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Uncertainty of weight measuring systems applied to weighing lysimeters

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ABSTRACT

The determination of measurement reliability in weighing lysimeters via error analysis is essential for scientific research and irrigation management. The objective of this study was to evaluate four different weight measuring systems (MSs) applied to load cell weighing lysimeters and compare the results with the expected uncertainty values obtained from data provided by manufacturers. A weighing lysimeter with an area of 0.385 m^2 and a volume of 0.289 m^3 was used, installed on three load cells. In MS1, the load cells were connected to a junction box and the box to a weighing indicator module in a six-wire configuration. In MS2, a four-wire connection was used between the junction box and a datalogger, whereas in MS3, there was a six-wire connection. For MS4, the connection between the load cells and datalogger was direct. The uncertainties of the measurement systems were determined from the calibration results. MS1 presented the lowest measurement errors and uncertainties, resulting in performance superior to those of the other MSs. After MS1, the best performances were obtained by MS2 and MS3, and MS4 presented the worst performance. The effect of the signal measurement uncertainties and the excitation by the datalogger had the greatest effects on the overall uncertainty of the system compared with the influence of temperature on the load cells. 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.

1. Introduction

Among irrigation investment activities, those that require the most care are management defined by irrigation depth and the most appropriate time for irrigation (Mantovani et al., 2009). This depth can be defined based on knowing the evapotranspiration of the cultivated area.

Lysimeters equipped with mechanisms for weighing by load cells enable automated measurements, and the signals resulting from weight changes in the system are generally recorded in a data acquisition system (Schmidt et al., 2013). According to Allen et al. (2011), weighing lysimeters using load cells have the advantage of measuring the water balance in the soil over a short time and with good accuracy. These authors cited the operational range and resolution of the load cells as factors that influence the accuracy of the device. Lysimeters with diverse design characteristics are presented in the literature (Allen and Fisher, 1990; Faria et al., 2006; Payero and Irmak, 2008; Santos et al., 2008; Campeche et al., 2011; Flumignan, 2011; Nascimento et al., 2011; Lorite et al., 2012; Carvalho et al., 2013; Lima et al., 2013; Schmidt, et al., 2013; Schrader et al., 2013); nonetheless, little information is available on the measurement and data acquisition systems.

It is known that different types of lysimeter are used as standard instruments for determining evapotranspiration (ET). Therefore, these devices are used in the calibration of ET estimation methods, as in the case of micrometeorological and sap flow methods, and also as a reference for irrigation management (Green et al., 1997; Vaughan et al., 2007; Liu and Luo, 2010; Bakhtiari et al., 2011; Cavalcante Júnior et al., 2011; Vellame et al., 2011; Carvalho and Oliveira, 2012; Coelho et al., 2012; Flumignan et al., 2012; Tolk and Howell, 2012; Marinho et al., 2013; Wegehenkel and Gerke, 2013; Kammerer et al., 2014). However, because it is a standard method it does not mean that the instrument is free of errors. Fidélis (2006) presents the characteristics necessary for a method to be a standard and emphasizes the imperfections that can be observed, causing errors to be incorporated into

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the measurement system to be calibrated. Therefore, the quantification of errors in lysimeters is essential for studies on water relationships and crop irrigation management.

Calibration is the process that establishes the relationship between standard values and the uncertainties associated with the measurement, seeking a measurement result (Silva Neto, 2012). According to the International Vocabulary of Metrology [*Vocabulário Internacional de Metrologia*] (INMETRO, 2012), the term measurement uncertainty is defined as the parameter associated with the result of a measurement that characterizes the dispersion of values that can be assigned to a measurement. The result of a measurement or calibration is only considered complete if the uncertainty in the measurement is included, as this parameter expresses how the result of the measurement represents the quantity measured, allowing the user of the measurement system to evaluate its reliability.

Erroneous use of terms such as precision, exactness and accuracy is common, even in the scientific literature, which leads the reader to confuse the application of metrological terms in the field of research. According to the Brazilian National Institute of Metrology, Quality and Technology [Instituto Nacional de Metrologia, Qualidade e Tecnologia – INMETRO] (2012), which ensures compatibility with international ISO standards (International Vocabulary of Basic and General Terms in Metrology), the term precision should not be used because it is a qualitative concept. According to this ordinance, measurement system errors can be divided into systematic and random. A graphical representation of the distinction between them is shown in Fig. 1.

The objective of this study was to evaluate four different weight measuring systems applied to load cell weighing lysimeters and compare the results with the expected uncertainty values obtained from data provided by the manufacturers.

2. Materials and methods

2.1. Description and characterization of the instrument under study

The study was conducted in a protected environment located in the Federal Institute of Goiano, Rio Verde Campus, Brazil. The protected environment was 17.60 m long, 7.00 m wide and 6.00 m high, covered on the sides by 11.50% shade screen and on the top by 150-µm transparent plastic tarp.

The lysimeter was constructed from galvanized sheet metal measuring 2.0 mm thick, with dimensions of 0.7 m in diameter and 0.75 m in height. The ground surface area and the volume corresponded to 0.385 m^2 and 0.289 m^3, respectively. The reservoir was supported on three load cells arranged beneath articulated supports fixed on pre-leveled steel bases. The load cells were chosen because they are currently the most used in tank weighing systems. The manufacture recommends setting on specific carbon-steel articulated supports, model Samel-2CF (Alfa Instrumentos, São Paulo, Brazil). This support can be used in the field, allowing free course of the lysimeter from 0.001 to 0.015 m with no loss of accuracy, with automatic alignment under the action of weight and self-cleaning system under conditions of dust, earth or sand (Fig. 2).

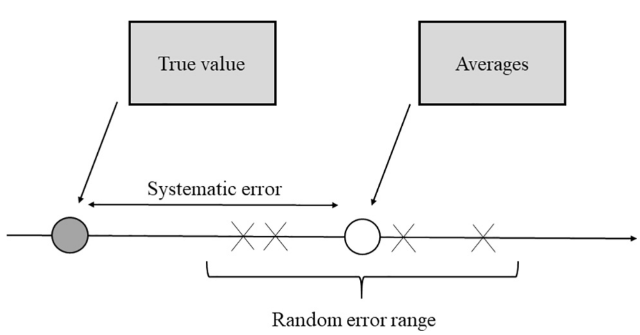

Fig. 1. Distinction between systematic and random errors.

The load cells used are type "I", composed of four extensometers connected in the form of bridge. When the load cell deforms, two extensometers expand, increasing the electrical resistance, and two contract, decreasing the resistance (Fig. 3). The relationship between the emitted differential signal (voltage difference between + Signal and – Signal) and excitation voltage (voltage difference between + Excitation and – Excitation) is known as sensitivity (Sy). Considering that the variations in the electrical resistance of the extensometers are uniform and that their resistances when deformed are equal, Sy can be calculated by Eq. (1).

$$Sy = \frac{S}{E} = \frac{\Delta R}{R} \tag{1}$$

where Sy = Sensitivity ($mV\,V^{-1}$), S = differential signal (mV), E = excitation voltage (V), ΔR = variation in the electrical resistance of the extensometers at maximum load, and R = electrical resistance of the extensometers without load.

The load cells used, model L-250 (Alfa Instrumentos, in São Paulo, Brazil), have sensitivity of 2 $mV\,V^{-1}$ ± 0.1% when at maximum load of 250 kg. One of the evaluated measuring systems uses an indicator module model 3101C, also manufactured by Alfa Instrumentos. According to the instrument's manual, conversions from analog to digital signal are made with resolution of 16,777,217 divisions and the internal calculations with 500,000 divisions. The manufacturer claims that in automatic systems the module can be programmed with up to 100,000 stable and exact divisions. Hence, it was programmed for a maximum capacity of 1000 kg and resolution of 0.01 kg (Table 1).

All measuring systems tested use a datalogger, model CR1000 (Campbell Scientific®, Logan, Utah, United States). This datalogger, besides the digital channels, has 8 inputs for differential voltage measurements and 3 programmable outputs of analog voltage. For its versatility and reliability, it is one of the most used instruments in studies involving monitoring in agricultural systems. According to the programming, average readings were stored at intervals of 15, 30 and 60 min (Table 1).

2.2. Description of the measurement systems

Various configurations for a weight measuring system (MS) are possible, depending on the number and characteristics of the load cells and on the type of instrument for display and recording. The most used devices in the research on lysimeters for signal conditioning and data display/recording are the dataloggers manufactured by Campbell Scientific. The literature presents a few MS configurations applied to weighing lysimeters: those in which the system measures the weight by only one cell connected to the datalogger (Carvalho et al., 2007; Bello and Van Rensburg, 2017; Beeson, 2016); more than one load cell, each of which individually connected to the datalogger (Fisher, 2012; Schmidt et al., 2013); load cells connected to a junction box and the box to a datalogger (Mariano et al., 2015) and also systems responsible for signal conditioning with digital transmission of information to the datalogger (Lorite et al., 2012).

To evaluate the instruments and determine the best form of connecting the load cells to the datalogger or signal conditioner (4 or 6 wires; with or without junction box), measurement uncertainty and effect of temperature were determined in four different MSs.

In measuring system 1 (MS1), the load cells were connected to a junction box, model 4134A, manufactured by Alfa Instrumentos, which in turn was connected to the indicator module in a 6-wire configuration (Fig. 3). The junction box only connects the load cells in parallel. Considering that the resistances of the cells are equal and making ΔR explicit in Eq. (1), based on the calculation of equivalent resistance for resistors in parallel, the output signal of the junction box (SJB) can be determined as a function of the sensitivity of each cell (Sy1, Sy2, Sy3) and excitation voltage (E) by Eq. (2).