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Alfalfa forage production under solid-set sprinkler irrigation in a semiarid climate

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ABSTRACT

Under sprinkler irrigation, local environmental conditions have an important influence on irrigation water losses, plant physiological changes and uniformity of irrigation, leading to different crop water production functions. We studied during three years the effect of irrigation depth on the plant growth, forage yield and N content, evapotranspiration and water use efficiency of an alfalfa (*Medicago sativa* L.) crop irrigated with a commercial solid-set sprinkler system in a semiarid Mediterranean climate. Six irrigation treatments were tested: 55%, 75%, 85%, 100%, 115% and 130% of the theoretical crop irrigation requirement (CIR_t), calculated without considering water losses or non-uniformity. The seasonal irrigation amount applied at the 100% of CIR_t ranged from 598 to 786 mm. The intercepted photosynthetically active radiation increased as the irrigation applied increased until the 115% of CIR_t. Plant height at harvest linearly increased as the irrigation applied increased until the 130% of CIR_t in two years. The maximum alfalfa forage yield was lower the first year (17 Mg ha^{-1}) than in the two following years (20–22 Mg ha^{-1}). The alfalfa forage yield increased linearly as the irrigation applied increased the first year of the experiment, but in the following two years this increase occurred until the irrigation applied was 115% of CIR_t. The N content of alfalfa linearly decreased as the irrigation applied increased. The relationship between alfalfa forage yield and evapotranspiration was linear until the 115% of CIR_t all years. The WUE of alfalfa was lower the first year of the experiment and was not affected by the irrigation applied in the rainiest year, but linearly increased as the irrigation applied increased up to 115% of CIR_t in the other two years. Considering yield and quality (N content) of alfalfa forage and WUE, sprinkler irrigation with a solid-set system must be increased by 15% over the CIR_t to optimize alfalfa forage production under the climatic conditions of the Ebro valley.

1. Introduction

Alfalfa for forage production is a main irrigated field crop in arid and semiarid areas (Abdul-Jabbar et al., 1985). In the Ebro valley (Spain), the highly calcareous soils and the long free frost period allow to obtain high yields (>16 Mg ha^{-1}), making alfalfa the highest user of irrigation water (Salvador et al., 2011). The alfalfa acreage in the Ebro valley is around 150,000 ha (MAGRAMA, 2016).

In the last decades modernization of irrigation districts in the Ebro valley river have resulted in the replacement of around half of the acreage from flood irrigation to sprinkler irrigation due to increased yields, decreased requirement and cost of labour and increased economic benefit (Playán and Mateos, 2006; Lecina et al., 2010). High energy costs and regionally occurring shortages of water necessitate the development of adequate crop water production functions. Alfalfa and maize are the main irrigated field crops in the Ebro valley. The response of maize to irrigation has been studied in the semiarid climate of this region (Cosculluela and Faci, 1992; Farre and Faci, 2006), but similar studies are not available for alfalfa, particularly under solid-set sprinkler irrigation, the technology of choice for irrigation modernization projects in the valley. Knowledge of the effect of limiting water on yield allows appropriate economic decisions to be made when resources are limiting.

Sprinkler irrigation allows more flexible irrigation scheduling compared to traditional flood irrigation. However, some water is lost through evaporation at each sprinkler irrigation event. These losses are higher at daytime irrigation events than at nighttime

Abbreviations: CIR_t, theoretical crop irrigation requirement; ETo, reference evapotranspiration; ETc, crop evapotranspiration; GMT, greenwich mean time; PAR, photosynthetically active radiation; WUE, water use efficiency.

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irrigation events (Cavero et al., 2008; Playán et al., 2005; Urrego-Pereira et al., 2013a,b). In the case of alfalfa sprinkler irrigation evaporation losses ranged from 4% at nighttime to 10% at daytime (Cavero et al., 2016; Stambouli et al., 2013). The irrigation water evaporated during the sprinkler irrigation modifies the microclimate of the irrigated area (decrease of VPD and temperature of the air) during the irrigation event and 2–3 h after the irrigation event (Cavero et al., 2009; Cavero et al., 2016; Tolk et al., 1995; Urrego-Pereira et al., 2013a,b). These changes are more relevant during daytime irrigation, causing some physiological changes in the plants. In the case of alfalfa a decrease of crop transpiration (Stambouli et al., 2013) and crop canopy temperature (Cavero et al., 2016; Stambouli et al., 2013), and a slight increase of net photosynthesis have been found (Urrego-Pereira et al., 2013c). Another relevant difference between flood irrigation and sprinkler irrigation is that the distribution uniformity of water in sprinkler irrigation decreases as the wind speed increases (Dechmi et al., 2003; Seginer et al., 1991; Tarjuelo et al., 1999).

Thus, the local environmental conditions can have an important influence on sprinkler irrigation water losses, plant physiological changes and uniformity of irrigation, leading to different crop water production functions. In this sense, Cavero et al. (2016) found that sprinkler irrigation time of the day (daytime versus nighttime) did not affect alfalfa forage yield in the Ebro valley, although at daytime water losses were higher and irrigation uniformity was slightly lower. Montazar and Sadeghi (2008) found that alfalfa forage yield depended on both the applied water and the sprinkler water uniformity but that was more sensitive to the variations in applied water than to the variations in sprinkler water uniformity.

A number of research works have focused on the relationship between irrigation depth and alfalfa yield (Carter and Sheaffer, 1983; Grimes et al., 1992; Retta and Hanks, 1980; Sammis, 1981; Shani and Dudley, 2001; Smeal et al., 1992; Peel et al., 2004; Undersander, 1987). Most of them have been performed with the single sprinkler line source system, while others have used surface irrigation (Carter and Sheaffer, 1983). However, information is not available on the application of varying irrigation depths with a commercial solid-set system in large plots (18 × 18 m), in which microclimatic and crop physiological changes, and irrigation uniformity can affect alfalfa forage production. Thus, the objective of this research was to study the effect of irrigation depth on the alfalfa forage yield and quality and on the water use efficiency using a commercial solid-set sprinkler irrigation system in the semiarid conditions of the Ebro valley.

2. Materials and methods

2.1. Experimental site

The field experiment was carried out during three years (2012–2014) in a 2 ha field irrigated with a 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).

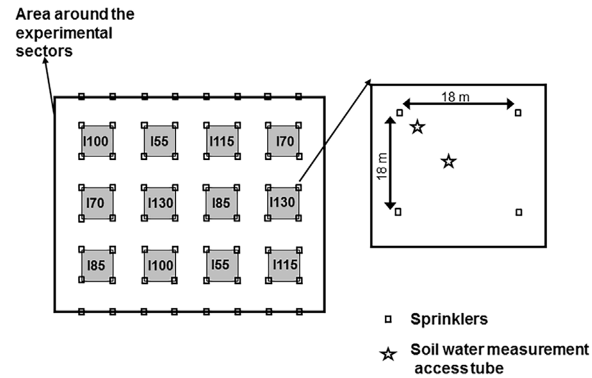

Fig. 1. Experimental layout, with 12 irrigation sectors irrigated independently by four sprinklers each. The irrigation treatments in each irrigation sector are shown. The shaded areas are the experimental plots where alfalfa yield and soil water content were measured. The location of the two access tubes for soil water measurement installed in all the plots is shown in one of them.

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 x 18 m, as generally used in commercial fields in the area. The impact sprinkler (RC-130, Riegos Costa, Lérida, Spain) 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 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 a flow meter (Woltman WP).

Alfalfa cv. Aragón was planted on 20 Sept. 2011 at 33 kg ha^{-1}. The previous crop was wheat (*Triticum aestivum* L.). Sprinkler irrigation was applied the following day after planting and during Sept.-Oct. at 5–10 mm rates 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 best management practices of the area. To control weeds, imazamox at 0.5 kg a.i. ha^{-1} was applied on February 2013 and metribuzin at 0.52 kg a.i. ha^{-1} was applied on January 2014.

2.3. Irrigation treatments

The meteorological data recorded at a weather station over grass located 1 km southwest from the experimental field were used to compute the reference ET_o using the FAO Penman-Monteith method (Allen et al., 1998). Crop coefficients (K_c) were calculated as a function of thermal time considering the duration of the four phases proposed by Allen et al. (1998) and the Kc initial (0.4),

Table 1
Soil characteristics of the experimental field.

Depth (m)	pH	C (%)	N (%)	$CaCO_3$ (%)	Sand (%)	Silt (%)	Clay (%)	FC[a] (m m^{-1})	WP[b] (m m^{-1})
0.0–0.3	8.2	1.04	0.12	36.0	21.3	51.1	27.6	0.338	0.174
0.3–0.6	8.3	0.71	0.10	36.0	19.4	49.7	30.9	0.350	0.190
0.6–0.9	8.2	0.54	0.08	35.0	14.5	54.6	30.9	0.356	0.189
0.9–1.2	8.0	0.48	0.07	34.0	14.0	53.3	32.7	0.362	0.199
1.2–1.6	8.1	0.45	0.07	36.0	17.2	52.5	30.3	0.348	0.185

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