Agricultural Water Management 163 (2016) 275–284

Contents lists available at ScienceDirect

Agricultural Water Management

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

Analysis of water application with semi-portable big size sprinkler irrigation systems in semi-arid areas

Omid Sheikhesmaeili[a], Jesús Montero[b,*], Santiago Laserna[b]

[a] Faculty of Water Science Engineering, Shahid Chamran University of Ahvaz, Iran
[b] Centro Regional de Estudios del Agua, Universidad de Castilla-La Mancha, Campus Universitario s/n, 02071 Albacete, Spain

ARTICLE INFO

Article history:
Received 4 July 2015
Received in revised form
29 September 2015
Accepted 3 October 2015
Available online 26 October 2015

Keywords:
Big size sprinkler
Drift
Efficiency irrigation
Evaporation
Uniformity.

ABSTRACT

Sustainability of irrigated agriculture depends heavily on getting a high efficiency application for the irrigation. It is very important to understand the factors that affect to irrigation uniformity and discharge efficiency, especially using semi-portable big size sprinkler. There are not studies conducted with big size sprinklers which work on high flow rates and big layouts spacing. In this paper, the spray losses (L_s) and water distribution of sprinkler irrigation system with semi-portable big size sprinkler on semi-arid areas have been characterized. The factors affecting on discharge efficiency and irrigation uniformity were analysed (working pressure, irrigation layout and weather conditions). The field tests were conducted in outdoor conditions with a single sprinkler system. Six predictive equations were obtained to estimate drift and evaporation losses. The proposed equations use operating pressure, wind speed and vapour pressure deficit. The results show an increment of 3.26% for Ls for each increment of 1 m s^{-1} of wind speed. Spray losses rise up to 22.7% at 450 kPa operating pressure when wind speed and vapour pressure deficit increased up to 4.2 m s^{-1} and 6 kPa, respectively. A significantly effect of wind is appreciated on the spray losses and water distribution pattern under different conditions with regard for working pressure and sprinkler spacing. This behaviour is very similar to obtained with medium size sprinklers. Technical criteria can be used to optimize irrigation management according to the design factors and the climatic parameters.

1. Introduction

The sustainability of irrigated agriculture in windy and semi-arid areas depends on achieve a proper design and management of the irrigation systems. When the irrigation is applied by sprinkler, water is distributed over the irrigated area by spraying through the air.

Many works have been conducted to understand the main factors affecting on efficiency and uniformity on sprinkler irrigation systems, but mostly, with medium size sprinklers. However, there are not studies conducted with big size sprinklers which work on high flow rates (greater than 3 l s^{-1}) and big layouts spacing (higher than 24 m sprinkler spacing).

The semi-portable big size sprinkler is a very common irrigation system on the irrigated areas with semi-arid climatic conditions. Focused on Iran, 48.7% of the total pressurized irrigation surface and 85% of sprinkler irrigation surface are irrigated with this system (660,000 ha) (Report, 2014). Actually, this irrigation system is the main configuration in certain Iranian regions, such as Khuzestan province, where it represents the 73.1% (22,634 ha) of the total pressurized irrigation area and 99% of sprinkler irrigation area.

Meteorological variables, such as wind speed (W) and direction, are the main factors that influence the water distribution pattern in sprinkler irrigation, playing an important role in wind drift and evaporation losses (Dechmi et al., 2003; Keller and Bliesner, 1990; Tarjuelo et al., 2000). These references have led to two firm conclusions. First, applied water is lost partially by evaporation, particularly through drift out of the irrigated area; second, under windy conditions, the water distribution pattern of an isolated sprinkler is distorted and narrowed. The consequence of this problem could be either over- or under-irrigation of in portions of the field. To get a good operation of any sprinkler, it is very important that it works in the proper pressure range recommended by the manufacturer. The drop size is controlled by pressure and nozzle size.

The range of smaller drops cause that a significant portion of the discharged droplets do not reach the crop canopy. Spray losses (L_s), also known as evaporation and drift losses, can be estimated as the

* Corresponding author.
E-mail address: jesus.montero@uclm.es (J. Montero).

http://dx.doi.org/10.1016/j.agwat.2015.10.004
0378-3774/

Table 1
Empirical equations used for spray losses (L_s) estimation.

Reference	Empirical equation	
Yazar (1984)	$L_s = 0.389 \times e^{0.18 \times W} \times (Es–Ea)^{0.7}$	Moving lateral
Trimmer (1987)	$L_s = [1.98 \times D^{-0.72} + 0.22 \times (Es–Ea)^{0.63} + 0.00036 \times P^{1.16} + 0.14 \times W^{0.7}]^{4.2}$	
Keller and Bliesner (1990)	$L_s = [1 - (0.976 + 0.005 \times ET_0 - 0.00017 \times ET_0{}^2 + 0.0012 \times W-$ $IG \times (0.00043 \times ET_0 + 0.00018 \times W + 0.000016 \times ET_0 \times W))] \times 100$ where $IG = 0.032 \times P^{1.3}/D$ (if $IG < 7 \Rightarrow IG = 7$; if $IG > 17 \Rightarrow IG = 17$)	
Seginer et al. (1991a)	$L_s = 3.22 \times e^{0.075 \times W} \times (T_a - T_w)^{0.69}$	Single sprinkler test
Montero (1999)	$L_s = 7.63 \times (Es–Ea)^{0.5} + 1.62 \times W$	Block irrigation test
Tarjuelo et al. (2000)	$L_s = 18.1 \times (Es–Ea)^{0.5} + 1.41 \times W - 3.43$	Single sprinkler test
Tarjuelo et al. (2000)	$L_s = 0.007 \times P + 7.38 \times (Es–Ea)^{0.5} + 0.844 \times W$	On-farm test
Playán et al. (2005)	$L_s = 20.3 + 0.214 \times W^2 - 0.00229 \times H^2$	Solid-set
Playán et al. (2005)	$L_s = -2.1 + 1.91 \times W + 0.231 \times T$	Moving lateral

where ETo (evapotranspiration, mm day^{-1}), D (nozzle diameter, mm), P (operating pressure, kP_a), W (wind speed, m s^{-1}), Es–Ea (vapour pressure deficit, kP_a), T (air temperature, °C), T_a (dry bulb temperature, °C), T_w (wet bulb temperature, °C), H (relative humidity, %).

difference between the volume of water discharged by sprinklers and the volume of water collected by catch cans.

Furthermore, irrigation uniformity, or uniformity of water distribution, is an important performance characteristic and the most relevant parameter of the sprinkler irrigation systems. Indeed, this design factor affects on important aspects such as water use efficiency, leaching of fertilizers and crop yield (Seginer et al., 1991b). So, field evaluation is an excellent procedure to research the factors affecting on the real irrigation uniformity under different combinations of climate and design factors on sprinkler irrigation systems.

The spray losses effect has been reported on many researches (e.g. laboratory, field tests and analytical studies). The most important work that starts to study this effect was done by Frost and Schwalen (1955, 1960),) in Arizona. In their works, Frost and Schwalen summarized the results of 700 field tests conducted under different climate conditions. These studies allowed them to develop a nomograph to estimate the evaporation losses rate during sprinkler irrigation as function of the sprinkler characteristics, operating pressure, and the climate factors.

The value of spray losses could become very relevant under certain climate conditions. While Frost and Schwalen (1955) found spray losses that reached 45% under full sun conditions with high temperatures and very low humidity, characteristic of Arizona zone, other authors has got maximum values of 30% (Yazar, 1984; Kohl et al., 1987; Kincaid, 1996; Kincaid et al., 1996; Montero, 1999; Tarjuelo et al., 2000). Spurgeon et al. (1983) reported that hot, dry, and windy conditions could cause spray losses at about 30% of the water applied on sprinkler irrigation systems. Other study, based on volume measures collected by rain-gauges, conducted in Kansas by Steiner et al. (1983), show that the average spray losses found under conditions of high evaporation were about 15%.

Edling (1985), Kohl et al. (1987), and Kincaid and Longley (1989) concluded from their experiences that the evaporation of the droplets in sprinkler irrigation was almost negligible for droplet diameters between 1.5–2 mm.

It is well known that the evaporation losses in the air mainly depend on air relative humidity, air and water temperature, drop size and wind speed (Yazar, 1984) and wind drift losses depend on wind speed, drop size and the distance to be covered before landing.

Some studies reported losses of 5–10% under moderate evaporative demand (Keller and Bliesner, 1990). In the average meteorological conditions of Zaragoza (Spain), the seasonal average spray losses measured for the solid-set system were 15.4 and 8.5% during day and night irrigations, respectively (Playán et al., 2005).

Several authors have identified the influence of irrigation system and meteorological variables on spray losses. The predictive equations are presented in Table 1. These equations were obtained for different sprinkler systems and operating parameters. The independent variables shown are: evapotranspiration (ETo, mm day^{-1}), nozzle diameter (D, mm), operating pressure (P, kP_a), wind speed (W, m s^{-1}), vapour pressure deficit (Es–Ea, kP_a), air temperature (T, °C), dry bulb temperature (T_a, °C), wet bulb temperature (T_w, °C), relative humidity (H, %).

A non-uniform distribution not only could leave some parts of the crop on a deficitary water situation, also could over-irrigate other parts causing ponding water, plant damage, soil salinisation, and leaching of chemical substances to ground water (Solomon, 1983). James and Blair (1984) also stated that non-uniform irrigations might waste energy and chemicals. Increasing water application uniformity can improve irrigation efficiency by preventing deep percolation and surface runoff due to over irrigation.

Several authors have argued that, although wind speed is the most important climatic parameter affecting sprinkler irrigation performance (Tarjuelo et al., 1999a,b; Sánchez et al., 2010), its effect is affected by system design parameters such as operating pressure, spacing between sprinklers (Se), nozzle size and sprinkler type (Keller and Bliesner, 1990; Tarjuelo et al., 1992). One of the decisive factors in raising water distribution uniformity is the extent of overlapping of the sprinklers. Sprinkle systems require proper overlapping of spray patterns between lines of sprinklers (Sl) to get good distribution uniformity.

Canessa and Hermanson (1994) described that a correct overlap is the result of a correct combination of sprinkler spacing, pressure and nozzle size. They believe experienced irrigation engineers/specialists should combine manufacturer's recommendations with experience with local conditions to design efficient sprinkle systems.

Burt et al. (1997) indicated that the most influential factors of heterogeneity in water distribution are working pressure variation at the hydrant, sprinkler design, sprinkler layout, as well as climate conditions such as wind speed. In fact, W is the most complicated and uncontrollable parameter so that, wind generates the most important effect on wind drifts, evaporation losses and water distribution uniformity (Sheikhesmaeili, 2003).

Keller and Bliesner (1990) identified that most sprinkle irrigation systems require a minimum value of water distribution uniformity such as Christiansen's coefficient of uniformity (CU) $\geq$ 80%. Low values of CU are usually indicators of a faulty combination of the number and size of nozzles, working pressure and sprinkler spacing (Tarjuelo et al., 1999a).

Phocaides (2007) from FAO consultants recommended that in order to obtain good CU by overlapping, the Se should not exceed 65% of the sprinkler diameter coverage under low to moderate wind conditions in the square and rectangular patterns. He also stated that in strong wind conditions, the sprinkler spacing should be 50% of the diameter coverage with the lateral direction perpendicular to the wind direction.