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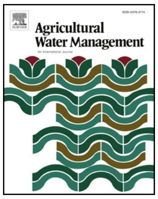

Low-pressure sprinkler irrigation in maize: Differences in water distribution above and below the crop canopy

N. Zapata[a,*], O. Robles[a], E. Playán[a], P. Paniagua[a], C. Romano[a], R. Salvador[b], F. Montoya[a]

[a] *Dept. Soil and Water, Estación Experimental Aula Dei (EEAD),CSIC. Av. Montañana 1005, Zaragoza 50059, Spain*
[b] *Dept. of Soils and Irrigation, CITA-DGA (Associated Unit to EEAD-CSIC), Avda. Montañana 930, 50059 Zaragoza, Spain*

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ABSTRACT

Reducing the working pressure at the sprinkler nozzles is one of the alternatives to reduce energy requirements in solid-set sprinkler irrigation systems. Previous studies reported ≈10% lower seasonal Christiansen uniformity coefficient (CUC) for low-pressure treatments than for standard treatments, but no differences in maize yield. This research analyses the effect of maize canopy water partitioning on irrigation performance indexes (CUC and wind drift and evaporation losses, WDEL). Three irrigation treatments were considered, based on the working pressure: 1) A standard brass impact sprinkler operating at a pressure of 300 kPa (CIS300); 2) A standard brass impact sprinkler operating at a pressure of 200 kPa (CIS200); and 3) A modified plastic impact sprinkler (with a deflecting plate attached to the drive arm) operating at a pressure of 200 kPa (DPIS200). Irrigation performance was measured using a catch-can network located above the maize canopy (CUC_{ac}, $WDEL_{ac}$) along the whole crop season and using stemflow and throughfall devices below the maize canopy (CUC_{bc}, $WDEL_{bc}$) in eight irrigation events. Maize growth, yield and its components were measured. Under low-wind and fully developed canopy conditions (a frequent situation for maize irrigation), CUC_{bc} resulted higher than CUC_{ac} for the low-pressure treatments, while the opposite was observed for the standard pressure treatment. Maize canopy partitioning reduces the differences in irrigation performance indexes between pressure treatments, explaining why there are no differences in grain yield between them. Caution should be used when measuring sprinkler irrigation performance above tall canopies, since the elevation of the catch-cans and the crop canopy partitioning affect performance estimations.

1. Introduction

Reducing the energy requirements of pressurized irrigation systems is one of the key objectives of farmers and Water Users Associations (WUA). The optimization of irrigation facilities (pumping stations and collective pressurized networks) has proven useful and cost effective (Rodríguez Díaz et al., 2009; Moreno et al., 2010; Fernandez García et al., 2013). Additional solutions are currently being analyzed at the WUAs. Among them, the reduction of energy requirements at the farm level by reducing the working pressure at the sprinkler nozzles (Robles et al., 2017). Reducing pressure at the nozzles will result in lower pumping requirements and therefore in a reduction of the energy bill. Further, when low-pressure is considered at the design phase of the collective network, the area of a WUA requiring pumping can be reduced.

Coefficient of Uniformity (CUC) (Christiansen, 1942) measurement above the crop canopy is the standard method used to analyze the variability in sprinkler irrigation water application for irrigation design and management purposes. Such measurements intend to characterize variability at the horizontal plane where sprinkler irrigation water is intercepted by the crop. For solid-set sprinkler systems, Keller and Bliesner (1990) classified irrigation uniformity as “low” when the CUC is below 84%. Irrigation design is a compromise between investment cost, system performance and net income. For high-value crops, the chances of investing in high-uniform irrigation systems are higher than for low value crops (Seginer, 1978).

Uniformity is a key performance indicator for irrigation design purposes. Environmental factors − such as wind speed and direction – change during the crop season, affecting uniformity in each irrigation event. Over-irrigation, a common practice of farmers in windy areas, reduces the effect of low irrigation uniformity on crop yield (Sánchez et al., 2010). Measuring uniformity on tall crop canopies (such as fully developed maize) constitutes an experimental challenge. Additionally, the distribution of water measured above a developed crop canopy may

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[*] Corresponding author.

E-mail addresses: v.zapata@csic.es (N. Zapata), coctaviorobles@eead.csic.es (O. Robles), enrique.playan@csic.es (E. Playán), pilucap@eead.csic.es (P. Paniagua), cromano@eead.csic.es (C. Romano), rsalvadore@aragon.es (R. Salvador), fmontoya@eead.csic.es (F. Montoya).

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differ from the distribution measured below the canopy or in the soil.

The effect of sprinkler irrigation CUC (measured above the crop canopy) on crop yield has been analyzed in a number of papers. Rezende et al. (2000) reported than the yield of grain bean changed between uniformity treatments, although the highest uniformity did not lead to the highest yield. Li and Rao (2003) analyzed irrigation events differing in uniformity and did not observe any effect on wheat yield. It is important to note that only half of the wheat water requirements were applied by irrigation, while the rest come from precipitation and soil water. Mateos et al. (1997) reported that for crops with curvilinear crop production function (such as cotton) low irrigation uniformity did not reduce yield. However, it induced variations in vegetative growth and in the time of boll opening, hindering mechanical harvest. Montazar and Sadeghi (2008) reported that sprinkler uniformity had a direct effect on alfalfa growth and hay yield. Brennan (2008) found important economic incentives for adopting more uniform sprinkler irrigation systems in lettuce production. Jiménez et al. (2010) reported a strong effect of sprinkler CUC on onion yield. The experimental research found in the literature on sprinkler irrigated maize (Stern and Bresler, 1983; Dechmi et al., 2003; Sánchez et al., 2010; Cavero et al., 2008; Urrego-Pereira et al., 2013) agreed that when irrigation was applied according to crop water requirements, grain yield and its variability were affected by irrigation uniformity.

Several research works have focused on soil water redistribution in sprinkler irrigated crops (van Wesenbeeck and Kachanoski, 1988; van Wesenbeeck et al., 1988; Li and Kawano, 1996; Paltineanu and Starr, 2000; Sánchez et al., 2010; Martello et al., 2015). In particular, Paltineanu and Starr (2000) and Sánchez et al. (2010), measured soil water dynamics at row and interrow maize positions using capacitance probes. They reported on the importance of canopy-induced water redistribution, which affected the spatial variability of soil water.

Irrigation precipitation reaching the soil surface after its passage through a developed crop canopy can have a different spatial variability than the precipitation collected above the canopy. In fact, the canopy architecture distributes the incident precipitation into three processes: stemflow, throughfall and interception storage (Bui and Box, 1992). Stemflow is the portion of water that is intercepted and collected by leaves and branches, and flows down the stem to the soil surrounding the plant. Throughfall is the water that falls on the soil surface directly or indirectly through the leaves. Interception storage is the amount of water that temporally remains on the plant after irrigation and that evaporates directly from the leaves and stems. Several authors (van Wesenbeeck and Kachanoski, 1988; van Wesenbeeck et al., 1988; Lamm and Manges, 2000; Li and Rao, 2000; Paltineanu and Starr, 2000; Canone et al., 2017; Sun et al., 2017) reported that crop canopy architecture plays a major role on the spatial distribution of rainfall and sprinkler irrigation water.

Measuring the sprinkler water distribution above the crop canopy is a well-defined task, regulated by standards (ISO Standard 7749/1, ISO Standard 7749/2, ASAE, 1994). However, the measurement of sprinkler water distribution below the crop canopy is not standardized, and remains within the research domain. Several authors have reported the interaction between sprinkler or rainfall water and crop canopies (van Wesenbeeck and Kachanoski, 1988; van Wesenbeeck et al., 1988; Lamm and Manges, 2000; Li and Rao, 2000; Paltineanu and Starr, 2000). These works presented different measurement methodologies, often focusing on stemflow determination. Van Wesenbeeck and Kachanoski (1988) and van Wesenbeeck et al. (1988) did not measure stemflow directly, but measured soil water content with Time Domain Reflectometry (TDR) at maize rows and interrows. These authors reported on the importance of water partitioning induced by the crop canopy when it comes to determining the spatial pattern of soil water. Li and Rao (2000) measured soil water distribution above and below a wheat canopy by using the same catch-can devices. The catch-cans installed below the wheat canopy did not separate stemflow and throughfall. These authors reported that wheat irrigation uniformity was higher below the canopy than above the canopy. Lamm and Manges (2000) directly measured stemflow and throughfall in 18 individual plants within a center-pivot irrigated maize field. The stemflow measurement device was a plastic pipe tube with a diameter of 0.05 m and a full length slot cut fitted around the plant stem. These authors found that stemflow decreased linearly with plant spacing and increased linearly with irrigation depth, whereas throughfall increased linearly with both plant spacing and irrigation depth. Hupet and Vanclooster (2005) estimated stemflow as the difference between measured incident rainfall, measured throughfall and estimated crop interception. These authors reported that rainfall reaching the ground below the maize canopy was very spatially variable, with coefficients of variation ranging between 78% and 189%. Martello et al. (2015) measured maize water partitioning (stemflow and throughfall) in twelve plants positioned in pairs across a plot irrigated by a travelling big-gun sprinkler. The devices used for stemflow measurement were similar to those used by Lamm and Manges (2000). Martello et al. (2015) concluded that the stemflow/throughfall ratio logarithmically decreased with the increase in precipitation, suggesting that under water stress conditions maize can effectively confine precipitation water close to the roots. Liu et al. (2015) used high water adsorption sheets wrapped around each maize stem to measure water stemflow. Twenty plants were selected for stemflow measurements in a total experimental area of 6 m^2. These authors concluded that stemflow increased with increasing precipitation and leaf area index, but decreased with increasing precipitation intensity.

In a clear precedent to this research, Robles et al. (2017) performed two years of experimental field work to measure differences in maize yield and irrigation performance (CUC and WDEL) resulting from three irrigation treatments. These included two nozzle pressures (standard of 300 kPa and low-pressure of 200 kPa) and, in the case of low-pressure, two sprinkler models (conventional brass impact sprinkler CIS and plastic impact sprinkler with deflecting plate in the drive arm DPIS). These authors did not find statistical differences in maize yield between the three irrigation treatments guided by crop water requirements. However, the CUC measured above maize canopy was 10% higher for the standard pressure treatment (93%) than for the low-pressure treatments (averaging 83%).

The objective of this research was to analyze why a considerable (10%) and consistent (two crop seasons) difference in CUC measured above the maize canopy between two pressure irrigation treatments (200 kPa and 300 kPa) had no effect on maize yield. The experimental design reported by (2017) was repeated for one additional year, implementing its three treatments CIS300, CIS200 and DPIS200. Treatments had the same application rate and irrigation scheduling. To accomplish this objective, differences in drop size distribution, radial distribution curves, soil water distribution and maize canopy water partitioning were experimentally measured for the three irrigation treatments. The effect of irrigation water distribution (above and below the maize canopy) on grain yield was statistically analyzed for all irrigation treatments.

2. Materials and methods

2.1. Technical characterization of the sprinklers

Three impact sprinklers were used in the field experiment: 1) A standard brass impact sprinkler (RC FARM 130, Riegos Costa, Lleida, Spain) equipped with double brass nozzle (4.4 mm and 2.4 mm) operating at a pressure of 300 kPa (CIS300); 2) A standard brass impact sprinkler (RC FARM 130, Riegos Costa, Lleida, Spain) equipped with double plastic nozzle (5.16 mm and 2.5 mm) operating at a pressure of 200 kPa (CIS200); and 3) A modified plastic impact sprinkler with a deflecting plate attached to the drive arm (5035, NaanDanJain, Naan, Israel) equipped with double plastic nozzle (5.16 mm and 2.5 mm) operating at a pressure of 200 kPa (DPIS200). Commercial sprinklers and nozzles were used in all cases. The average flow of the three