Agricultural Water Management 102 (2011) 13–24

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

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

The effects of pressure, nozzle diameter and meteorological conditions on the performance of agricultural impact sprinklers

I. Sanchez[a,*], J.M. Faci[a], N. Zapata[b]

[a] Unidad de Suelos y Riegos (asociada al CSIC), Centro de Investigación y Tecnología Agroalimentaria (CITA), Gobierno de Aragón, Avenida Montañana 930, 50059 Zaragoza, Spain
[b] Dept. Soil and Water, Estación Experimental de Aula Dei (EEAD), CSIC, Apdo. 202, 50080 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 14 December 2010
Accepted 6 October 2011
Available online 1 November 2011

Keywords:
Sprinkler irrigation
Evaluation
Wind
Uniformity
Water-losses

ABSTRACT

This study evaluates agricultural impact sprinklers under different combinations of pressure (p), nozzle diameter (D) and meteorological conditions. The radial curve (Rad) of an isolated sprinkler, i.e., the water distribution along the wetted radius, was evaluated through 25 tests. Christiansen's uniformity coefficient (CUC) and the wind drift and evaporation losses (WDEL) were evaluated for a solid-set system using 52 tests.

The Rad constitutes the footprint of a sprinkler. The CUC is intimately connected to the Rad. The Rad must be characterized under calm conditions. Very low winds, especially prevailing winds, significantly distort the water distribution. The vector average of the wind velocity (V') is recommended as a better explanatory variable than the more popular arithmetic average (V). We recommend characterizing the Rad under indoor conditions or under conditions that meet $V' < 0.6\ \mathrm{m\,s^{-1}}$ in open-air conditions.

The Rad was mostly affected by the sprinkler model. V' was the main explanatory variable for the CUC; p was significant as well. V was the main variable explaining the WDEL; the air temperature (T) was significant, too.

Sprinkler irrigation simulators simplify the selection of a solid-set system for farmers, designers and advisors. However, the quality of the simulations greatly depends on the characterization of the Rad. This work provides useful recommendations in this area.

1. Introduction

Sprinkler irrigation depends on many operating, environmental and agronomic factors. The uniformity of the water distribution mainly depends on the spacing and arrangement of the sprinklers, the environmental conditions, the number and diameter of the nozzles, the sprinkler model and the operating pressure (Carrión et al., 2001; Keller and Bliesner, 1990; Playán et al., 2006) and on the crop irrigated (Sanchez et al., 2010a,b). Among these variables, those controlled by design are particularly interesting to people involved with irrigation technology. Playán et al. (2005) reported that the wind velocity is the meteorological variable most directly related to irrigation performance through its effects on Christiansen's uniformity coefficient (CUC, Christiansen, 1942) and on the wind drift and evaporation losses (WDEL).

The evaluation of a solid-set system ranges from the assessment of the distribution pattern of an isolated sprinkler in no-wind conditions (Tarjuelo et al., 1999a) to the study of the whole-field irrigation in real conditions (Mateos, 1998). The operational, atmospheric and agronomic conditions in which sprinkler irrigation can be used are vast. To study all the cases with field experiments is cost prohibitive. Therefore, sprinkler simulators have been developed and used to analyze an ample range of conditions, with minimal experimental effort. Most of these models have been developed using the ballistic approach first proposed during the 1980s (Fukui et al., 1980; Von Bernuth and Gilley, 1984; Vories and von Bernuth, 1987). In these models, the superposition of the water distribution of an isolated sprinkler can provide an acceptable approximation to simulate the distribution of a group of sprinklers on a field scale when adjustments for wind drift and evaporation losses are correctly made (Carrión et al., 2001). Experimental irrigation evaluations were performed under isolated and block-sprinkler configurations for calibration and validation processes.

The procedure for the evaluation of an agricultural impact sprinkler, conducted by the calibration and validation of an irrigation simulator, has been described in numerous studies (Carrión et al., 2001; Dechmi et al., 2004a,b; Playán et al., 2006; Seginer et al., 1991a,b). The radial curve (Rad) for an isolated sprinkler, i.e., the irrigation depth (ID) as a function of the distance from the sprinkler, is the basis for the characterization of the drop-size

* Corresponding author. Tel.: +34 976 71 6324; fax: +34 976 71 6335.
E-mail address: ingancio@gmail.com (I. Sanchez).

0378-3774/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2011.10.002

population from which the irrigation performance of a solid set can be simulated under different conditions.

This study analyzes the effects of the sprinkler model and of the solid-set arrangement on irrigation performance under different technical (nozzle diameter and operating pressure) and meteorological (wind velocity and direction, temperature and relative humidity of the air) conditions. The paper discusses the drawbacks of the common procedures used to evaluate sprinklers and to calibrate and validate the empirical models for the simulation of irrigation performance.

2. Material and methods

Two experiments designed to evaluate the irrigation performance of agricultural impact sprinklers were conducted at the experimental farm of the Agricultural and Food Research and Technology Centre in Zaragoza, Spain (41°43′N, 0°48′W, 225 m altitude) during the years 2003 and 2004. One experiment was performed using an isolated sprinkler. The other experiment was performed using a rectangular 15 m × 15 m (R15 × 15) solid-set arrangement.

The isolated sprinkler experiment was designed to evaluate the Rad. It was performed on bare soil and under calm conditions as specified by the most relevant international standards. The solid-set experiment was designed to evaluate the irrigation performance using the CUC and the WDEL parameters under different wind conditions. This experiment was also conducted on bare soil. Both experiments were designed according to the recommendations of Merriam and Keller (1978) and the relevant International Standards (ANSI/ASAE, 2003; ISO, 1990, 1995).

In the isolated sprinkler experiment, the ID emitted by a model Somlo 30C sprinkler (Zaragoza, Spain), assembled in a riser tube at 2 m above the ground level (a.g.l), was collected into pluviometers located at 0.25 m a.g.l. along four radii at distances from the sprinkler ranging from 0.75 to 16.75 m, in increments of 0.5 m (Fig. 1). The radii faced north (N), west (W), south (S) and east (E), respectively. The evaluated sprinkler was an agricultural impact sprinkler made of brass and equipped with a drive nozzle that included a straightening vane (SV). Three diameters of the main nozzle (D) were tested: 4, 4.4 and 4.8 mm. The sprinkler also included a spreader nozzle, 2.4 mm in diameter (d). An ample range of operating pressures (p) from 180 to 420 kPa was tested. All the tests were performed for 2 h under low wind conditions. The wind velocity (V) and direction (WD) and the temperature (T) and relative humidity (RH) of the air were monitored by an automatic weather station located in the same plot. The average records were collected every 5 min using a model CR10X data logger (Campbell Scientific Ltd, UK).

A set up with 24 sprinklers was used in the solid-set experiment (Fig. 1). The distance between the laterals was 15 m, and the distance between the sprinklers along the lateral was 15 m. The sprinklers were arranged according to a rectangular layout (R15 × 15). The sprinkler model and the combination of nozzles were the same as used for the isolated sprinkler test. The experimental area was located between the four central sprinklers. A matrix of 25 pluviometers was installed at 0.25 m a.g.l. using a 3 m × 3 m grid that covered the experimental area of the four central sprinklers. One manometer was installed at each of the four sprinklers. Three p were evaluated: 240, 320 and 420 kPa. Meteorological factors cannot be controlled, but we sought low, medium and strong winds. For the solid-set experiment, all the tests lasted 3 h.

For each test of the solid-set experiment, the CUC and the WDEL were assessed from the ID collected in the pluviometers. The WDEL was estimated as the percentage of the water emitted by the sprinklers (ID_e) but not collected inside the pluviometers (Dechmi et al., 2003; Playán et al., 2005; Sanchez et al., 2010a) according to the following formula:

$$\mathrm{WDEL} = \frac{\mathrm{ID_e} - \mathrm{ID}}{\mathrm{ID_e}} \times 100 \quad (1)$$

$$\mathrm{ID_e} = \frac{Q \times t}{15 \times 15} \quad (2)$$

where Q was the water discharge ($\mathrm{l\,s^{-1}}$), t (s) the operating time and 15 × 15 the area ($\mathrm{m^2}$) assigned to each sprinkler.

Q was assessed by collecting the water emitted by the sprinkler into a tared container. The discharge was calculated by dividing the weight of the collected volume by the time of filling. This operation was repeated twice for each combination of D and p (nine combinations in total). The discharge was estimated using the equation:

$$Q = C_D \times A \times (2gp)^n \quad (3)$$

where C_D is the discharge coefficient, A is the area of the nozzle orifice, g is the gravity acceleration, and n is the discharge exponent.

A meteorological station similar to the one used during the isolated-sprinkler experiment was located at an adjoining plot during the solid-set experiment (Fig. 1). The experiment was performed under an ample range of meteorological conditions in an attempt to characterize the CUC and the WDEL resulting from different combinations of D, p and V. The variation of the CUC and of the WDEL with several meteorological and technical variables was analyzed using multiple regression analysis.

Traditionally, the average wind velocity during an irrigation event is calculated as the arithmetic mean considering the records as positive rational numbers. This will be called the *arithmetic average* (V). In addition, we assessed the *vector average* (V') considering each 5-min record a Euclidean vector endowed with magnitude and direction. Fig. 1 shows the Cartesian coordinate systems used for each experiment. The projections of each 5-min vector on the X and Y axes (V_x and V_y, respectively) were calculated and averaged separately. The resultant of the axial components was calculated. Its magnitude was considered the *vector average* (V'), and the direction of the resultant was the WD during the irrigation event.

For each isolated sprinkler test, the Rads resulting from each radius were compared. The tests in which the differences between the radii were the smallest were used to characterize the Rad. For each test, we calculated the average deviation of the volume collected along the four radii (AD, %), the ratio of the volume of water collected along the leeward radius to the volume collected along the windward radius, and the fraction of the water drifted from the leeward radius to the windward radius.

The average Rad was calculated for each test from the four Rads corresponding to each radius. Then the CUC was calculated from the average Rad as follows: the ID of each position on the grid of pluviometers was assessed by interpolation from the average Rad as a function of the distance from each position to each sprinkler. This was calculated for a R15 × 15 solid set. The values of the CUC evaluated under low winds during the solid-set experiment and the CUC calculated from the Rad were compared.

Four sprinkler models were compared: the Somlo 30C, the VYR 70 (VYRSA, Burgos, Spain) and the RC 130 (Riegos Costa, Lleida, Spain) evaluated by Playán et al. (2006) and the VYR 35 evaluated by Zapata et al. (2009). All are widely used in the Ebro Valley (Spain). A comparison was made for calm and windy conditions. For the calm conditions, we compared the average Rad and the CUC calculated from the average Rad for two solid sets (R15 × 15 and R18 × 15). For the windy conditions, we compared the CUC for the same combination of D, p and V evaluated during the solid-set experiment. The latter was assessed using the Ador-sprinkler simulator for the VYR 70, the RC 130 and the VYR 35.