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Drought response and yield formation of spring safflower under different water regimes in the semiarid Southern High Plains

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ABSTRACT

Safflower (*Carthamus tinctorius* L.) is a deep rooted drought tolerant crop that originated in desert environments of the Middle East, and could be very well adapted to the semi-arid Southern High Plains. A field experiment was conducted at Clovis, New Mexico during 2012 and 2013 seasons to assess drought physiology and yield formation of two diverse spring safflower cultivars under different irrigation levels with or without preseason irrigation. One half of the experimental blocks received preseason irrigation of 164 mm in 2012 and 153 mm in 2013 to refill the soil profile utilized by the previous crops, while the other half remained depleted. Five in-season irrigation levels (I_1–I_5) ranging from 88 to 392 mm in 2012 and from 83 to 373 mm in 2013 were imposed on both preseason irrigation and no-preseason irrigation blocks. Higher leaf water potential (Ψ_l) was observed under increased water availability either by preseason irrigation or by higher in-season irrigation level in safflower during two observation dates in both years. Osmotic potential at full turgor ($\Psi_{\pi 100}$), photosynthesis rate (P_n) and transpiration rate (T_r) decreased with a reduction in Ψ_l under water stress conditions. The relative water content (RWC) was affected only by the in-season irrigation levels in both years. The preseason irrigation increased seed yield of safflower by 39 and 118% over no-preseason irrigation in 2012 and 2013, respectively. A gradual increase in seed yield was observed with an increase in irrigation levels; and the highest irrigation level, I_5 increased seed yield by 85 and 171% over the lowest irrigation level, I_1 in 2012 and 2013, respectively. Seed yield increased with increase in P_n, plant biomass, number of heads per plant, and number of seeds per head but not with 1000-seed weight under increased water availability. Overall, increased availability of water through preseason irrigation or through in-season irrigation levels improved safflower physiology and yield formation.

1. Introduction

Irrigated agriculture is a mainstay of economic stability in the Southern High Plains of New Mexico and West Texas. Being a semi-arid region with low and highly variable precipitation, the stability and productivity of agriculture is mainly dependent on Ogallala aquifer for irrigation (McGuire, 2012). However, the aquifer is a hot spot for water depletion especially in the southern part (Scanlon et al., 2012). Ogallala water table declined more than 30 m in 30 years in parts of New Mexico, Texas and Kansas due to higher water withdrawals from the aquifer compared to its recharge (Sophocleous, 2000). It is estimated that 35% of the Southern High Plains will not be able to irrigate in the next 30 years (Scanlon et al., 2012). Water deficit is a major factor limiting crop productivity in the region and more drought tolerant crops are needed to sustain agriculture.

Safflower is an important oilseed crop developed in arid and semi-arid regions of the world and often credited to perform well in drier environments due to its deep root system (Armah-Agyeman et al., 2002; Merrill et al., 2002). Safflower contains 35–45% high quality vegetable oil (Kaya et al., 2003; Mahasi et al., 2009). Seeds are also valuable as bird seed (Bagheri and Sam-Daliri, 2011). Safflower petals are used for producing food color and flavor (Bagheri and Sam-Daliri, 2011). Although safflower is considered a drought resistant crop (Hojati et al., 2011), research on its adaptability, drought response including genetic variation and yield formation under diverse water management is not available in the semiarid Southern High Plains.

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Drought response by a crop is a complex phenomenon, since plants routinely encounter drought along with other abiotic stresses (Mittler, 2006). Most plants modify their physiological, cellular and molecular processes in response to drought (Chaves et al., 2009). Plant responses to water stress vary with intensity, duration and progression rate of drought imposed. Water stress decreases plant growth by reducing cell division and cell elongation caused by turgor loss (Lawlor and Cornic, 2002). Photosynthesis (P_n) is one of the primary metabolic processes affected by water stress (Pieters and El Souki, 2005). Water stress alters leaf water potential (Ψ_l), relative water content (RWC) and osmotic potential (Ψ_π) along with impairment of P_n. Drought resistant plants adopt several mechanisms such as reduction in water loss by increasing stomatal resistance, increase in water uptake by developing a large and deep root system, and acclimation to water stress by increasing osmolyte accumulation (Bohnert et al., 1995). A precise knowledge of physiology and water relations of safflower under water stress is, therefore, important for water management in the region.

Deep rooted crops like safflower can extract water from depth to satisfy their water requirement. Although the amount of water extracted from deeper profile is small, it can relieve stress at critical growth stages and help in yield formation processes (Wasson et al., 2012). In a center pivot irrigation system, which is the predominant method of irrigation in the Southern High Plains, preseason irrigation with bubbler pads can be used to store water in the lower soil profiles. This will be of great help, if preseason irrigation reduces competition for irrigation during the peak irrigation requirement of the main crops like corn. In abundant irrigation water situation, the preseason irrigation is less efficient in comparison to in-season irrigation for meeting crop water needs of traditional shallow rooted crops (Musick and Lamm, 1990; Stone et al., 1987). However, under the declining irrigation resources in the Southern High Plains, preseason irrigation may be a very useful technique for alternative crops. However, there is no latest information available on the dependence of crop plants (especially safflower) on the soil water reserves in the region.

Water storage from preseason irrigation for use by the following crop might be affected by in-season precipitation and irrigation amounts. Irrigation amounts that result in water stress can have significant effect on safflower growth and yield. At the same time it is important to know how much yield of safflower can be expected from a given water allocation in the region. Therefore, the present study was aimed to investigate the effect of irrigation amounts with or without preseason irrigation on physiology and yield of spring safflower cultivars in the Southern High Plains.

2. Materials and methods

2.1. Site description

A field experiment was conducted during 2012 and 2013 summer seasons at the Agricultural Science Center (ASC), Clovis of New Mexico State University (34° 35′ N, 103° 12′ W and altitude of 1348 m above mean sea level). The study location is characterized by a semi-arid climate with an annual average precipitation of 445 mm, and the annual mean maximum and minimum temperatures of 22 °C and 7 °C, respectively (Contreras-Govea et al., 2011). Soil type of the study site was Olton clay loam (fine, mixed, superlative, thermic Aridic Paleustoll). Soil pH was 7.7 and 7.9, and organic matter content was 1.5% and 1.6% in 2012 and 2013, respectively.

2.2. Field preparation and planting

The experiment field was disked and ploughed before planting to incorporate residue and to form a seedbed each year. The field was divided into four blocks. Two blocks were randomly assigned to preseason irrigation and the other two were assigned to no-preseason irrigation. The preseason irrigation blocks received a total preseason irrigation of 164 mm in 2012 and 153 mm in 2013 to refill the soil profile emptied by previous crops of corn (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.), respectively (Table 1). The total preseason irrigation was applied in four splits to the preseason irrigation blocks between February and March to avoid any runoff. A center pivot system with bubbler pads was used for irrigating the blocks. Bubbler pads helped ensuring a deeper percolation of the irrigation water, while reducing wind and evaporation losses. The no-preseason irrigation blocks did not receive any preseason irrigation and were separated from the preseason irrigation blocks with buffer strips (1.83–3.66 m wide) to keep out any irrigation water from the preseason irrigation blocks. The final 25 mm of irrigation, before planting, was applied with spray pads to all four blocks to create uniform seed bed moisture for the entire trial. The experiment field was fertilized with 100 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} based on soil test recommendations at planting in both the years. A pre-plant herbicide application of 2.5 L Treflan® HFP ha^{-1} was incorporated into the soil for weed control each year.

Safflower was planted on 9 April 2012 and 4 April 2013, respectively using a plot drill (Model 3P600, Great Plains Drill, Salina, KS, USA). Target population of 625,000 plants ha^{-1} with 85% emergence rate was used for seed calculation. The plot size was 9 m × 4 m with two passes (11 rows per pass) in each plot. To ensure good plant stand, a total of 88 and 83 mm of irrigation was applied to the entire trial over a two-week period in 2012 and 2013, respectively (Table 1). Extremely dry, warm and windy spring weather in both seasons necessitated higher amounts of establishment irrigation than planned. After the safflower seedlings started emerging, an above ground drip irrigation system with water meters was installed on each plot to regulate irrigation application to each experimental unit separately. Once the crop was well established, surface drip system took over the irrigation. The goal was to develop crop response to irrigation ranging from near rainfed to 300 mm of in-season irrigation, which is the maximum irrigation a farmer in the region can afford on a crop like safflower. Irrigations were scheduled to meet the target amount of water assigned to a particular treatment covering all critical growth stages. The scheduled irrigation was skipped when significant rainfall occurred around the time of a planned irrigation event. Therefore, a total of five to six in-season irrigations were applied during the whole growing season (Table 1).

2.3. Data collection

2.3.1. Physiological measurements

All physiological observations were recorded during midday at 55 (vegetative stage) and 85 (reproductive stage) days after planting (DAP). These two observation days were selected with an aim to determine if the effect of different water management practices remains the same throughout the growing season on the performance of both cultivars. Study plots were divided into two sets to complete all the observations in four days. The first set comprised of no-preseason irrigation treatment with in-season irrigation levels of the lowest (I_1), middle (I_3) and the highest (I_5), and both cultivars. Thus, the first set of observations aimed at assessing safflower drought physiology under range of water availabilities without significant contribution of stored soil moisture. This set of observations was used to express the relationships among different physiological and agronomic traits (Figs. 2 and 3). The second set of observations included both levels of preseason irrigation (preseason irrigation and no-preseason irrigation), the lowest (I_1) and the high-