Technical note

Design, installation and calibration of a block of lysimeters to adjust the crop coefficient

Diseño, instalación y calibración de un bloque de lisímetros para ajustar el coeficiente de cultivo

Delineamento, instalação e calibragem de um bloco de lisímetros para ajustar o coeficiente de cultivo

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Abstract

The efficient management of water resources using techniques that improve it uses, based on knowledge of evapotranspiration are key elements for crop production. Amongst main techniques for water management, the use of drainage lysimeter installed in the field below vegetable fields may be used to quantify the amount of water needed. The aim of this work is to design, install and calibrate a set of lysimeters for adjusting crop coefficient (Kc). In the calibration of the lysimeters, it was obtained that to induce drainage in lysimeters from one to five, an over-irrigation of 25% of the field capacity was needed, while the rest needed 50%. With lysimeters built the physical characteristic of soil could be simulated in this study.

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Resumen

El manejo eficiente del recurso hídrico a través de técnicas que mejoren su uso, basado en el conocimiento de la evapotranspiración, son elementos de gran importancia en el manejo de los cultivos. Entre las principales técnicas para la gestión del agua se destaca el uso de lisímetros de drenaje. El objetivo de este trabajo fue diseñar, instalar y calibrar un bloque de lisímetros para ajustar el coeficiente de cultivo. Se desarrolló un protocolo para el diseño, construcción y calibración de lisímetros de drenaje para la determinación del coeficiente de cultivos (Kc). En la calibración de los lisímetros se obtuvo que para inducir el drenaje en los lisímetros del uno al cinco se necesitó un sobre riego del 25 % de la capacidad de campo, mientras que el resto necesitó un 50 %. Con los lisímetros construidos se pudo simular las características físicas del suelo que se empleó en el estudio.

Palabras claves: Coeficiente Kc, evapotranspiración, lisimetría, suelo, riego, diseño.

Resumo

O manejo eficiente do recurso hídrico por meio de técnicas que aprimorem seu uso, baseadas no conhecimento da evapotranspiração, são elementos de grande importância no manejo das lavouras. Dentre as principais técnicas para a gestão da água destaca-se o uso de lisímetros de drenagem. O objetivo deste trabalho é projetar, instalar e calibrar um bloco de lisímetros para ajustar o coeficiente de cultivo. Desenvolveu-se um protocolo para o desenho, construção e calibragem de lisímetros de drenagem para a determinação do coeficiente de cultivo (Kc). Na calibragem dos lisímetros obteve-se como resultado que para induzir a drenagem nos lisímetros de um a cinco foi necessária uma rega de 25% a mais da capacidade do campo e nos restantes foi necessário uma rega de 50%. Com os lisímetros construídos foi possível simular as características físicas do solo utilizado no estudo.

Paravras-chave: Coeficiente de cultivo (Kc), evapotranspiração, lisímetros, solo.

Introduction

In underdeveloped countries, part of the population depends largely on agriculture, which is conditioned by climate change. Alterations that are manifested in rainfall are detrimental to agricultural production, this situation that occurs threatens people's access to food (Nelson *et al*., 2009).

Rain regimes are altered and the need to irrigate crops increases. In agriculture, the largest volume of water is consumed and at the same time it is affected the most, which causes decrease of existing water resources (Villa, 2014). In developing countries, consumption reaches 95%, so it is necessary to study demand and consumption (Paguay, 2017).

The proper use of water will mitigate the scarce availability of this resource in many parts of the world. Knowing about evapotranspiration has become an indicator of vital importance for the maintenance of crops (FAO, 2008). For León (2016), knowing the evapotranspiration of crops allows knowing their water requirements.

"Knowing the necessary amount of water for the application of irrigation implies determining the demand or water requirement of the crop considering the phenological phase in which it is found. The water demand of crops is the water consumption or crop evapotranspiration (ETc) with the soil without water deficiency…" (García *et al*., 2017:2). Evapotranspiration when it occurs under optimal conditions is determined as the crop coefficient (Kc); can be specified by different methods. One of the most used and effective direct methods are lysimeters.

Lysimeters are classified into two types, one of weighing where weight of the water used is determined and the drainage lysimeter where the water expenditure is specified by the difference between the water that is applied and that which is drained (Chávez and Mesías, 2018). According to García (2017), drainage lysimeters can be rectangular or round and Bochetti (2010) classifies them with or without suction.

Due to the importance of lysimeters in determining the crop coefficient (*Kc*), it is proposed to design, install and calibrate a lysimeter block that allows determining the crop coefficient.

Materials and methods

The study was developed at the Centro Experimental del Riego (CER) of the Escuela Superior Politécnica de Chimborazo, Ecuador.

Design phase

With the two types of lysimeters designed (Figure 1) (A: 2, 5, 7 and B: 1, 3, 4, 6), a block of seven lysimeters was built, with an external wall thickness of 0.15 m and the internal ones of 0.17 m. On the front part of lysimeters 1, 2, 4, 5 and 7, a viewing window was placed, made up of a metal frame (1.1 m X 0.5 m) and 0.1 m tempered glass and on the external part a geomembrane of 1000 microns thickness (1.1 m X 0.5 m) was placed. To collect the drainage, glass tanks (0.5 m X 0.5 m X 0.40 m) were placed, equipped with a metal ruler to measure the level of water (figure 2).

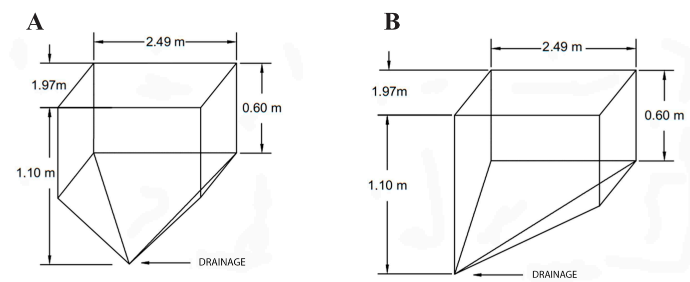

Figure 1. Type A pentagonal prism and type B trapezoidal prism lysimeters.

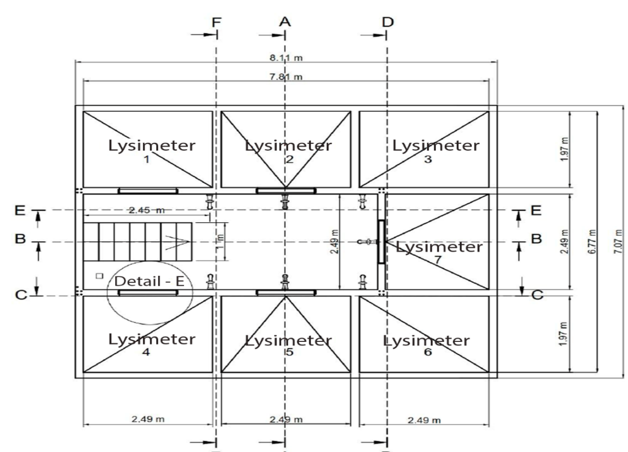

Figure 2. Planimetry of the lysimeter block.

Field phase

a. Block construction

The excavation was carried out with a backhoe sectioned into four layers of soil at 0.20, 0.40, 0.60 and 0.80 m, respectively. The walls were formed with an electro-welded mesh and simple concrete and were later waterproofed.

b. Block installation

To install the lysimeters, two meters from their location, the infiltration speed, field capacity, permanent wilting point, useful water, apparent density were evaluated. In addition, physical and chemical parameters, texture, hardness, pH, macro, microelements, organic matter and electrical conductivity were evaluated.

Figure 3. Metallic mesh.

Figure 4. Completed lysimeter.

A metallic mesh was placed at the deepest end of the lysimeters to prevent the obstruction of the drainage pipes and valves (Figure 3). The soil layer between 0.6 m and 0.8 m was replaced by stone material, on which a plastic mesh was placed to filter the water. The filling of the lysimeter was completed with the soil removed in the excavation and placed in the reverse order as it was extracted, it was compacted until reaching the same level of the sampled soil. Figure 4 shows that three ridges of 0.30 m separated by 0.60 m were built. An irrigation system made up of 32 mm PVC pipes, a stop valve, a flow meter, and a tape with drippers (1.6 $L.h^{-1}$) every 0.30 m was designed and installed. Three tensiometers were also placed at 0.10 m, 0.30 m and 0.50 m depth.

Lysimeter Block Calibration

Soil moisture was determined with tensiometers, gypsum blocks at depths of 0.15, 0.30 and 0.45 m and by the gravimetric method using the equation proposed by Ekanayake (1994).

$$CAS = \frac{Pf - Ps}{Ps} \times 100$$

Where CAS is the water content in the soil (%), *Pf* is the fresh weight of the sample (g) and *Ps* is the dry weight of the sample (g).

The volume of water used up to the field capacity (*VCC*) in the first irrigation was calculated by the equation of León (2012).

$$VCC = \frac{CC - CAS}{100} * Z * \frac{Dap}{\rho w} * Al$$

The value of field capacity (*CC*) (%), the water content in the soil (*CAS*) (%), the depth of the layer (*Z*) (m), the apparent density of the layer of soil (*Dap*) (g/cm^3), the density of water (ρw) (g/cm^3) and the lysimeter area (*Al*) (m^2).

In the first irrigation, water is supplied in the lysimeters until reaching the field capacity and to promote drainage, an extra volume is applied, equivalent to 25 % of the *VCC*. If drainage does not occur, additional water is supplied until it occurs. The volume of water to apply (*Va*) for the second time was calculated by the following equation (León, 2016):

$$Va = Etp \times Nd \times Al \times Cd$$

Where, *Etp* is the evapotranspiration of the reference crop (mm), *Nd* is the irrigation interval, at the time the lysimeter stops draining (days between one irrigation and another), *Al* is the area of the lysimeter (m^2) and *Cd* is the drainage coefficient.

Results and discussion

Construction of the lysimeter block

Seven drainage lysimeters, with an area of 4.9 m2 each (2.49 m X 1.97 m) made up the block. Lysimeter seven was taken as a reference to determine evapotranspiration, one species will be planted in numbers one, two and three and another species will be planted in four, five and six. In this way, there will be three repetitions for each species at the time of the study to determine the crop coefficient. Rhizotrons or viewing windows of the root system are located on the inner wall of each lysimeter (Figure 5).

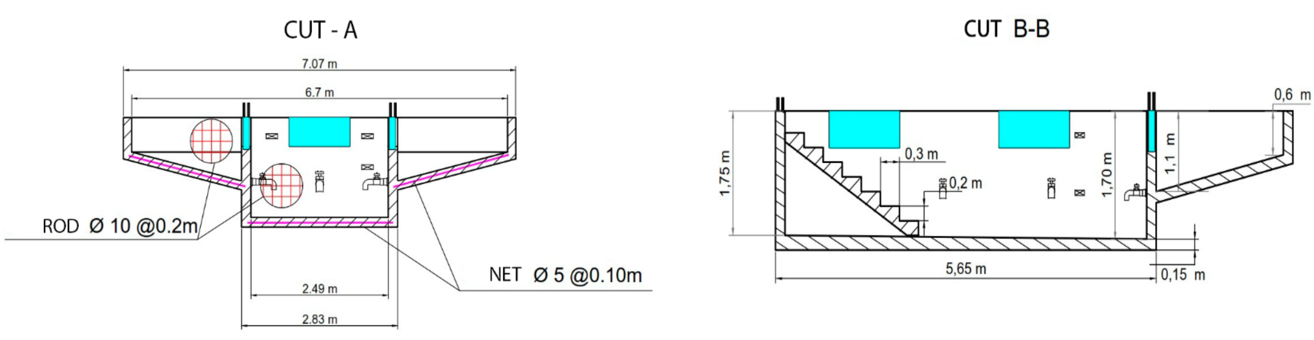

Figure 5. Cross-sectional views of the block design.

Block Installation

The physical characteristics of the soil, determined in the lysimeters, indicate that it has a silty-loam texture, which coincide with those of the soil evaluated around the lysimeters (Table 1).

The average infiltration rate in the block ranged from 1000 $mm.h^{-1}$ in the first 10 minutes to 7 $mm.h^{-1}$ at 280 minutes, with a correlation coefficient of 0.9. The speed decreases with depth and the level of compaction present, which coincides with Villazón *et al*. (2015), who obtained high levels of compaction at 0.30 m and therefore decreased water infiltration. On the other hand, Denioa *et al*. (2011) observed for a silty loam soil, such as the type of the present work, that infiltration decreases in compacted soils.

A chemical analysis of the soil was carried out in each lysimeter, the results coincide with those determined by Rioja (2002). The organic matter (OM) content is scarce, the electrical conductivity (EC) is inestimable, the potential hydrogen pH) is moderately basic, the phosphorus (P) low, the potassium (K) and calcium very low, and the magnesium (mg) very high.

Lysimeter Block Calibration

Once the irrigation corresponding to each lysimeter was carried out until reaching the field capacity and the additional irrigation, to induce drainage, it was obtained that the lysimeters from one to five needed 25 % of the CC, of over-irrigation, while the rest needed 50 %. The (soil moisture content in the 3 layers was: layer 1 (21.74 %), layer 2 (6.25 %) and layer 3 (8.33 %). The volume required to reach field capacity in each of them was 0.07 m^3, 0.32 m^3 and 0.32 m^3, respectively, for a total volume in the entire lysimeter of 0.71 m^3.

Conclusions

A protocol is available for the design, construction and calibration of drainage lysimeters for the determination of the crop coefficient (*Kc*).

The lysimeters from one to five needed 25 % of the CC, of over irrigation, the rest needed 50b%, a total volume of water of 0.71 m3 was required to reach field capacity.

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Table 1. Physical parameters of the soil determined in the lysimeters.

Lysimeter	Compactcion (kgf/cm^2)	Infiltration rate ($mm.h^{-1}$)	Apparent density ($kg.L^{-1}$)	Field capacity (%)*	Permanent wilting point (%)*	Texture*
1	4.90	104.17	1.48	28.34	10.11	Silty loam
2	5.64	108.33	1.40	28.34	10.11	Silty loam
3	5.12	102.11	1.50	28.34	10.11	Silty loam
4	5.16	115.61	1.43	28.45	9.68	Silty loam
5	5.17	144.40	1.38	28.45	9.68	Silty loam
6	5.08	79.96	1.45	28.45	9.68	Silty loam
7	5.23	104.83	1.42	28.77	10.00	Silty loam
$\bar{x}$	5.19	108.49	1.44	28.02	9.91	