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Effect of growth stage based irrigation on soil water extraction and water use efficiency of spring safflower cultivars

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ABSTRACT

The Ogallala Aquifer is depleting at faster rates, and jeopardizing the future sustainability of agriculture in the Southern High Plains. We hypothesize that adoption of drought tolerant crops such as safflower (*Carthamus tinctorius* L.) will sustain crop production in the region. However, information on water use of safflower is limited. A field study was conducted during 2013 and 2014 to monitor the soil water extraction patterns, water use efficiency (WUE) and oil productivity of spring safflower under deficit irrigation. Three safflower cultivars (PI8311, 99OL and Nutrisaff) having different growth habits and yield potentials were grown under four irrigation treatments [fully irrigated (FI), stress at vegetative stage (VS), stress at reproductive stage (RS) and dryland (DL)]. The soil water extraction was observed in all irrigation treatments or cultivars down to the depth of 1.6 m in both years; however, there was difference in water extraction at each depth. Safflower exposed to water stress extracted more soil water from the deeper depths. The maximum water was extracted from 1.0 to 1.6 m soil layer. The water extraction down to 1.6 m from planting to harvest was the highest in RS treatment while it was next to FI treatment in terms of evapotranspiration (ET) and oil yield. The higher WUE of RS treatment compared to FI and VS treatments suggest that RS treatment utilized the available water more efficiently. The cultivar 99OL showed higher WUE and oil yield. Thus, deficit irrigation at reproductive stage of safflower and adoption of 99OL cultivar can improve WUE and oil yield benefits under limited water conditions.

1. Introduction

Safflower (*Carthamus tinctorius* L.) is a broadleaf oilseed crop primarily cultivated for high quality edible oil and birdseed (Koutroubas et al., 2009). It is well adapted to arid and semi-arid regions. Deep root system enables it to extract water down to a depth of 2.2 m and presence of xerophytic spines indicates its ability to tolerate drought and heat (Dajue and Mündel, 1996). Safflower gives flexibility to farmers in crop rotation, and it is also beneficial in breaking disease and weed cycles (Mündel et al., 1994). In addition, the inclusion of safflower into the cropping system increases local production of healthy vegetable oil for human consumption and the protein-rich meal for the animal industry.

The Southern High Plains (including Texas High Pains, the Oklahoma Panhandle, part of eastern New Mexico and southwest Kansas) is a semiarid region with an average annual rainfall from 380 mm in the southwest to 580 mm in the northeast (Xue et al., 2014). The Ogallala aquifer is the main source of irrigation in the Southern High Plains (Xue et al., 2014). The aquifer is a closed system with minimum recharge capacity, and excessive water withdrawal from the aquifer for crop irrigation has resulted in a significant decrease in the water table (Colaizzi et al., 2009). This dramatic water extraction from the aquifer reduced the saturated thickness by 50% in some areas of the region (Xue et al., 2014). It is estimated that there will be a 35% decrease in the irrigated area over the Ogallala aquifer in the Southern High Plains in next 30 years (Scanlon et al., 2012). With declining water supplies, growers are facing problems to meet the water requirements of the crops during growing season (Stone et al., 2008). To manage irrigation with the limited capacity wells, strategies such as irrigation based on critical crop growth stage, growing crops of less water requirement than the conventional crops, and reducing irrigated crop area should be adopted by the growers. Therefore, safflower can be a potential crop in the Southern High Plains since its water requirement is less than the current crops (e.g. corn and sorghum) grown in the region.

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Water used from the lower soil depths especially later in the growing season contribute more significantly to crop yield compared to water withdrawn from shallower depths (Cutforth et al., 2013). Deep rooting crops such as safflower have an advantage to use water from the deeper layers to alleviate drought stress. Extensive root system has been suggested as the main drought avoidance characteristic to sustain seed yield under terminal drought conditions (Kashiwagi et al., 2005; Turner et al., 2001). The methods used to evaluate the role of root system in drought avoidance or tolerance are destructive, laborious, time consuming, and do not provide continuous information of the rooting zone (Zaman-Allah et al., 2011). Indirect, non-destructive methods such as water use patterns across the root zone have an advantage over destructive root assessments by providing more useful data with little ease and in less time.

In addition to stress tolerant crops, deficit irrigation (water application below the evapotranspiration requirements of a crop) is another approach to cope with declining water situation in the region. When supply of irrigation water is limited, the goal of the farmers should be to maximize water use efficiency (WUE) rather than increasing land use efficiency (Fereres and Soriano, 2007). Deficit irrigation is a sustainable method to increase WUE. The main objective of deficit irrigation is to stabilize crop yield rather than maximizing it by eliminating irrigations at drought-tolerant growth stages (Geerts and Raes, 2009). Irrigation water can be saved with deficit irrigation without significant reduction in yield; and saved water can be allocated to irrigate additional land (Chartzoulakis and Bertaki, 2015). However, information on water extraction patterns of spring safflower in response to deficit irrigation is lacking. The objective the study was to assess soil water extraction patterns, WUE, and oil yield of spring safflower under deficit irrigation in the Southern High Plains.

2. Materials and methods

2.1. Experimental description

A field experiment was conducted at the Agricultural Science Center, Clovis of New Mexico State University (34° 35′ N, 103° 12′ W and altitude of 1348 m above sea level) during 2013 and 2014. The study location is characterized as an semi-arid climate with an annual average precipitation of 445 mm, and the mean maximum and minimum temperatures of 22 °C and 7 °C, respectively (Singh et al., 2014). Soil type of the study site was Olton clay loam (fine, mixed, superlative, thermic Aridic Paleustoll). Soil pH was 7.3 and 7.6, and organic matter content was 16 and 19 g kg^{-1} in 2013 and 2014, respectively.

The experiment field was disked and ploughed before planting to incorporate residue and to form a seedbed each year. Pre-season irrigation was applied before planting. Based on soil test results, field was fertilized before planting with 77 kg N ha^{-1} and 28 kg P_2O_5 ha^{-1} in 2013, and 55 kg N ha^{-1} and 17 kg P_2O_5 ha^{-1} in 2014. A pre-plant herbicide application of 2.5 L Treflan® HFP ha^{-1} was incorporated into the soil for weed control each year. Spring safflower cultivars PI8311, 99OL and Nutrisaff, having different growth habits and yield potentials (Singh et al., 2016b) were planted on 30 April 2013 and 23 April 2014, respectively using a plot drill (Model 3P600, Great Plains Drill, Salina, KS, USA) at a row spacing of 0.15 m. Seeding rate was determined based on row spacing, seed weight and an estimated field emergence rate of 85%. A population density of 62 plants m^{-2} was targeted. The plot size was 9 m × 5.5 m with three planting passes (11 rows per pass) in each plot. A severe hail storm on 7 June 2014 destroyed the well-established safflower crop in the field. Hence, we replanted the whole trial on 17 June 2014. To ensure good plant stand, a total of 51 and 38 mm of irrigation was applied to the entire trial over a two-week period in 2013 and 2014, respectively (Fig. 1). Irrigation treatments were started after the crop was well established, and a center pivot system with spray pads was used to irrigate plots. Two important growth phases were considered for irrigation treatments. In the first, irrigation was stopped after crop establishment to limit vegetative growth. In the second, irrigation was stopped after flower initiation to stress reproductive growth and yield formation. Four irrigation treatments [fully irrigated (FI), stress at vegetative stage (VS), stress at reproductive stage (RS), and non-irrigated or dryland (DL; this treatment did not receive any irrigation water after establishment, and survived on rainfall)] were applied. The goal was to evaluate crop response to water stress occurring at different growth stages (VS and RS) in comparison to a least stressed irrigated crop (FI) on one end and a crop stressed all season under dryland condition (DL) on the other end. Each experimental unit was irrigated at the same time as the fully irrigated treatment with an amount that maintained soil moisture levels above 50% of available water between field capacity (28%) and wilting point (15%). All the treatments were treated alike except for omitting irrigation application at a specific growth stage to impose water stress in VS and RS treatments. The total irrigation amounts for FI, RS, VS and DL treatments are 303, 171, 183 and 51 mm in 2013, and 272, 146, 165 and 38 mm in 2014 (Fig. 1). The crop was harvested on 27 August 2013 and 6 October 2014.

2.2. Data collection

The volumetric soil water content ($cm^3\,cm^{-3}$) was recorded seven times during the growing season, using a field-calibrated soil moisture neutron gauge (Model 503 DR, Campbell Pacific Nuclear Inc., CA, USA). Neutron access tubes were installed in the crop rows near the center of each plot to measure soil moisture to a depth of 1.6 m. Neutron probe readings were made from 0.1 m to 1.5 m depth at 0.2 m depth increments to assess the moisture to the depth of 1.6 m (Hao et al., 2015). Soil water content (mm) at each depth was calculated by multiplying depth increment (mm) with volumetric water content for that depth increment. Soil water depletion at each depth between two sampling dates was determined by subtracting the soil water content of later measurement from the earlier measurement. The total water content was calculated using measurements to a depth of 1.6 m. Seasonal crop evapotranspiration (ET) was calculated by using water balance equation: ET = RF + I + SD + R + D, where RF is rainfall (mm), I is irrigation (mm), SD is the difference in soil water content between planting and post-harvest (mm), R is runoff (mm), and D is drainage (mm) below root zone (Xue et al., 2014). Since the experiment field was leveled and did not receive any high irrigation/rainfall amounts, the runoff and drainage were considered zero. An area of 9.2 m^2 was harvested using a plot combine (Model Elite Plot 2001, Wintersteiger, Ried, Austria) for seed yield and weights were adjusted to 10% seed moisture (Singh et al., 2016b; Singh et al., 2016c). Water use efficiency (WUE) was calculated as follows: WUE = Y/ET, where Y is seed yield (kg ha^{-1}) and ET is evapotranspiration (mm).

2.3. Experimental design and statistical analysis

The experiment was laid-out in a blocked split plot design with irrigation treatment as the main factor with four levels: FI, VS, RS and DL. Three cultivars (PI8311, 99OL and Nutrisaff) were randomized into sub-plots. All treatment combinations were replicated four times. The analysis of variance was performed using General Linear Model (GLM) procedure of SAS software (Version 9.2, SAS Institute Inc., NC, USA) by using appropriate error term to evaluate each factor and interaction. The means were separated by Fisher's protected least significant difference (LSD) test at 0.05 probability