Computers and Electronics in Agriculture 151 (2018) 31–40

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Development of an automatic test bench to assess sprinkler irrigation uniformity in different wind conditions

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ARTICLE INFO

Keywords:
Solid set sprinkler systems
Irrigation evaluation
Automation

ABSTRACT

In sprinkler irrigation the water distribution uniformity in field conditions is not always a known factor, mainly due to the many variables involved, especially the wind. The main objective of this study was to design, install and test an automatic sprinkler bench to measure the irrigation uniformity of solid set systems for multiple wind conditions in real time. The system developed measures the different wind speeds and directions while simultaneously recording the rainfall distribution automatically. Consequently, the system requires little manual intervention, thus reducing the operating costs. All the information generated is stored in a database, obtaining multiple results of irrigation uniformity for each stable wind regime. As a second step, uniformities in different situations (layouts and wind directions) were studied. In addition, this study shows the potential for assessing the influence of different variables on irrigation uniformity for several sets of sprinklers. As an example of possible applications, 12,150 results of uniformity coefficients for conventional impact rotary head sprinklers with hexagonal nozzles in windy conditions were generated. These data were used to establish comparisons between different sprinklers. To do this, a multiple linear regression methodology was applied in order to analyse the influence of the different contour variables on the irrigation uniformity. The test bench presented along with the methodology to simulate and generate multiple scenarios constitutes a powerful tool for designers, farmers and technicians both for the improvement of existing installations and for future designs. The generation of a large amount of irrigation uniformity results for sprinkler irrigation in different wind conditions will lead to a large database with the potential to be able to determine the irrigation uniformity in all common scenarios.

1. Introduction

The modernization processes carried out in the irrigated areas have led to the installation of pressurized networks. This fact has induced a change from surface irrigation to sprinkler or trickle irrigation, which are purported to have higher water application efficiencies, better control of the water depth applied and enable automation. However, sprinkler systems have certain disadvantages with respect to trickle irrigation. The most important is the poor uniformity of irrigation in wind conditions and the means to determine it. Water application uniformity is the main indicator of irrigation quality. It can be expressed through different parameters or coefficients, such as the Distribution Uniformity (DU) (Merriam and Keller, 1978) or the Christiansen's Uniformity coefficient (CU) (Christiansen, 1942). Irrigation management with sprinkler irrigation systems would benefit from site-specific, comprehensive and accurate information about irrigation uniformity, especially in windy conditions. With one study using a well-executed irrigation schedule based on crop requirements, yield increased with a higher irrigation uniformity (Li, 1998). According to Keller and Bliesner (1990), most irrigation sprinkler systems require a minimum CU value greater than 80%. Bralts et al. (1994) indicated that a 5–12% increase in CU could lead to 3–17% more yield in wheat grain. Moreover, according to Tarjuelo et al. (1999b), low CU values generally indicate a faulty combination of the number and size of nozzles, pressure and spacing of sprinklers.

Many factors affect the performance of sprinkler irrigation. However, the wind is an uncontrollable variable and has a decisive influence on sprinkler irrigation efficiency and uniformity (Tarjuelo et al., 1999b). Therefore, knowing the DU for each irrigation scenario and possible wind regime is desirable. This allows for determining the optimal timing for irrigation in order to minimize the effects due to wind (Sánchez et al., 2011).

Wind speed and direction are the main parameters that have a greater impact on the water distribution model (Tarjuelo et al., 1999b)

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https://doi.org/10.1016/j.compag.2018.05.036
Received 1 July 2017; Received in revised form 27 April 2018; Accepted 29 May 2018
0168-1699/

and play an important role in drift and evaporation losses (Tarjuelo et al., 2000; Keller and Bliesner, 1990). Many authors indicate that the influence of the wind depends greatly on system design parameters, such as working pressure, spacing, nozzle size or type of sprinkler (Keller and Bliesner, 1990).

Different methods can be used to determine sprinkler irrigation uniformity. Each procedure is adapted to information requirements, with a more or less limited scope of results. In a Radial model (Vories and Von Bernuth, 1986), an isolated and windless evaluation of the sprinkler is performed, using a certain nozzle and a specific operating pressure. It is basically an evaluation with a row of rain gauges along the radius of the wet area of the sprinkler. The results obtained are used to measure the irrigation uniformity that the entire wet area in the field would have. It is mainly used to characterize the sprinklers and nozzles in ideal conditions without wind (Tarjuelo et al., 1999a). It is required information for sprinkler manufacturers which offer basic data for the irrigation design.

The Matrix model (ISO 15886-3:2012, 2012) is also an evaluation of an isolated sprinkler, but having the advantage of knowing the complete water distribution pattern of the sprinkler in the whole wet area. It is mainly used to characterize the sprinkler and the nozzles in windy conditions. It consists in setting a network of rain gauges covering the wetted surface of an isolated sprinkler. This will allow for overlapping data according to the operation layout. This procedure has three disadvantages: (1) the variability of the climatic conditions during the test, (2) the different evaporation rate in the peripheral collectors with respect to the central ones and (3) the high manpower requirements for each test. It is mainly used in research centres dedicated to the study of sprinkle irrigation.

Lastly, the evaluation of the system (Merriam and Keller, 1978; Merriam et al., 1980) consists of the actual field evaluation of an existing irrigation facility. It is performed in a sample area of the installation and by the provision of a network of collectors. It is ideal to determine the quality of irrigation in specific conditions (wind, pressure, etc.) in which the evaluation is done.

However, in recent decades, many simulation models for irrigation have been developed with different theories, in order to avoid the problems of experimental field tests. Ballistic models are based on simulating the trajectory of drops of water in the air when they come out of the sprinkler and are distorted by the action of wind (Carrion et al., 2001; Montero et al., 2001; Playan et al., 2006; Li et al, 2015; Yongchong et al., 2015). Semi-empirical models simulate the shape of water distribution distorted by the wind, starting from results in windless conditions (Richards and Weatherhead, 1993; Han et al., 1994; Molle and Le Gat, 2000; Granier et al., 2003; Oliveira et al., 2013). Other models use mathematical techniques of artificial neural networks, simulating the effect of the wind on the sprinkler water distribution pattern (Lazarovitch et al., 2009; Hinnell et al., 2010; Sayyadi et al., 2012). In each case, the simulation models should be calibrated and validated through experimental tests.

Depending on the chosen method, the quantity and quality of information will vary. In ballistic models, a large database that characterizes all the sprinklers can be obtained but only for the conditions of operation without wind. Semi-empirical models can be considered the most accurate and their results can be easily extrapolated. However, this evaluation is costly both in time and resources, and requires a specific infrastructure. In the third case, many field evaluations can be performed but in such specific conditions that they will not readily adapt to other circumstances.

For obtaining water distribution data from isolated sprinklers, radial or matrix models can be used. Both can be automated to avoid labour costs, while they have the advantage of reducing the error due to evaporation from the collectors during the test. Hodges et al. (1990) used the matrix system in an automated test facility programmed to operate unattended when wind speed exceeded 2.2 m·s^{-1}. Although, as has been stated, previous attempts have been made, it is necessary to consolidate a system in order to have an operational tool that addresses the lack of knowledge about irrigation uniformity under multiple real operating conditions.

The main objective of this work is the design of an automatic test bench for the study of uniformity in solid set sprinklers systems in different wind conditions. The main differences with respect to the bench developed by Hodges et al. (1990) are:

- Increasing the surface area of the bench so as to permit rain collection with winds greater than 2.2 m·s^{-1}.
- Improving measurement precision by increasing collector size.
- Having a more accurate and efficient data acquisition system which permits real-time data analysis. This allows for instantaneous extraction of data concerning water distribution and wind speed and direction, therefore permitting the execution of more trials per working day thus increasing bench performance.

The development of this equipment involves a complex data acquisition and processing system which allows further analysis. This tool will not only generate a large amount of experimental data, but coupled with the simulation method proposed by Han et al. (1994) will be able to recreate solutions for any real situation that may occur in the field.

2. Materials and methods

2.1. Design requirements

The test bench was located at the Agrarian Research and Training Centre of Chipiona in Cadiz, Spain (Geographical coordinates: 36.751351, −6.4003860). The following requirements were contemplated:

1. Isolated sprinkler test following the method proposed in ISO 15886-3:2012 (2012).
2. Instant and continuous measurement of the temporal and spatial water distribution, using automatic rain gauges with a tipping bucket, that register the amount and the time in which water is collected at each sampling point. The sprinkler is located in the centre of the grid of rain gauges, which are electronically interconnected, with a spacing of 2 by 2 m.
3. Instantaneous measurement of the wind speed and direction at all times with an automatic wind sensor. The relative wind directions are standardized in a later simulation, with respect to the irrigation lateral (Norenberg et al., 2017), in three directions: parallel, oblique and perpendicular, independent of the wind direction (Fig. 1). This

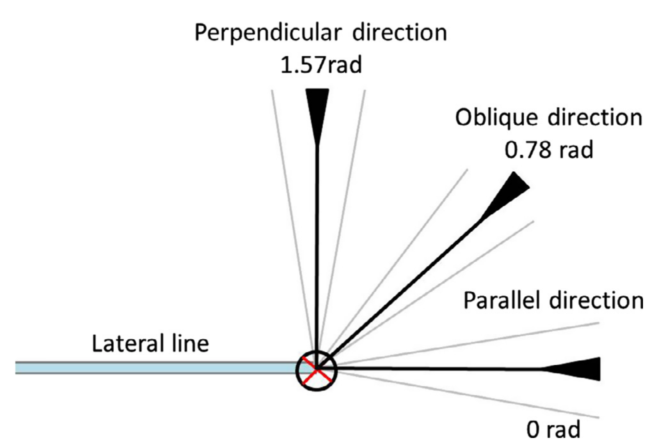

Fig. 1. Standardization of relative wind directions with respect to the lateral line.