



Yield response of sunflower to irrigation and fertilization under semi-arid conditions



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ABSTRACT

Until recently, irrigation of traditionally rainfed crops such as sunflower in the semi-arid regions of southern Spain was limited to supplementary irrigation given the very limited water supply. This was primarily due to a poor understanding of the irrigation management of this crop. However, thanks to irrigation and N-fertilization research carried out between 2012 and 2014 in southern Spain, functions of sunflower yield response to irrigation and N-fertilization have been determined, thus identifying the optimal irrigation and fertilization scheduling to optimize both yield and water productivity. The study found that irrigation volumes of around 60–80% of the optimum and N-fertilization doses of around 100 and 150 units of N, depending on if stressed or non-stressed conditions were found, provided the maximum yield.

Significant interactions between irrigation and N-fertilization supply were demonstrated, as N crop status also depended on the water stress conditions, with N deficiencies detected when water supply was limited, demonstrating the utility of using the nutritional crop status for combined fertilization and irrigation recommendations. Likewise, sowing date affected the yield response of sunflower to water supply, with early sowing dates resulting in higher yields (an increase of around 11.4% compared to traditional sowing dates) due to the mitigation of heat and water stress during the flowering period.

Irrigation practices for sunflower under semi-arid conditions have demonstrated significant benefits, especially with limited rainfall supply. However these practices must be combined with N-fertilization practices in order to maximize input efficiency. Optimized irrigation and fertilization practices for sunflower must therefore be encouraged as a way to achieve a similar performance as traditional irrigated crops.

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1. Introduction

Historically, rainfed agriculture has formed the economic foundations for vast areas of Southern Europe. This type of agriculture is characterized by low inputs and low yields, and is severely affected by droughts as the sole source of water is the generally limited rainfall (Valverde et al., 2015). Similarly, fertilization is very limited since farmers in these areas normally apply little or no fertilizer. These restrictions in input supply lead to a huge year-over-year variability in yield, mostly linked to annual rainfall (García López et al., 2014). Traditionally, this rainfed agriculture stems not only from the unavailability of water for irrigation but also the farmers' supposition that to apply water resources to wheat, olive or sun-

flower crops is not economically viable as water applied to other crops could potentially generate a higher profit (García Vila et al., 2008; Lorite et al., 2012, 2013).

In recent years, the profitability of irrigated agriculture has fallen significantly, with irrigation water productivity values very close to the profitability thresholds, especially for traditionally irrigated crops such as maize (Lorite et al., 2012, 2013). Consequently, in some irrigation districts the amount of available water is higher than the irrigation demand (Lorite et al., 2012), due to a clear lack of alternatives for obtaining profitable crop patterns. Faced with this new situation, the consideration of new irrigated crops such as biomass crops or almond/walnut orchards, or even watering traditionally rainfed crops, are some of the alternatives that are currently being contemplated in many irrigated areas of southern Europe.

Sunflower (*Helianthus annuus* L.) is an oilseed plant grown in Spain since the 1960s and is characterized by its adaptability to a wide range of environments. The sunflower is nowadays the most important oilseed crop in Spain and in recent years there has been

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a significant increase in the area under cultivation. In the European Union (EU), 4.32 million ha of sunflowers were planted in 2012 with a production of 7.23 million Mg. In Spain, 753,000 ha were cultivated in 2012 (200,000 ha in Andalusia) and sunflower has subsequently become an important component of the crop rotation systems in the rainfed areas located in the south. Only around 10% of the total surface area planted with sunflower was cultivated using irrigation, with an average yield of 2200 kg per ha, while the remaining 90% is cultivated using rainfed systems with average yields of around 700 kg per ha (MAGRAMA, 2012).

Compared to other crops, sunflower is well-adapted to sub-arid environments (Stone et al., 2002; Moroke, 2002) due to its ability to extract water from deeper soil layers with the pronounced development of the root system under water stress (Connor et al., 1985; Fereres et al., 1993). However, sunflower is particularly sensitive to water stress (Osman and Talha, 1975; Unger 1983; Göksoy et al., 2004) and heat stress from early flowering to the achene filling stage (Ploschuk and Hall, 1995; García López et al., 2014). Previous studies have therefore shown that substantial yield increases are achieved through irrigation (Unger, 1982; Connor et al., 1985; Cox and Jolliff, 1986; Sadras et al., 1991; Stone et al., 1996; Karam et al., 2007). Likewise, nitrogen fertilization is a critical component of sunflower yield production (Zubriski and Zimmerman, 1974; Yousaf et al., 1986; Sarmah et al., 1994). Thus, a rational mineral nutrition is needed for the crop to reach optimum growth and high yields (Andrade et al., 2000) since N plays an important role, either directly or indirectly, in processes such as growth and leaf senescence and in determining yield components (Merrien, 1992). Previous studies have shown that N deficiency in sunflowers reduces vegetative and generative growth, induces premature senescence (Narwal and Malik, 1985; Tomar et al., 1999) and leads to a fall in yield due to reductions in crop leaf area and therefore, a lower uptake of solar radiation (Massignam et al., 2009). On the other hand, excess N-fertilization may shift the balance between vegetative and reproductive growth toward excessive vegetative development, thus delaying crop maturity (Hocking et al., 1987), increasing the susceptibility of the plant to a number of diseases (Seassau et al., 2010) as well as producing a reduction in the accumulation of seed oil (Steer et al., 1986; Ozer et al., 2004).

In order to address the level of crop fertilization, the use of Critical Nitrogen Dilution Curves (CNDC) has been proposed. These curves reflect the critical concentration of N in the above ground biomass and are unique for a species or group of species (Andrade and Ferreira, 1996). There are specific CNDC for many crops such as wheat (Justes et al., 1994; Ziadi et al., 2010), maize (Plénet and Lemaire, 1999) and cotton (Xiaoping et al., 2007). However, until recently, no specific CNDC for sunflowers existed and those that did were based on analogies with other C3 species (Merrien, 1992; Reau et al., 2001; González-Dugo et al., 2010). Consequently, the equation developed by Merrien (Merrien, 1992) has been used as a reference to determine the nutritional status of sunflower (Sosa et al., 1999; De Caram et al., 2007). Finally, Debaeke et al. (2012) recently proposed a sunflower-specific CNDC as an alternative to the Merrien's equation based on a comprehensive dataset that includes field experiments in Argentina, Australia, France, Italy and Spain.

Although irrigation and fertilization are key factors for sunflower production, studies combining both factors are not very common (Muriel et al., 1980; Alvarez de Toro, 1987), with the majority focusing on the assessment of irrigation (Rinaldi, 2001; Göksoy et al., 2004; Sezen et al., 2011) or fertilization impacts on yield (Reau et al., 2001; Ozer et al., 2004; Massignam et al., 2009), but with both factors examined separately. To fill this gap, a three-year experiment involving different irrigation schedules and fertilization strategies was carried out. These experiments revealed the effect of different irrigation volumes and fertilization treat-

Table 1
Crop phenology for each treatment.

	2012	2013	2014-D1	2014-D2
Sowing date	30/03/2012	11/04/2013	28/01/2014	14/03/2014
Emergence	13/04/2012	25/04/2013	14/02/2014	25/03/2014
Flowering	18/06/2012	26/06/2013	17/05/2014	31/05/2014
End grain filling	16/07/2012	25/07/2013	13/06/2014	03/07/2014
Harvest	16/08/2012	15/09/2013	16/07/2014	04/08/2014

Table 2
Weather conditions, water and heat-stress impact (f.Rain and f.Temp) calculated according to the methodology used by García López et al. (2014) and initial N conditions for each treatment. FL and EGF indicate flowering and end of grain filling periods respectively.

	2012	2013	2014-D1	2014-D2
Rainfall (mm)	314.2	915.4	510	510
f.Rain	0.56	0.96	0.71	0.71
ET ₀ (mm)	1485.4	1314.8	1406.1	1406.1
ET ₀ (FL-EGF) (mm)	220.7	220.3	165.6	187.6
Max. Temperature on FL (°C)	34.5	34.4	24.8	30.3
f.Temp	0.81	0.82	1.04	0.94
Available N at beginning (kg ha ⁻¹)	25.7	16.9	5.2	5.6

ments and their possible interactions on sunflower seed yield, oil content, and the other yield components.

2. Material and methods

2.1. Field experiments

The experiments were carried out during the 2012, 2013 and 2014 growing seasons, between the months of March and September, at the "IFAPA - Alameda del Obispo" experimental farm located near the city of Cordoba, southern Spain (latitude 37°51'42"N, longitude 4°48'0"W). For both 2012 and 2013, a single trial was carried out, while in 2014 two identical trials were carried out, the only difference being their sowing dates. Phenology of the crop for each trial and year is detailed in Table 1.

The climate in Cordoba is considered to be semi-arid, with the rainy period concentrated between autumn and spring, and with a very hot, dry summer season. Weather conditions during the time period under analysis are summarized in Table 2, highlighting the high temporal heterogeneity in annual rainfall (from 314 to 915 mm). Temperature pattern during flowering was influenced by sowing date.

The soil is a deep sandy loam, with a Typic Xerofluvent classification. Soil analyses were carried out each year, just before planting, to determine the amount of available nitrogen in the soil. Depending on the year and the experimental site, available nitrogen ranged from 5.2 kg ha⁻¹ (2014-D1) to 25.69 kg ha⁻¹ (2012), with intermediate values for the rest of the trials (5.6 kg ha⁻¹ for 2014-D2 and 16.9 kg ha⁻¹ for 2013; Table 2). Irrigation water was extracted from an alluvial aquifer with connection with wells from nearby mountains with stable values of nitrates and nitrate as nitrogen (NO₃-N) of around 32 and 7.2 ppm, respectively.

All trials were arranged as split-plots on randomized block designs, with four replications, where irrigation levels were the main plots and N fertilizer dosages were the sub-plots. Experimental plots consisted of 8 rows with a North-South orientation, 10 m long, 70 cm apart, 25 cm between plants within rows, and with a plant population of around 55,000 plants per hectare. All experiments were seeded with Bosfora cultivar (Syngenta).

The irrigation method consisted of a drip system with one meter drip emitter spacing. Optimal irrigation scheduling was based on a water balance approach described later in Section 2.2. For each year and trial different irrigation schedules were considered, provid-

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