Agricultural Water Management 178 (2016) 304–313

Contents lists available at ScienceDirect

Agricultural Water Management

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

Relevance of sprinkler irrigation time of the day on alfalfa forage production

Jose Cavero[a,*], Jose M. Faci[b], Antonio Martínez-Cob[a,1]

[a] Departamento de Suelo y Agua, Estación Experimental de Aula Dei (CSIC), Avda. Montañana 1005, 50059 Zaragoza, Spain
[b] Unidad de Suelos y Riegos (Unidad Asociada EEAD-CSIC), Centro de Investigación y Tecnología Agroalimentaria (CITA-DGA), Avda. Montañana 930, 50059 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form 7 October 2016
Accepted 8 October 2016

Keywords:
Water losses
Irrigation uniformity
Semiarid
Microclimatic changes
Water use efficiency

ABSTRACT

Nighttime sprinkler irrigation usually results in lower water losses and higher irrigation uniformity compared with daytime sprinkler irrigation due to lower wind speed. However, daytime sprinkler irrigation modifies the microclimatic conditions within the crop canopy which could result in improved crop growth. We studied during three years the effect of daytime and nighttime irrigation on the yield, N content, N uptake, water use efficiency, microclimate and canopy temperature of an alfalfa (*Medicago sativa* L.) crop irrigated with a solid-set sprinkler system in a semiarid Mediterranean climate. Two irrigation treatments were tested: daytime irrigation and nighttime irrigation. The same irrigation amount was applied in both treatments (552 to 757 mm $year^{-1}$). The water losses of daytime irrigation (10%) tripled the water losses of nighttime irrigation (3%). In one year, daytime irrigation decreased the mean Christiansen coefficient of uniformity (CU) by 4% and the seasonal CU by 2%. Microclimatic and canopy temperature changes during sprinkler irrigation were higher for daytime irrigation as compared to nighttime irrigation. Daytime irrigation slightly reduced the soil water content of the surface layer (0–0.3 m). The actual seasonal crop evapotranspiration was slightly higher (+3.7%) in the daytime irrigation treatment compared to the nighttime irrigation treatment only in one of the years. The annual alfalfa forage yield (16 to 22 Mg ha^{-1}), N content (3.16 to 3.38%), N uptake (514 to 740 kg ha^{-1}) and water use efficiency (17.7 to 25.9 kg ha^{-1} mm^{-1}) were not affected by the irrigation time of the day. Although nighttime sprinkler irrigation results in some water saving, daytime sprinkler irrigation of alfalfa can be performed if necessary.

1. Introduction

In order to reduce investments costs, sprinkler irrigation systems are usually designed to operate during daytime and nighttime hours. Irrigation efficiency depends on both water losses and uniformity of water distribution. For sprinkler irrigation systems these two factors are affected by the environmental conditions during the irrigation event, which are very different during daytime and nighttime irrigation events (Cavero et al., 2008; Playán et al., 2005).

In sprinkler irrigation wind is the main environmental factor affecting water losses (Playán et al., 2005) and irrigation uniformity (Dechmi et al., 2003; Kincaid et al., 1996; Seginer et al., 1991; Tarjuelo et al., 1999a). It is well known that wind speed is higher during daytime than during nighttime (Doorenbos and Pruitt, 1977). Consequently, higher water losses (Cavero et al., 2008; Playán et al., 2005) and lower irrigation uniformity (Cavero et al., 2008) are found during daytime irrigation compared to nighttime irrigation.

The irrigation water evaporated during the sprinkler irrigation changes the microclimate of the irrigated area during the irrigation event and some time (2–3 h) after the irrigation event (Cavero et al., 2009; Playán et al., 2005; Robinson, 1970; Tolk et al., 1995; Urrego-Pereira et al., 2013a,b). These changes (decrease of VPD and temperature of the air) are more relevant during daytime irrigation and cause some physiological changes: a decrease of crop transpiration (Cavero et al., 2009; Martínez-Cob et al., 2008; McNaughton, 1981) and crop canopy temperature (Cavero et al.,

Abbreviations: CIR, crop irrigation requirement; CWSI, crop water stress index; CU, Christiansen coefficient of uniformity; ETo, reference evapotranspiration; ETc, crop evapotranspiration; GMT, greenwich mean time; WDEL, wind drift and evaporation losses.

* Corresponding author.
E-mail address: jcavero@eead.csic.es (J. Cavero).

[1] Dr. A. Martínez-Cob passed away during this research.

http://dx.doi.org/10.1016/j.agwat.2016.10.008
0378-3774/

Table 1
Soil characteristics of the experimental field.

Depth (m)	pH	C (%)	N (%)	$CaCO_3$ (%)	Sand (%)	Silt (%)	Clay (%)	FC[a] ($m^3 m^{-3}$)	WP[b] ($m^3 m^{-3}$)
0.0–0.3	8.2	1.12	0.14	35.0	19.6	50.2	30.2	0.351	0.189
0.3–0.6	8.3	0.77	0.11	35.0	14.9	47.5	37.6	0.381	0.227
0.6–0.9	8.3	0.54	0.10	32.0	7.7	47.5	44.8	0.364	0.207
0.9–1.2	8.2	0.43	0.08	31.0	11.9	47.1	41.0	0.359	0.187
1.2–1.6	8.3	0.43	0.07	33.0	20.3	49.2	30.5	0.344	0.187

[a] FC, field capacity (−0.033 MPa).
[b] WP, wilting point (−1.5 MPa).

2009; Saadia et al., 1996; Steiner et al., 1983; Tolk et al., 1995), and an increase of leaf water potential (Cavero et al., 2009; Howell et al., 1971). Moreover, during the daytime sprinkler irrigation events the net photosynthesis of crops can be affected (Urrego-Pereira et al., 2013c).

Previous work with maize has shown that daytime sprinkler irrigation with a solid-set system in a Mediterranean climate decreased the grain yield by 5 to 13% compared to nighttime sprinkler irrigation (Cavero et al., 2008; Urrego-Pereira et al., 2013b). This yield decrease was mainly caused by the lower irrigation uniformity of daytime irrigation (Urrego-Pereira et al., 2013b) and by the decrease of maize net photosynthesis during the daytime irrigation events (Urrego-Pereira et al., 2013c). The reduction of net photosynthesis of maize during sprinkler irrigation was related both with the high wettability of maize leaves, which reduced the exchange of CO_2, and with the reduction of canopy and air temperature, which resulted in temperatures below the optimum for photosynthesis of maize (Urrego-Pereira et al., 2013c). Thus, daytime sprinkler irrigation with solid-set systems under similar climatic conditions to that study site should be avoided for maize due to decreased yield.

Alfalfa for forage production is a main irrigated field crop in Mediterranean areas. It is rather different to maize in terms of sensitivity to water stress, crop height, leaf water wettability and optimal temperature for growth. Alfalfa for forage is considered to be less sensitive to water stress than maize due to its deep rooting system and because it does not have a phenological stage very sensitive to water stress as maize (Sheaffer et al., 1988). Sanchez et al. (2010a,b) reported that irrigation uniformity of sprinkler irrigation was higher for alfalfa than for maize due to the lower plant height of alfalfa. They also found higher soil water recharge with sprinkler irrigation in alfalfa compared to maize. This could be related to the higher hydrophobicity of alfalfa leaves (Holder, 2012; Urrego-Pereira et al., 2013c). Urrego-Pereira et al. (2013c) found that daytime sprinkler irrigation with a solid-set system at the same Mediterranean site did not affect net photosynthesis of alfalfa. The low wettability of alfalfa leaves prevented sprinkler irrigation water from interfering with the CO_2 uptake and therefore did not decrease net photosynthesis. Moreover, sprinkler irrigation did not decrease air and canopy temperature below the optimum range for photosynthesis of alfalfa.

There is no field data about how the sprinkler irrigation time of the day affects the alfalfa forage yield and quality. The main objective of this research was to study the effect of daytime versus nighttime irrigation on the forage yield and quality and water use efficiency of an alfalfa crop using a solid-set sprinkler irrigation system. We also studied the microclimatic and alfalfa canopy temperature changes due to daytime and nighttime sprinkler irrigation.

2. Materials and methods

2.1. Experimental site

The field experiment was carried out during three years (2012–2014) in a 2.34 ha field irrigated with solid-set sprinkler system, located at Zaragoza, Spain (41°43′N, 0°48′W, 225 m altitude). The climate is Mediterranean semiarid with long-term annual averages of 14.1 °C for air temperature, 298 mm for precipitation, and 1243 mm for grass reference crop evapotranspiration (ET_o). The soil is clay loam and classified as Typic Xerofluvent (Table 1).

2.2. Experimental layout

The experimental field was divided in twelve irrigation sectors which were irrigated independently by four sprinklers each (Fig. 1). The borders of the field were irrigated independently of the main twelve irrigation sectors. The sprinkler spacing was a square of 18 m × 18 m. The impact sprinkler and nozzles were manufactured in brass (RC-130, Riegos Costa, Lérida, Spain). The sprinkler has a vertical throw angle of 25°, the nozzle diameters were 4.4 mm (main) and 2.4 mm (auxiliary), and the nozzle height was 2.50 m above the soil surface. The nozzle operating pressure was kept constant at 0.3 MPa with a hydraulic pressure control valve. Sprinkler application rate was 5 mm h^{-1} and the wetted radius was 15 m. The irrigation volume was measured with an electromagnetic flow meter (Promag 50, Endress + Hauser, Reinach, Switzerland) with ±0.5% measurement error.

Alfalfa cv. Aragón was planted on 20 Sept. 2011 at a planting rate of 33 kg ha^{-1}. The previous crop was wheat (*Triticum aestivum* L.). Several sprinkler irrigation events of 5 to 10 mm were applied on Sept.–Oct. 2011 after planting to promote the emergence of alfalfa. A total of 14 irrigation events and 105 mm were applied. Fertilization consisted of 200 kg ha^{-1} P_2O_5, and 200 kg ha^{-1} K_2O applied on March every year. Pests control was carried out following the

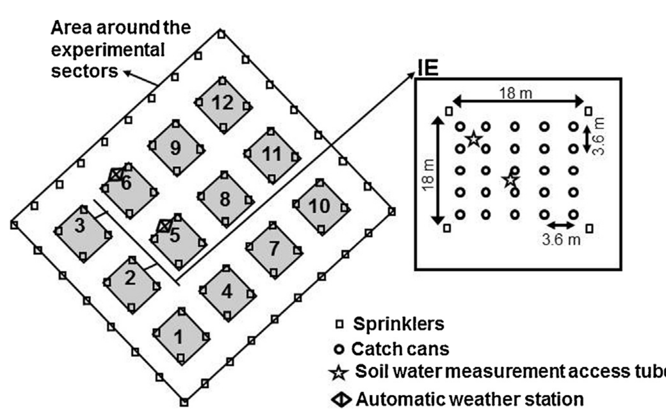

Fig. 1. General experimental layout, with 12 irrigation sectors (1–12) irrigated independently by four sprinklers each. The irrigation sectors with even numbers were irrigated during nighttime in 2012, during daytime in 2013, and during nighttime in 2014. The irrigation sectors with odd numbers were irrigated during daytime in 2012, during nighttime in 2013, and during daytime in 2014. The shaded areas are the experimental plots where irrigation events were characterized and alfalfa yield and soil water content were measured. IE, experimental plots where irrigation was characterized. The location of the two access tubes for soil water measurement installed in all the plots is shown in one of them. Two automatic weather stations were located in irrigation sectors 5 and 6 in the sprinklers line.