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Effect of the interaction of water and nitrogen on sunflower under drip irrigation in an arid region

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ABSTRACT

Sunflower has become an important crop for oil production in many arid regions across the globe. However, with water as a scarce resource, efficient water and nutrient management systems need to be identified. The goal of this project was to determine the interaction between water and nitrogen (N) for sunflower grown in an arid environment. Experiments were conducted during 2010 and 2011 in an arid region in Iran that included two sunflower hybrids, four levels of surface drip irrigation, ranging from severe deficit irrigation to over irrigation, and three levels of N fertilizer, i.e. 0, 47, and 93 kg N ha^{-1}. The treatments were arranged in a strip-plot design with complete randomized blocks with three replications. Irrigations were based on daily monitoring of soil moisture in the experimental plots. For both hybrids, irrigation and the interaction of water and N had a significant effect ($P < 0.01$) on total biomass, seed yield, oil yield, and N Use Efficiency (NUE). Maximum sunflower seed and oil production (4031 and 1635 kg ha^{-1}, respectively) occurred in over irrigation and 93 kg N ha^{-1}. The lowest soil N uptake was 31 kg ha^{-1} for deficit irrigation, while the highest was 99.5 kg ha^{-1} for over irrigation. The highest seed NUE was 26.7 kg kg^{-1} and oil NUE was 12.2 kg kg^{-1} for over irrigation with no N input. Increasing the amount of N fertilizer was not a suitable strategy under severe deficit irrigation. Overall, the optimal levels of N depended on the sunflower hybrid type and varied for different levels of irrigation. Adjusting N fertilizer rates to meet crop requirements based on the amount of water applied and the type of hybrid not only prevented a negative environmental impact, but also increased yield and conserved agricultural inputs for sunflower grown in an arid region.

1. Introduction

Water and nitrogen (N) management play a significant role in crop growth, development and ultimately yield for irrigated production in arid areas. Considering the interaction between water and N, optimizing N applications and irrigation water use are critical for sustainable agricultural management (Mahajan et al., 2012), because of lack of sufficient water for irrigation, high irrigation costs, high fertilizer expenses, and environmental concerns such as environmental pollution due to excessive use of N (Badr et al., 2012; Gheysari et al., 2009b; Seassau et al., 2010).

Sunflower (*Helianthus annuus* L.) is one of the most important oil crops in the world (Olalde et al., 2001). Due to its high-quality oil, usable parts, and moderate production requirements, 8.9% of the world's arable land under oilseeds is devoted to sunflower. Sunflower's ability to withstand short periods of severe soil water deficit (FAO, 2013; Flagella et al., 2002) and the popularity of biofuels in recent years (Lopes and Steidle Neto, 2011), requires more research, especially in areas where available irrigation water is limited (De Giorgio et al., 2007).

Proper irrigation management is essential to achieve an acceptable crop yield and associated revenue, especially when the available water cannot meet crop water requirements for the entire growth cycle (Sadeghi and Peters, 2012; Zheng et al., 2012). Deficit irrigation is a well-accepted management practice to optimize water use and to save water and energy (Gheysari et al.,

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Table 1
Chemical and physical properties for the soil at the experimental site.

Soil depth(cm)	chemical properties		Physical properties					
	pH	EC(dS m^{-1})	Clay(%)	Silt(%)	Sand(%)	Field Capacity(%)	Bulk density(g cm^{-3})	Organic C.(mg m^{-3})
0–30	8.10	0.97	27.7	32.4	39.9	25.9	1.41	0.97
30–60	7.83	0.86	25.8	30.8	43.4	32.8	1.55	0.54
60–90	7.77	0.99	27.1	29.3	43.6	30.9	1.53	0.30

2015). However, the implementation of deficit irrigation requires the quantification of crop response to water limitations (Farré and Faci, 2009). Several studies have assessed the effects of various methods of deficit irrigation on sunflower growth, development, and yield. These includes the elimination of one or more irrigation events (based on crop developmental stages) during the growing season (Demir et al., 2006; Göksoy et al., 2004; Karam et al., 2007), application of a potential evapotranspiration ratio (Razi and Assad, 1999), and replenishment of a fraction of depleted soil water (Sezen et al., 2011) throughout the entire growing season. Also, remotely-sensed canopy temperature has been used to monitor water stress in sunflower under deficit irrigation (Taghvaeian et al., 2014).

N is a dominant nutrient for the growth and productivity of sunflower (Massignam et al., 2009; Sincik et al., 2013). Various studies on the effect of different amounts of N on sunflower response have identified this element as an important factor affecting the crop's total biomass (Cechin and Fumis, 2004; Wabekwa et al., 2012) and seed and oil yield (De Giorgio et al., 2007; Olalde et al., 2001; Sincik et al., 2013). Some of these results have been contradictory, especially with respect to proper amount of N fertilizer. The common recommendation, therefore, is that N fertilizer should be applied in accordance with the amount of extractable soil water (Sincik et al., 2013), residual N, the amount of nitrate in the irrigation water (Olalde et al., 2001), and genotypes (De Giorgio et al., 2007; Scheiner et al., 2002).

The effects of water and N fertilizer interaction on maize (Gheysari et al., 2015, 2009a), potato (Badr et al., 2012), and rice (Haefele et al., 2008) have all shown that there is an optimal level of N for each irrigation level. Proper irrigation scheduling will reduce N loss and enhance crop growth and yield by improving nutrient use efficiency of the crop (Mahajan et al., 2012). Nevertheless, limited comprehensive field research has used the soil water balance method based on the soil-water status (Jones, 2004; Kloss et al., 2014) to evaluate the effect of water and N interaction on sunflower at different water application levels.

According to Köppen's climatic classification, most parts of Iran have arid (BW) and semi-arid (BS) climates. These climates have extremely irregular rainfall, which mostly occurs during the winter months (Tabari and Talaee, 2011). Drip irrigation is now being recommended by government officials due to several factors, such as the lack of available water resources, water lost due evaporation, wind drift, and concerns about environmental pollution (Seassau et al., 2010; Sadeghi and Peters, 2012). Farmers who use drip irrigation are applying deficit irrigation management due to water scarcity. Therefore, preventing environmental pollution, conserving agricultural inputs, increasing seed and oil yield, and reducing production costs mandate further research to examine the response of sunflower to water and N inputs under a drip irrigation system in arid and semi-arid regions. The objectives of this study were:

(I) To quantify the response of different sunflower hybrids to variable drip irrigation levels and N fertilizer rates.

(II) To determine the optimal level of irrigation water and N to optimize biomass, seed, and oil production for each hybrid; and

(III) To determine the effects of variable irrigation levels and N fertilizer rates and their interaction on N use efficiency (NUE) of sunflower under arid conditions.

2. Materials and methods

2.1. Experimental location

The experiment was conducted during the spring and summer seasons of 2010 and 2011 at the research farm of Isfahan University of Technology located in Lavark, Iran (32°32′ N, 51°23′ E, 1630 m.a.s.l). According to Köppen's climatic classification, Lavark has a cold desert climate with hot summers, i.e. BWk (Assari and Mahesh, 2011). Based on 40 years meteorological data, annual average minimum and maximum air temperature are 7.3 °C and 23.1 °C, respectively. The long-term average annual precipitation is 151 mm and is mostly concentrated during the autumn and winter months. The soil of the experimental field was a clay loam, classified as thermic Typic Haplargids according to the United States Department of Agriculture Soil Taxonomy (Lakzian, 1989). The field capacity (FC) and wilting point (WP) for the top 50 cm of the soil profile were 26% and 11%, on gravimetric base, respectively. Moreover, the groundwater Table was more than 50 m below the ground level in the study area.

2.2. Experimental design and growth conditions

The experimental treatments were a combination of four irrigation levels and three levels of N fertilizer arranged in a strip-plot design according to complete randomized blocks with three replications. The four levels of irrigation were applied based on the replenishment of a fraction of soil moisture depletion (SMD). The consisted of two deficit irrigation levels, i.e. 0.6 SMD (I1) and 0.8 SMD (I2), a full irrigation level, i.e. 1.0 SMD (I3), and an over-irrigation level, i.e. 1.2 SMD (I4). The three N fertilizer levels were 0 (N0), 47 (N50), and 93 (N100) kg ha^{-1}.

The size of each individual plot was 5 m in length and 3.75 m in width with five rows. One half of the plot was planted with the hybrid Sirna and the other half with the hybrid Euroflor, which are the current commercial oleic sunflower hybrid cultivated in many arid and semi-arid regions of Iran (Tabrizi, 2012). The two hybrids were planted on June 2, 2010 and June 3, 2011 with a plant density of 6.66 plants per m^2. Weather data were measured on a daily basis at the Najafabad meteorological station, located at a distance of 5 km from the experimental site (http://www.najafabadmet.ir/) (Fig. 1). No rainfall was recorded during any of the two crop growing seasons. Prior to sowing, soil samples were obtained at 30-cm increments to a depth of 90 cm. The measurements were performed at three different points 15 m apart. The bulk density and physicochemical properties for each depth were determined from three composite samples (Table 1). Moreover, the initial soil N content was obtained by measuring NO_3-N and NH_4-N. The average amounts of these compounds at the top 50 cm of the soil profile were 80 kg N ha^{-1} in 2010 and 84 kg N ha^{-1} in 2011.

2.3. Fertilization management

Based on the soil analysis report, the study area contained adequate phosphorus and potassium levels to meet the nutrient requirements of sunflower. A Venturi fertilizer injector was used to