2) a suction controlled lower boundary condition for sucking off seepage water, thus emulating undisturbed field conditions; 3) comparative soil temperature, water content and matrix potential measurements inside and outside the lysimeter at different depths; 4) an installation of the lysimeters directly into test plots; 5) a removable upper lysimeter ring enabling machinery soil tillage. They have concluded that lysimeters installed at Wagna site did not show any fringe effects, and, thus, are appropriate tools for measuring water balance elements and nitrogen leaching of arable and grass land at point scale.

Marin *et al.* (2010) noted that confined aquifers can act as large-scale geological weighing lysimeters that can be used to monitor changes of total water balance on a scale of kilometers. They have showed that how geological weighing lysimeters offer a promising potential for testing and calibrating distributed hydrological models at the scale of typical grid cells. All load cell based lysimeters require calibration and frequent calibration may lead to excessive workload although a sensible level of quality control is warranted, and analysis of the costs for the mini-lysimeter system indicates that evapotranspiration can be measured economically at a reasonable accuracy and sufficient resolution with robust method of load cell calibration (Misra *et al.,* 2011). To avoid the exposure effects, a lysimeter must be surrounded by a crop stand wide enough to prevent rain, which falls at an angel towards the lysimeter from reaching it, and it depends on the type of crop the required width may vary from less than one to several meters (Hagenau *et al.,* 2015; Valtanen *et al.,* 2017). Tripler *et al.* (2012) highlighted that the high resolution (high cost) weighing lysimeters proved to be an efficient system for accurate data acquisition, which is necessary for accurate modeling. Berglund *et al.* (2010) stated that a lysimeter method was evaluated for its suitability in gas emission studies by studying the effect of temperature on CO_2 emission (dark respiration) from cultivated peat soils. They have mentioned that CO_2 emission data fitted well to a semi-empirical equation relating CO_2 emissions to air temperature, and the lysimeter method proved to be well suited for CO_2 emission studies. The effect of geometrical factors on leaching behavior and waste decomposition in lysimeter studies is shown in *Fig. 1*.

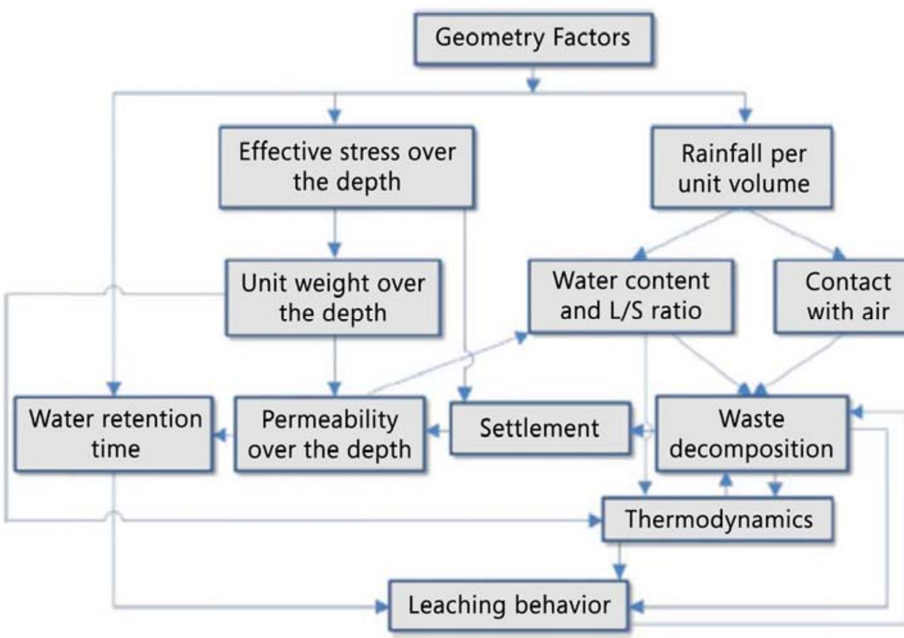

Figure 1 – The effect of geometrical factors on leaching behavior and waste decomposition in lysimeter studies

Evapotranspiration and functional food production

The amount of water that a crop uses consists of the water is transpired by the plant and the water is stored in the tissue of the plant from the process of photosynthesis (Sun *et al.,* 2020). The water use of a crop is considered to be equal to the water transpired or evaporated by the plant. Evaporation rates are influenced by solar radiation, temperature, relative humidity, and the wind. ET, which consists evaporation from soil and transpiration from plants, is also evaporative, so the ET rate is also influenced by solar radiation, temperature, relative humidity and the wind. The amount of water which crop needs is measured by the ET rate of crop, and the ET rate included water which is transpired or evaporated through the plant, and the ET rate varies depending on climatic conditions, the plant characteristics, and the soil conditions (Soleymani and Shahrajabian, 2017; Abdollahi *et al.,* 2018). Transpiration is principally E of water to the atmosphere from plants roots to small pores on the underside of leaves (Chen *et al.,* 2013; Ogbaji *et al.,* 2013; Shahrajabian *et al.,* 2017). Another type of water loss from the uninjured leaf or stem of the plant, mainly by stomata, is called guttation. Climatic factors, which affecting ET, is shown in *Table 4*. The most important crop management and growing experimental conditions, which may influence ET, is presented in *Table 5*.

Table 4 - Climatic factors which affecting ET

Radiation
Temperature
Relative humidity (% RH)
Wind
Crop factors that affecting ET
Crop species
Radiation reflection coefficient
Leaf area index (LAI) in different growth stages of plant
Plant height
Rooting depth of plant (depth of the radicular system)
Crop management and growing environmental conditions also impact the ET

Table 5 - The most important crop management and growing environmental conditions which may influence the crop ET

Row to row or plant to plant spacing
Crop orientation
Soil properties (structure and texture)
Chemical/physical impediements
Interrelationship atmospheric demand: soil water supply

CONCLUSION

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. 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 evapotranspiration process is composed of soil evaporation (E), and transpiration (T). Crop water use, also known as evapotranspiration (ET), represents soil evaporation and the water used by a crop for growth and cooling purposes. Transpiration is the water transpired or lost to the atmosphere from small openings on the leaf surfaces, and evaporation is the water evaporated or lost from the wet soil and plant surfaces.

Crops differ in their response to water stress at a given growth stage, and different crops have different water requirements and response differently to water stress.

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 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, 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. With technical improvements and lower costs, the use of small-size and medium size lysimeters has become more widespread. High resolution load cells connected to data loggers facilitate accurate long-term measurement of the mass. 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.

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