DETERMINING IDEAL IRRIGATION TERMINATION DATES UNDER DEFICIT IRRIGATION STRATEGIES

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Abstract

Irrigation termination is a very important, but complicated decision in cotton (*Gossypium hirsutum* L.) production due to complex interactions and uncertainties related to irrigation water use, cotton yield and fiber quality, water costs, and market factors. While an early termination of irrigation results in yield loss, late termination results in the wastage of valuable irrigation water, delays harvest and increases pest management costs. Implementing appropriate irrigation termination dates along with deficit irrigation strategies could not only ensure good cotton yield, but also increase irrigation water use efficiency (IWUE). In this study, a previously evaluated CROPGRO-Cotton module within the Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (CSM) was used. The model was evaluated using measured data from a cotton IWUE field experiment conducted at Halfway, TX during 2010 to 2013. The treatment factors in the field experiment included irrigation capacity (0 mm/day, Low (L); 3.2 mm/day, Medium (M); and 6.4 mm/day, High (H)) and irrigation application within three specific growth stage windows of pre-bloom, peak bloom, and post peak bloom. The evaluated model was used to simulate the long-term (1978-2016) effects of a combination of deficit/excess irrigation practices (Evapotranspiration (ET)-replacement of 55%, 70%, 85%, 100% and 115%) and irrigation termination dates (ranging from August 15th to September 30th with one-week intervals). The results from this study revealed that applying more irrigation water than the cotton ET requirement resulted in reduced IWUE, and sometimes yield. Based on the simulated cotton yield, the optimum irrigation termination period was found to be the 1th week of September for 115% ET-replacement, 2nd week of September for 100% and 85% ET-replacement, and 3rd week of September for 70% and 55% ET-replacement irrigation strategies. Based on the simulated IWUE, the optimum irrigation termination period was found to be the 1th week of September for 115% ET-replacement, 2nd week of September for 100% ET-replacement, and 3rd week of September for 85%, 70% and 55% ET-replacement irrigation strategies.

Introduction

Cotton production in the Texas High Plains (THP) region relies heavily upon irrigation with water mined from the underlying Ogallala Aquifer (Allen et al., 2008). However, rapidly declining groundwater levels in the Ogallala Aquifer (Colaizzi et al., 2009; Chaudhuri and Ale, 2014a, b) and increasing groundwater pumping costs pose challenges for sustainability of irrigated cotton production in this region. In addition, climate change studies for this region (Modala et al., 2017) project warmer and drier summers in the future. Such trends would lead to more groundwater withdrawals to meet the higher evapotranspiration demand of cotton. In view of depleting groundwater resources, the Groundwater Conservation Districts (GCDs) in the THP have started imposing restrictions on groundwater pumping for irrigation purposes to ensure certain desirable future conditions (DFCs) (HPWD, 2015). For example, the High Plains Water District set the annual allowable groundwater pumping for irrigation at 46 cm (18" or 1.5 acre-feet per contiguous acre). It is therefore essential to develop and adopt efficient irrigation strategies for cotton under declining irrigation water availability.

Irrigation termination is one of the important decisions in cotton production. While an early termination of irrigation results in yield loss, late termination results in the wastage of valuable irrigation water, causes undesirable vegetative growth and delay in boll maturity, and increases pest management costs (Silvertooth, 2001; Tronstad et al., 2003; Vories et al., 2006). Grimes and Dickens (1974) used a multiple-regression model that included irrigation termination date and water retention capacity of soil as independent variables to describe the influence of these variables on cotton production potential, and reported that when the final irrigation is timed correctly, an increase in the rate of mature boll opening was observed, and irrigation water was also saved. Although many researchers have suggested different efficient irrigation strategies for the THP region (Howell et al., 2004; Gowda et al., 2006; Snowden et al., 2013), none of them focused on suggesting irrigation termination dates for sustainable cotton production with prolonged life of Ogallala aquifer has not been documented well for different climatic conditions. The decision as to when to terminate the irrigation on a cotton crop is a function of many variables that include lint yield and quality, the costs of irrigation and market value (Lascano et al., 2017).

The ideal irrigation termination time in a given year also depends on the environmental conditions in that year, mainly air temperature, and distribution and amount of precipitation during the cotton growing season. Identifying optimum irrigation termination periods for the THP region, where about a quarter of the US cotton is produced, would therefore be important for efficient utilization of precious irrigation water from the Ogallala Aquifer. Implementing appropriate irrigation termination strategies along with deficit irrigation practices could ensure good cotton yield and increase IWUE. It is therefore important to study the effect of irrigation termination date on cotton yield and IWUE under full and deficit irrigation conditions over a longer period of time to make appropriate recommendations. The CROPGRO-Cotton module within the Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (CSM) is very useful for this purpose. The overall objective of this study was to determine optimum irrigation termination dates for cotton under full and deficit irrigation strategies by assessing the long-term (1978-2016) effects of a combination of deficit/excess irrigation practices (Evapotranspiration (ET)-replacement of 55%, 70%, 85%, 100% and 115%) and irrigation termination date (ranging from August 15th to September 30th with one-week intervals) on IWUE and seed cotton yield using a previously evaluated DSSAT CSM CROPGRO-Cotton model (Adhikari et al., 2016).

Materials and Methods

Study area and Data description: The THP region, which consists of 41 counties in northwest Texas (Figure 1) is one of the most intensive agricultural areas in the United States. Major crops grown in the region include cotton, sorghum (*Sorghum bicolor* L.), winter wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.). The annual precipitation in the region ranges between 36 and 61 cm and a majority of this precipitation occurs during the months of May and September (Allen et al., 2008). The Ogallala aquifer, which underlies almost all of the THP counties, is the major source of irrigation water for this region, and the center pivot irrigation is the most common method of irrigation.

A previously evaluated DSSAT CSM CROPGRO-Cotton model (Adhikari et al., 2016) was used in this study. The model was evaluated using the field data from 27 treatments in a cotton irrigation water use efficiency field experiment at the Texas A&M AgriLife Research Center at Halfway, Texas (34°10' N, 101°56' W; elevation 1075 m) over a period of four years (2010-2013). The treatment factors in the field experiment were in-season irrigation capacity (0 mm/day, Low (L); 3.2 mm/day, Medium (M); and 6.4 mm/day, High (H)) and irrigation application within three specific growth stage namely, vegetative, reproductive and maturation stages by the low energy precision application (LEPA) center pivot irrigation system (Bordovsky et al., 2015). The climate at the study site is semi-arid and the soil is deep well-developed Pullman Clay Loam. The weather data required for the modeling including precipitation (mm), maximum and minimum air temperature (°C), wind speed (ms^{-1}), solar radiation (MJm^{-2}) and relative humidity (%)) for the period of 1977 to 2016 was obtained from the Texas High Plains Evapotranspiration Network (TXHPET) (Porter et al., 2005) weather station located at Halfway, TX. The crop management data were based on Bordovsky et al. (2015) cotton IWUE field experiment.

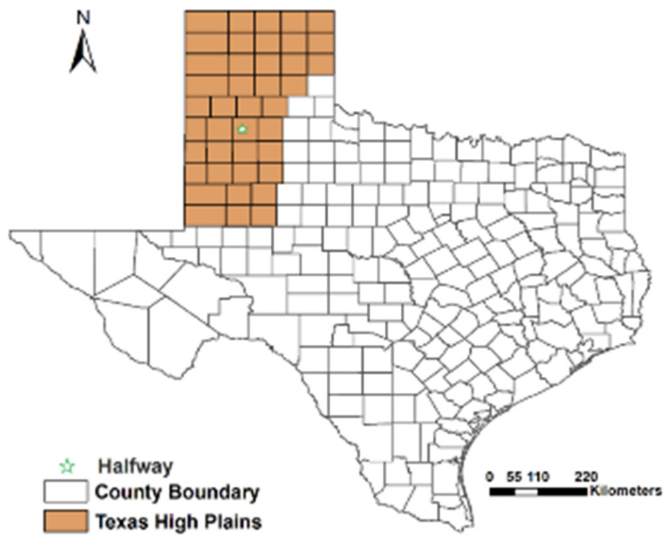

Figure 1. Study area location map

Methodology for long-term simulations: The evaluated DSSAT CSM CROPGRO-Cotton model (Adhikari et al., 2016) was used to simulate the long-term (1978-2016) effects of a combination of deficit/excess irrigation strategies (55%, 70%, 85%, 100% and 115% ET-replacement) and irrigation termination dates (ranging from August 15th to September 30th with one-week intervals). The irrigation was simulated assuming sprinkler irrigation system with an efficiency of 95%. The planting and harvesting dates were considered as May 11th and November 7th, respectively. Other assumptions were made based on the observations from cotton IWUE field experiment conducted at Halfway, TX during 2010 to 2013 (Bordovsky et al., 2015). The ideal irrigation termination period was suggested based on simulated cotton yield and IWUE (equation 1). A termination date was considered as ideal if the yield increase between that termination date and the subsequent termination date was < 5%.

The IWUE (kg m^{-3}) was estimated as:

$$IWUE = \frac{(Yield_{irr} - Yield_{dry})}{Irrigation} \quad \text{(Equation 1)}$$

Where,

$Yield_{irr}$: Irrigated seed cotton yield (kg/ha)

$Yield_{dry}$: Dryland seed cotton yield (kg/ha)

Irrigation: Total amount of irrigation water applied (m^3)

DSSAT-CSM model description: The DSSAT CSM simulates crop growth, development and yield in response to weather conditions, soil properties and management practices (Jones et al., 2003; Hoogenboom et al., 2012; Thorp et al., 2014). The latest version of DSSAT contains over 42 different crop growth simulation models including CROPGRO-Cotton for cotton (Hoogenboom et al., 2015). The DSSAT CROPGRO-Cotton module has been extensively used by researchers worldwide for various applications (Buttar et al., 2007; Thorp et al., 2014; Modala et al., 2015; Adhikari et al., 2016, 2017; Mauget et al., 2017; Amin et al., 2018). In the present study, long-term (1978-2016) simulations were performed using the Adhikari et al. (2016) DSSAT CSM CROPGRO-Cotton model to assess the effect of irrigation termination dates on cotton irrigation water use efficiency (IWUE) and seed cotton yield under full and deficit irrigation strategies. Flow chart showing the methodology adopted in this study is illustrated in Figure 2.

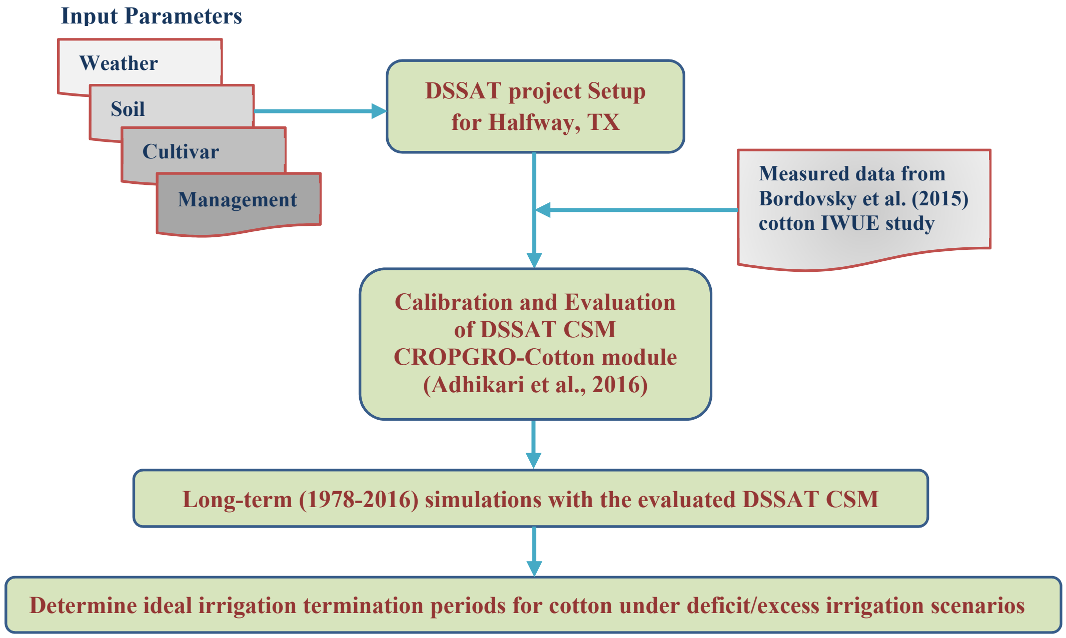

Figure 2. Flow chart showing the methodology adopted in this study

Results and Discussion

Simulated average (1978-2016) seed cotton yield and IWUE under a combination of ET-replacement practices and irrigation termination dates are presented in Figures 3 and 4, respectively. Providing excess irrigation than ET (115% ET-replacement) did not contribute to increase in cotton yield, especially in case of later irrigation termination dates. The simulated cotton yield in case of 55% ET-replacement was found to be the lowest under different irrigation termination dates among all irrigation practices followed by 70% ET-replacement practice. The reduction in simulated seed cotton yield when switching from 85% ET-replacement to 70% ET-replacement strategy was found to be much higher compared to switching from 100% ET-replacement to 85% ET-replacement strategy (Table 1). Based on the simulated cotton yield, the optimum irrigation termination period was found to be the 1st week of September for 115% ET-replacement, 2nd week of September for 100% and 85% ET-replacement, and 3rd week of September for 70% and 55% ET-replacement irrigation strategy (Table 1).

Simulated IWUE in case of 85% ET replacement was higher when compared to other treatments for most termination dates. In general, simulated IWUE in case of 115% ET-replacement was lower than that of 100%, 85% and 70% ET-replacement strategies with late irrigation termination dates. The simulated IWUE in case of 55% ET-replacement was found to be the lowest under different irrigation termination dates among all irrigation practices followed by 70% ET-replacement practice. Early termination of irrigation in the month of August could cause greater losses in cotton yield and IWUE, because during this time cotton passes through the peak bloom growth stage, which requires high amount of water due to growth and development of most of the reproductive structures. Water scarcity during peak bloom stage increases shedding (dropping of flower buds), reduces boll retention and flowering rate, and consequently loss in yield and IWUE. Based on the simulated IWUE, the optimum irrigation termination period was found to be the 1st week of September for 115% ET-replacement, 2nd week of September for 100% ET-replacement, and 3rd week of September for 85%, 70% and 55% ET-replacement irrigation strategy. Overall, the 85% ET-replacement irrigation strategy with irrigation termination of around 3rd week of September was found to be an efficient irrigation strategy for cotton under limited irrigation water availability.

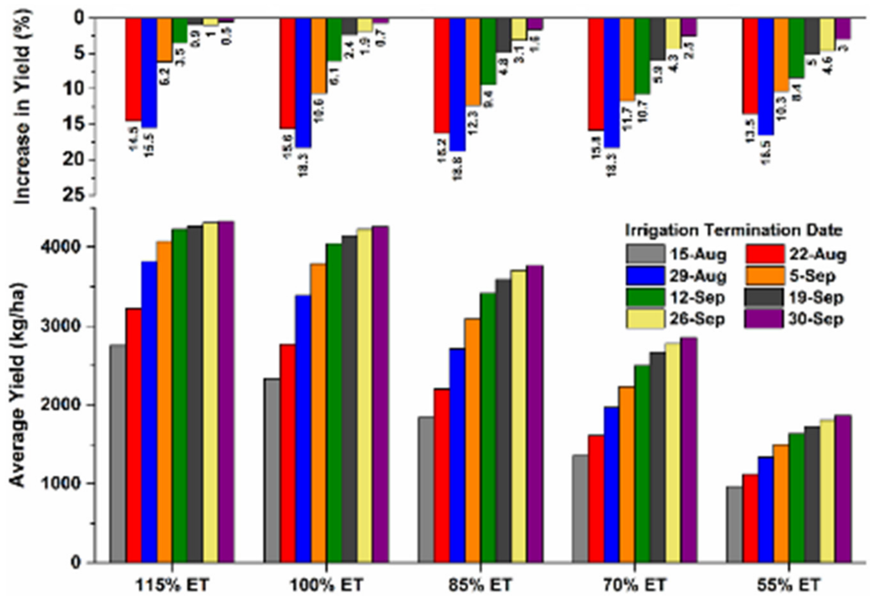

Figure 3. Simulated average (1978-2016) cotton yield under various scenarios considered in this study

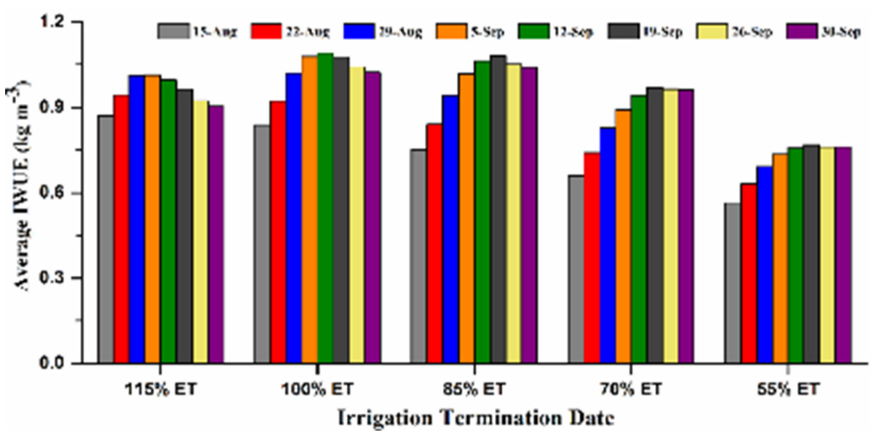

Figure 4. Simulated average (1978-2016) irrigation water use efficiency under various scenarios considered in this study

Table 1. Ideal irrigation termination periods under different deficit/excess irrigation practices based on average seed cotton yield and IWUE

Criteria	Ideal Irrigation termination period					Average yield*/IWUE**				
	115% ET	100% ET	85% ET	70% ET	55% ET	115% ET	100% ET	85% ET	70% ET	55% ET
Yield* (IWUE**)	Sep. 5	Sep. 12	Sep. 12	Sep. 19	Sep. 19	4075 (1.01)	4043 (1.09)	3418 (1.06)	2661 (0.97)	1724 (0.77)
IWUE (Yield)	Sep. 5	Sep. 12	Sep. 19	Sep. 19	Sep. 19	1.01 (4075)	1.09 (4042)	1.09 (3592)	0.97 (2661)	0.77 (1724)

*units: kg ha^{-1} **units: kg m^{-3}

Summary

Implementation of appropriate irrigation termination dates along with deficit irrigation strategies could ensure good cotton yield and increase IWUE. Based on the simulated cotton yield, the optimum irrigation termination period was found to be the 1th week of September for 115% ET-replacement, 2nd week of September for 100% and 85% ET-replacement, and 3rd week of September for 70% and 55% ET-replacement irrigation strategies. Similarly, based on the simulated IWUE, the optimum irrigation termination period was found to be the 1th week of September for 115% ET-replacement, 2nd week of September for 100% ET-replacement, and 3rd week of September for 85%, 70% and 55% ET-replacement irrigation strategies. Overall, the 85% ET-replacement irrigation strategy with irrigation termination around 3rd week of September was found to be an efficient irrigation strategy for cotton to conserve precious irrigation water from the Ogallala Aquifer.

Acknowledgements

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