Agricultural Water Management 191 (2017) 37–49

Contents lists available at ScienceDirect

Agricultural Water Management

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

Assessing low-pressure solid-set sprinkler irrigation in maize

O. Robles, E. Playán, J. Cavero, N. Zapata*

Dept. Soil and Water. Estación Experimental Aula Dei (EEAD), CSIC. Av., Montañana 1005, Zaragoza 50059, Spain

ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 22 May 2017
Accepted 2 June 2017

Keywords:
Solid-set
Sprinkler irrigation
Energy efficiency
Low pressure sprinklers
Maize yield

ABSTRACT

Water and energy are limited and expensive resources. Conserving water and energy is a requirement to ensure the viability of modern pressurized irrigation systems. The objective of this research was to analyze the possibilities of reducing the nozzle operating pressure of impact sprinklers from 300 kPa (standard pressure) to 200 kPa (low pressure) in solid-set irrigation systems without reducing the sprinkler spacing and maintaining crop yield. Three treatments resulting from combinations of sprinkler type, and working pressure were analyzed: 1) Conventional impact sprinkler operating at 300 kPa (CIS300); 2) Conventional impact sprinkler operating at 200 kPa (CIS200); and 3) Modified deflecting plate impact sprinkler operating at 200 kPa (DPIS200). A randomized experimental design was applied to a maize crop during two seasons (2015 and 2016). Irrigation performance was measured by catch-can monitoring at one replicate of each treatment. Maize growth, yield and its components were measured. Differences between treatments in soil water, maize growth and yield variables were analyzed using ANOVA. Seasonal irrigation uniformity evaluated at the top of the canopy was larger for the standard pressure treatment (93%) than for the low pressure treatments (82% and 84% for DPIS200 and CIS200, respectively). The average wind drift and evaporation losses for the 2016 irrigation season were higher for the CIS300 treatment (17%) than for the low pressure treatments, DPIS200 (15%) and CIS200 (13%). Low pressure treatments did not reduce grain yield compared with the standard pressure treatment. Differences in irrigation performance and maize yield between the low pressure treatments, DPIS200 and CIS200, were not statistically significant. The reduction in energy use by reducing the operating pressure from 300 kPa to 200 kPa would allow to increase the net farming benefit of individual and collective systems. This is particularly true if low pressure irrigation is considered at the design phase of the irrigation system.

1. Introduction

A number of countries have devoted intense efforts in the last years to modernize their irrigation systems. Among them, Spain, where new collective pressurized irrigation networks and on-farm irrigation systems have been designed to operate at the highest water management standards. Designs paid attention to energy dependence and to the resulting costs for the farmers. However, modernization projects did not foresee the sudden rise in agricultural electricity prices in 2008, resulting from the discontinuation of the specific electricity tariff for agricultural irrigation (Rocamora et al., 2013; Tarjuelo et al., 2015). This new situation forced Water Users Associations operating pressurized networks with pumping stations to optimize irrigation management and to apply water in the daily or weekly periods of relatively low tariffs (Moreno et al., 2010). In our days, being efficient in the use of water (applying irrigation when needed and in the amount that the crops need) is not sufficient when water is applied through energy-dependent pressurized irrigation systems. In these cases, farmers reduce the energy used per unit volume of water and schedule irrigation when energy cost is low. Taking these challenges into consideration, many recent research works have focused on improving the energy efficiency of irrigation facilities, optimizing pumping stations and irrigation network designs (Rodríguez Díaz et al., 2009; Moreno et al., 2010; Fernandez Garcia et al., 2013). However, it is necessary to move forward in energy optimization, paying attention to irrigation in its agricultural context: the plot, the crop, its yield and the resulting economic profit.

Traditional solid-set irrigation systems are usually designed to operate at a minimum of 300 kPa at the nozzle of the impact sprinklers. As energy costs increase, there is a need to find ways to operate sprinkler systems at reduced pressure without reducing the sprinkler spacing and maintaining high irrigation uniformity (Kincaid, 1991). Farmers would find it difficult to accept narrower

* Corresponding author.
E-mail addresses: coctaviorobles@eead.csic.es (O. Robles), enrique.playan@csic.es (E. Playán), jcavero@eead.csic.es (J. Cavero), v.zapata@csic.es (N. Zapata).

http://dx.doi.org/10.1016/j.agwat.2017.06.001
0378-3774/

sprinkler spacings because this would increase the cost of the installation and make mechanization more difficult. Additionally, Playán et al. (2006) reported very small differences in uniformity in the range of sprinkler layouts commonly used for field crops (from 21 × 18 m to 18 × 15 m, triangular and rectangular).

With standard pressure, 300 kPa, the jet breaks up sufficiently to produce an adequate conical water distribution pattern. As pressure is reduced the pattern becomes annular or doughnut shape, reducing the uniformity of the overlapped configuration. Recently, new impact sprinklers have been commercialized which are specially designed to operate at reduced pressure. These new sprinklers are based on developments by Kincaid (1991) who proposed a modification of the impact-type sprinkler adding a deflector attached to the drive arm. The device diffuses the jet of a standard circular-orifice nozzle, maintaining the radius range and potentially improving the distribution pattern. Kincaid (1991) proposed an intermittent deflection of the jet to fill in the intermediate and lower irrigated portion of the annular pattern (the proximal region).

Reductions in the energy requirements of center pivot and lateral move irrigation machines have been successfully achieved by replacing the traditional impact sprinklers by spray sprinklers. These spray sprinklers operate at reduced pressure without affecting irrigation performance (Omary and Sumner, 2001). Kincaid (1982) analyzed the possibilities of reducing energy requirements of a sprinkler stationary system, the sideroll wheeline lateral. His results indicated that for 12.2 m to 15.2 m lateral move distances, a pressure of 206 kPa produced irrigation uniformities nearly equivalent to those resulting from 379 kPa. For longer lateral move distances, the low pressure configuration significantly reduced uniformity.

Encouraging results were presented by Playán et al. (2006) in solid-set sprinkler irrigation systems when reducing the nozzle pressure from 300 kPa to 200 kPa in two conventional impact-type sprinklers. Differences were analyzed in a solid-set sprinkler layout of 18 × 15 m with a 2 m sprinkler riser height. The radial application patterns were very similar, and Distribution Uniformity was slightly higher (<5%) for the highest pressure. Paniagua (2015) analyzed the effect of reducing the pressure at the nozzle from 300 kPa to 200 kPa in modified impact sprinklers with a deflecting plate in the drive arm. The comparison was performed in two solid set sprinkler layouts commonly used to irrigate field crops (18 × 18 m and 18 × 15 m). The author concluded that for the experimental conditions, modified impact sprinklers operating at 200 kPa performed adequately and could substitute the traditional impact sprinklers operating at 300 kPa in solid-set layouts. Sahoo et al. (2008), working in solid-set spacings smaller than the previous authors (12 × 12 m or 6 × 12 m) and at pressures ranging from 100 kPa to 250 kPa, concluded that the nozzle pressure of 200 kPa performed better than the rest of analyzed nozzle pressures, using small and medium sized nozzles. For larger nozzles, the pressure of 200 kPa performed better than lower pressures and equal to the nozzle pressure of 250 kPa. These authors recommended selecting relatively large size nozzles for operating low pressure sprinklers in windy conditions.

Several variables affect the water distribution pattern of a solid-set sprinkler irrigation system: the spacing among sprinklers and laterals, wind speed and direction, sprinkler type, working pressure, nozzle size and sprinkler riser height (Tarjuelo et al., 1999; Playán et al., 2005). While the effect of reducing sprinkler nozzle pressure on irrigation performance of individual irrigation events has been analyzed in the literature (Kincaid, 1991; Playán et al., 2006; Sahoo et al., 2008; Paniagua, 2015), the seasonal effect on crop yield has not been assessed.

This research set out to analyze the possibilities of reducing energy requirements of solid-set sprinkler irrigation systems by reducing the pressure at the sprinkler nozzle from 300 kPa to 200 kPa, without reducing the sprinkler spacing and maintaining maize yield. A field experiment was designed to compare the irrigation performance and the crop yield of three treatments based on two sprinkler configurations (conventional impact sprinkler and modified impact sprinkler) and two operating pressures (300 kPa and 200 kPa).

2. Materials and methods

2.1. Experimental site and design

The experiment was conducted in a 2.0 ha solid-set facility located at the experimental farm of the Aula Dei Agricultural Research Centre in Montañana (Zaragoza, NE Spain). Geographical coordinates are 41°43′N latitude and 0°49′W longitude, and elevation is 225 m above mean sea level. The sprinkler layout of the irrigation system was square, with a spacing of 18 m between sprinkler lines and 18 m between sprinklers of the same line. Riser pipes were used to locate the sprinkler nozzle at an elevation of 2.5 m above the ground level. The irrigation system is composed by 14 irrigation blocks. Two linear blocks irrigate the borders of the experiment, while twelve square blocks correspond to the experimental plots. Each experimental plot is composed by four impact sprinklers (324 m^2) and is controlled by a hydraulic valve equipped with a pressure regulator. Blocks are named after the number of the valve irrigating them: from V1 to V14.

Three treatments were designed for this research, each of them with four replicates randomly distributed in the twelve experimental plots (Fig. 1). Two types of impact sprinklers were tested. The first one is a standard brass impact sprinkler, Costa RC-130 (CIS, Conventional Impact Sprinkler). The second one is a plastic impact sprinkler (NaanDanJain 5035) resulting from the application of the developments by Kincaid (1991). This modified impact sprinkler adds a deflecting plate to the drive arm (DPIS, Deflecting Plate Impact Sprinkler). Two nozzle pressures were evaluated: the standard 300 kPa and the low 200 kPa.

The three treatments are: 1) the standard brass impact sprinkler equipped with double brass nozzle (4.4 mm and 2.4 mm) operating at a pressure of 300 kPa (CIS300); 2) the standard brass impact sprinkler equipped with double plastic nozzle (5.16 mm and 2.5 mm) operating at a pressure of 200 kPa (CIS200); and 3) the modified plastic impact sprinkler equipped with double plastic nozzle (5.16 mm and 2.5 mm) operating at a pressure of 200 kPa (DPIS200). The treatments with low working pressure implement larger nozzles than the treatment with standard pressure to obtain a similar gross irrigation application rate, 5.2 mm h^{-1}.

The 14 irrigation blocks (including the 12 experimental plots) were irrigated from the same hydrant. Irrigation blocks of the field border, V1 and V14 (Fig. 1), were irrigated independently from the experimental plots. The 12 experimental plots were always irrigated at the same time. The collective irrigation network provided a quasi-constant pressure of 420–440 kPa upstream from the hydrant. The pressure at each experimental plot was manually adjusted using the pressure regulator of its hydraulic valve. Pressure was set according to the plot treatment (200 kPa or 300 kPa). A manometer was installed at each hydraulic valve to measure and verify pressure at each irrigation event. Additionally, a pressure transducer (Dickson, PR150) and a manometer were installed in one of the sprinkler risers of each irrigation block (Fig. 1). Pressure transducers were connected to a data logger recording measurements every five minutes.