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# Interactive effects of nitrogen fertilization and irrigation on grain yield, canopy temperature, and nitrogen use efficiency in overhead sprinkler-irrigated durum wheat

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ABSTRACT

Nitrogen and irrigation management are crucial in the production of high protein irrigated durum wheat (*Triticum durum* Desf.) in arid regions. However, as the availability of irrigation water decreases and potential costs and regulation of nitrogen (N) increase, there is a need to better understand how irrigation levels interacts with N fertilizer rates. A two-year field experiment was conducted in Maricopa, Arizona USA on a Casa Grande sandy loam to assess effects of N fertilizer and irrigation rates on grain yield, grain N, canopy temperatures yellow berry, and N use efficiency. Five rates of N fertilizer as urea ammonium nitrate (0, 84, 168, 252, and 336 kg N $ha^{-1}$) were applied in three equal splits at Zadoks stages 30, 32, and 39. Ten un-randomized, sequential rates of irrigation ranging from 0.35 to 1.14 fraction of a non-deficit base irrigation treatment (maintained >45% soil water depletion) were applied by sequentially varying the nozzles in a gradient in an overhead sprinkler system. Irrigation plus rain ranged from 230 to 660 mm in the first season, and 180 to 600 mm in the second season. Grain yield was maximum in 2013 at the 252 kg N $ha^{-1}$ fertilizer rate and at the 10th water level (1.14 irrigation), and between 168 kg and 252 kg N $ha^{-1}$ at the 8th water level (1.0 irrigation) in 2014. The maximum grain yield of 7500 kg $ha^{-1}$ in 2013 was reduced to 5000 kg $ha^{-1}$ in 2014 due to a warmer, shorter growing season. Economic optimum N rate was at water level 8 both years (196 and 138 kg N $ha^{-1}$ in 2013, and 2014, respectively). Recovery efficiency of added N was high in this system (i.e., >70%) at N fertilizer and water levels that maximized biomass and grain yields. Grain N was maximum at a lower water level (level 3 or 0.50–0.54 irrigation), was positively affected by N fertilizer rate, and was negatively related to yellow berry incidence. Canopy temperature minus air temperature values decreased linearly with increasing irrigation level. Nitrogen fertilizer applications reduced canopy temperature when water levels >0.54 and 0.69 irrigation fraction in 2013, and 2014, respectively. The study results suggested that canopy temperature and weather data that reflects the grain-filling period could be used to improve irrigation and N management, respectively. In short, irrigated durum wheat growers on this soil would achieve the economically optimum grain yield, with the least risk of yield or protein reduction, by applying 200 kg N $ha^{-1}$ at the base irrigation level which maintains root zone soil moisture depletion below 45%.

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## 1. Introduction

Durum wheat is an important winter crop in the desert regions of the southwestern United States. Due to a higher price paid for durum wheat, a large fraction of wheat producing areas of Arizona and California converted to durum wheat in the 1970s (Robinson et al., 1979). Currently, Arizona covers the third largest acreage of durum wheat grown in the United States, after North Dakota and Montana (USDA-NAAS, 2015). Durum wheat is a major crop in the EU, North Africa, and the Middle East (Garabet et al., 1998; Garrido-Lestache et al., 2005; Boukef et al., 2013). Similar to other crops, durum wheat production in an arid environment is limited by N and water availability. All field crop production in Arizona is irrigated (Schillinger et al., 2006). Due to growing populations and changes in climate patterns, water availability around the world is increasingly limited. Therefore, increasing crop yield and productivity with reduced water inputs is crucial.

Nitrogen management in durum wheat also faces constraints. Concerns include possible regulatory controls on N inputs or pressures from buyers to reduce carbon footprints associated with

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grain production. However, high N inputs are favored by producers because they receive a reduced price if durum grain protein is <14.3% protein (23 g N $kg^{-1}$) (Blandino et al., 2015; Liang et al., 2014). Several studies have reported that late N applications near heading can boost durum grain protein (Ottman et al., 2000; Garrido-Lestache et al., 2005; Blandino et al., 2015). In addition to N fertilizer management, irrigation amounts and timing strongly influence grain N (Ottman et al., 2000). Low supplemental irrigation was associated with high durum protein grain, and full supplemental irrigation resulted in reduced grain protein (Oweis et al., 1999).

Another important grain quality measure in durum wheat is hard vitreous amber count (HVAC). Durum grain protein is positively related to HVAC and negatively associated with yellow berry, a starchy condition (Robinson et al., 1979; Anderson, 1985; Boukef et al., 2013; Blandino et al., 2015). Ottman et al. (2000) reported that decreasing levels of irrigation during grain-fill in Arizona increased HVAC. Thus, tools to improve irrigation scheduling can assist in the production of durum wheat with high HVAC and protein content. Ehlerer et al. (1978) suggested that durum wheat canopy temperature can be used to guide irrigation scheduling. Much of the seminal research on the use of infrared thermometry to monitor crop water stress and guide irrigation management was conducted with durum wheat in Arizona (Jackson et al., 1977; Idso et al., 1978; Idso, 1982). Over-application of N and irrigation in excess of crop requirements lead to greater lodging, grain loss, and N loss to the environment (Riley et al., 2001; Yu-Hua et al., 2007). In Tunisia, N fertilizer applications improved water use-efficiency of irrigations in durum wheat (Latiri-Souki et al., 1998).

The interacting effects of water and nitrogen balances in durum wheat cropping systems can be described with crop growth simulation models (Thorp et al., 2009). After thorough evaluation against measured cropping system data, the models can be extended to study long-term impacts of field management, assess climate change impacts on cropping systems, and provide guidance for in-season management decisions. However, limited field-measured data is often a critical weakness for crop simulation model evaluation. In particular, field studies that thorough assess durum wheat responses over a wide range of water and nitrogen management conditions are lacking.

It is clear therefore, that irrigation water and N fertilizer require judicious management for high quality durum wheat production in arid and semiarid regions. However, studies are lacking that investigate interactive effects of N and irrigation levels for irrigated durum wheat in dry regions. Recently however, moving overhead sprinkler irrigation has become more common (NASA, 2008). This enables much finer control over irrigation schedules than was previously feasible (Evans and Sadler, 2008), and provides the opportunity to evaluate whether or not infrared thermometry has a corresponding role in improved water and N management. The objectives of this study were (1) to determine the effects of N fertilizer rate on grain yield, above-ground biomass, canopy temperature, total N uptake, N use efficiency, grain N content, kernel weight, and percent yellow berry at varying overhead sprinkler irrigation levels and (2) to estimate optimal N fertilizer rate and overhead sprinkler irrigation level for durum wheat grain yield and grain N.

## 2. Materials and methods

### 2.1. Experimental Layout and overhead sprinkler irrigation system

This field study was conducted in two growing seasons, 2012–2013 and 2013–2014, on a 1.3-ha, laser-leveled field at the Maricopa Agricultural Center (33.0675°N, 111.9715°W, 358 m above sea level) of the University of Arizona in Maricopa, Arizona. The site receives an average annual rainfall of 200 mm, and is classified as a hot desert climate (Köppen climate classification). The soil is a Casa Grande sandy loam (fine-loamy, mixed, superactive, hyperthermic, Typic Natrargid, USDA-NRCS, 2013).

The study was conducted under one span (55 m long) of a two-span end-feed linear-move an overhead irrigation system (Valmont Industries, Inc., Valmont, Nebraska). Sprinkler height was 1 m above the ground, and sprinkler spacing was 1.52 m. A 69-kPa pressure regulator was affixed to each sprinkler head to maintain near constant pressure to sprinklers regardless of overall system pressure fluctuations. Water was provided to the irrigation system through a 0.15 m diameter drag hose. The drag hose was connected to a nearby pumping station that could provide a flow of up to 1171 L $min^{-1}$ when operating the entire system.

### 2.2. Irrigation levels and scheduling

Irrigations were scheduled based on estimated daily evapotranspiration ($ET_c$) as calculated by the FAO-56 dual crop coefficient procedures (Allen et al., 1998):

$$ET_c = (K_{cb} K_s + K_e) ET_o \quad (1)$$

where the basal crop coefficient ($K_{cb}$) represents the transpiration portion of $ET_c$, $K_e$ is the wet soil evaporation coefficient, $K_s$ is the water stress coefficient, where $K_s < 1$ when the available soil water is insufficient for full $ET_c$, $K_s = 1$ when there is no soil water limitation on $ET_c$, and $ET_o$ is grass-reference evapotranspiration, in mm. Measured daily meteorological data, including solar radiation, rainfall, maximum and minimum air temperatures, wind speed, and humidity were used to compute daily values for $ET_o$ by the FAO-56 Penman-Monteith equation (Allen et al., 1998). Weather data were provided by a University of Arizona, AZMET weather station (http://cals.arizona.edu/azmet/), located approximately 200 m from the field. Monthly mean AZMET temperature data, monthly cumulative growing degree days (GDD), rain, and $ET_o$ for the 2012–13 and 2013–14 growing seasons are given in Table 1. Weekly mean air temperature, and GDD are shown in Fig. 1.

The seasonal $K_{cb}$ curve used in Eq. (1) was an empirically-derived function based on the hard red spring wheat (*Triticum aestivum* L.) 'Yecora Rojo' crop coefficient data obtained in prior field studies at this site (Hunsaker et al., 2007). The wheat $K_{cb}$ data were derived as a function of cumulative GDD, calculated using maximum and base temperatures of 30 °C and 4.44 °C, respectively. The benefit for using thermal-time GDD rather than days after planting for $K_{cb}$ is that actual $K_{cb}$ can be better-matched when growing season temperatures vary by season. The parameters used to evaluate the soil evaporation coefficient ($K_e$) were the FAO-56 recommendations for a sandy loam soil. The water stress coefficient ($K_s$) was evaluated using a daily root zone soil water balance (SWB).

A spreadsheet, similar to the one developed in Hunsaker et al. (2005), and originally patterned after Annex 8 in FAO-56, was developed to calculate a daily SWB for estimating soil water depletion of the wheat root zone. Inputs to the SWB included measured daily irrigation and rainfall data, while outputs were the calculated daily $ET_c$ (FAO-56 procedures), and deep percolation, which was calculated as the residual from the SWB equation. Runoff was assumed to be negligible for this laser-leveled field. Twenty-year historical MAC AZMET weather data and weather-based $ET_o$ data were used in the SWB spreadsheet to project root zone available soil water into the future.

Prior to imposing differential gradient irrigation to 10 un-randomized sections in the field, all 10 sections were uniformly irrigated from planting until January 17–18 with 70 mm and 46 mm in the 2012–2013 and 2013–14 seasons, respectively. During this