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Research Paper

Test methods for characterising the water distribution from irrigation sprinklers: Design, evaluation and uncertainty analysis of an automated system

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ARTICLE INFO

Article history:
Received 30 October 2017
Received in revised form
14 January 2018
Accepted 31 January 2018

Keywords:
Standardisation
Testing
Irrigation
Instrumentation

An automated system for indoor testing of irrigation sprinklers was developed and evaluated. The system was designed to test single sprinklers with jet lengths up to 18 m. The tests involve the use of 36 collectors (catch-cans) spaced at 0.5 m intervals along the jet radius. A single pressure transducer coupled to a manifold equipped with solenoid valves was employed to sequentially scan the water level in each collector. Radial application rates were determined based on water level measurements. Results obtained using the automated system were compared with those obtained using manual operation using mass measurements. Uncertainty analysis of the manual method was compared with the automated system. The automated system was found to be as reliable as the manually operated system for testing sprinklers. Although minor differences in the application rates measured by the two methods were detected, they did not cause appreciable differences in the distribution uniformity indicators used. The results presented will provide useful baseline for uncertainty analysis in irrigation sprinkler testing.

1. Introduction

Sprinkler systems are one of the most popular methods of irrigation worldwide. In Australia, Brazil, United States of America, and Europe, sprinklers are used in more than 50% of the total irrigated land (ABS, 2011; IBGE, 2009; USDA, 2009) and in France it is used in more than 90% of the irrigated area.

Overhead impact sprinklers, using either one or two nozzles, are one of the most common devices used for crop irrigation. In the field, sprinklers may be arranged in a variety of patterns, including rectangular, square and triangular. To

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https://doi.org/10.1016/j.biosystemseng.2018.01.011

Nomenclature

Symbols

c	Coefficient of sensitivity
CUC	Coefficient of Uniformity of Christiansen
d_c	Collector diameter, mm
d_{MT}	Measurement tube diameter, mm
DU	Distribution Uniformity
i	Application rate, mm h^{-1}
i_p	Electrical current as output signal of pressure transmitter
i_T	Electrical current as output signal of temperature transmitter
k	Coverage factor
m_f	Final mass (water + collector), g
m_i	Initial mass (collector), g
ρ	Water density, kg m^{-3}
p_f	Final pressure inside measurement tubes, mbar
p_i	Initial pressure inside measurement tubes, mbar
$r(x_i, x_j)$	Correlation coefficient
SC	Scheduling Coefficient
t	Test duration, s
T	Water temperature, °C
u_c	Combined uncertainty
u	Standard uncertainty
U	Expanded uncertainty, %
UCS	Statistical Coefficient of Uniformity
ν_{ef}	Effective degrees of freedom
V_i	Volume measured in an individual catch-can
$\overline{V}$	Mean applied volume

Abbreviations

ADC	Analogue-to-digital converter
DAC	Digital-to-analogue converter
DSP	Digital Signal Controller
ESALQ	"Luiz de Queiroz" Superior College of Agriculture
GUM	Guide to the Expression of Uncertainty in Measurement
INITL	International Network of Irrigation Testing Laboratories
IRSTEA	National Research Institute of Science and Technology for Environment and Agriculture
LEMI	Irrigation Testing Laboratory
PID	Proportional-integral-derivative
PReSTI	Irrigation Research and Testing Platform
USP	University of São Paulo
VFD	Variable frequency drive

achieve the desired level of uniformity, patterns and spacings are designed to allow for an overlap of water distribution. Yield and plant quality are strongly correlated to uniformity of water distribution, making it a key design parameter (Zhang, Merkley, & Pinthong, 2013).

To evaluate field performance, collectors (catch-cans) are arranged in either a square or rectangular grid with the test sprinkler located at the centre of the grid. However, tests undertaken indoors commonly use single leg tests whereby catch-cans are arranged along one or more radii from a single sprinkler. This method is generally used by most testing laboratories (Tarjuelo, Montero, Valiente, Honrubia, & Ortiz, 1999) because of space constraints and to reduce environmental influences (wind and evaporation). This method has been standardised since the 1980's (ISO7749-1, 1995; ISO 15886-3, 2012).

Tests of this nature have rigorous, long, and repetitive procedures, and the manual nature of the work is time and labour demanding. There is therefore a need to automate single-leg sprinkler testing, not only to reduce both the time and labour requirements, but also to potentially improve accuracy by reducing the uncertainties normally associated with manual operations. Automating the process could reduce the variability between tests (Zanon, Testezlaf, & Matsura, 2000), thereby improving the quality of results.

Automating sprinkler testing is not a new concept since it appears to have begun more than five decades ago (Seginer, Kaiitz, Nir, & von Bernuth, 1992). Some previous attempts at automating the process are discussed in literature (Fischer & Wallender, 1988; Hermsmeir, 1972; Hodges, Kroeger, & Ley, 1990; Zanon et al., 2000), although there is no evidence of the widespread use of any of these methods. In most of these designs, automation is achieved by using a sensor attached to the collectors to monitor the variation on the water collected. Approaches that use load cells are common, and although they show good results in terms of measurement uncertainty, they are influenced by minor vibrations, even those caused by wind or air flows. Other issues related to the use of load cells include the wetting of the outer surfaces of the collector, which has the potential to overestimate the application rate.

Pressure transducers, used to measure the change in water level within collectors, are not susceptible to such problems, but they are generally associated with a higher measurement uncertainty. When the application rate is determined using pressure transducers, water is transferred from the collector to a collection tube where the water level is measured. The diameter of the collection tube must be smaller than that of the collector so as to increase the pressure (i.e. the height of the water column to be measured). Each tube can have its individual transducer, or a single transducer can be installed in a manifold, linking all tubes using valves (Fischer & Wallender, 1988; Seginer et al., 1992; Tarjuelo et al., 1999). Using one sensor for each tube is more expensive than using one transducer in a manifold, although additional valves might be required. Also, the costs of periodically calibrating numerous transducers might be prohibitive for many testing laboratories.

Previous research undertaken by the authors (Koech et al., 2015, 2016) within the auspices of the International Network of Irrigation Testing Laboratories (INITL) suggested that there was scope to further improve and standardise the testing of irrigation equipment, including in relation to measurement uncertainties. Our review of literature did not yield any published article dealing with uncertainty analysis and budgets related to irrigation sprinkler testing.

The purpose of this paper is to describe and evaluate an automated system for testing irrigation sprinklers developed