Impacts of variable irrigation regimes on cotton yield and fiber quality

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Abstract
Water scarcity threatens the sustainability of irrigated cotton production in many regions around the world. Consequently, there is a critical need to identify and test strategies that optimize water use for cotton production. This 4-yr study evaluated the effects of three irrigation treatments (full irrigation [FI], reduced irrigation [RI] at 75% of FI, and no irrigation [NI]) on cotton yield, fiber quality, and irrigation water use efficiency (IWUE) at a field that relies on groundwater for irrigation in west-central Oklahoma. Compared with FI, lint and seed yields did not change significantly under RI. The reductions in lint and seed yields were significant at 64 and 65% under NI, respectively, compared with FI. No significant differences in fiber quality were observed among the irrigation treatments. In addition, reducing irrigation application improved the IWUE of lint and seed by 9 and 8%, respectively. Based on these findings, reducing groundwater extraction by 25% appears to be an effective strategy to achieve water conservation while limiting negative impacts on yield quantity and quality for cotton production in west-central Oklahoma.

1 INTRODUCTION

Reducing water use in irrigated agriculture has become a global priority because of the growing problems of recurring droughts and declining nonrenewable water resources (Brauman, Siebert, & Foley, 2013; Chen et al., 2020). Several irrigation management strategies to enhance water productivity have been discussed (Howell, 2006; Thorp, Thompson, & Bronson, 2020). For instance, deficit or reduced irrigation (RI) has been identified as an adaptive management strategy that can enhance water productivity and result in water conservation (Ali & Talukder, 2008; Mitchell-McCallister et al., 2020). Many reports have highlighted the need to conduct field studies to assess crop response to different levels of deficit irrigation (Geerts & Raes, 2009; Ünlü, Kanber, Koç, Tekin, & Kapur, 2011). Information on the effects of deficit irrigation on crop performance can assist producers with making informed decisions on the appropriate levels of deficit irrigation that would result in their desired water conservation and yield goals (Chen et al., 2020).

Field studies that optimize irrigation water conservation are particularly important in cotton production due to its global importance (Himanshu, Ale, Bordovsky, & Darapuneni, 2019; Mitchell-McCallister et al., 2020; Ulloa, De Santiago, Hulse-Kemp, Stelly, & Burke, 2020). However, several such studies have found mixed results of the
response of cotton yield and fiber quality to different levels of irrigation. Pettigrew (2004) and Snowden, Ritchie, Cave, Keeling, and Rajan (2013) observed inconsistencies in the response of fiber quality to RI. Witt, Ulloa, Schwartz, and Ritchie (2020) reported negative impacts of RI on fiber quality. Feng et al. (2014) reported an influence of location on the response of cotton yield and fiber quality to irrigation, an indication of the need to conduct local field studies.

In Oklahoma, cotton is one of the major irrigated crops that contribute significantly to the economy of the state (Masasi, Taghvaeian, Boman, & Datta, 2019). As in many other cotton-producing areas in the United States, Oklahoma cotton is mainly grown in areas that are water limited and vulnerable to drought (Khand, Taghvaeian, & Ajaz, 2017; Masasi, Taghvaeian, Gowda, Marek, & Boman, 2020; Taghvaeian & Boman, 2015). Hence, improving irrigation water use efficiency (IWUE) will play a critical role in the sustainability of Oklahoma cotton production (Masasi et al., 2019). The goal of this study was to investigate the responses of cotton yield, water use efficiency, and fiber quality to variable irrigation levels during four growing seasons at a site located in west-central Oklahoma.

2 MATERIALS AND METHODS

2.1 Study area, experimental design, and data analysis

The study was conducted over 4 yr (2014–2017) at a commercial cotton field under center pivot irrigation near the city of Hydro in west-central Oklahoma. The NexGen 1511 B2RF and NexGen 3406 B2XF cotton cultivars were planted in the first and last 2 yr of the study, respectively. In all years, the soil was covered with terminated winter wheat that was planted as cover crop. The predominant soil type at the study site is Pond Creek loam (Taghvaeian & Boman, 2015). Normal annual rainfall for the site is 801 mm (PRISM, 2020). Groundwater pumped from the Rush Springs aquifer is the source of irrigation water. This aquifer is highly responsive to variations in precipitation and irrigation extraction (Harlin & Wijeyawickrema, 1985), which was evident in its 2.1-m drop in water level during the drought of 2011–2015 (Khand et al., 2017).

The experimental design consisted of three irrigation treatments (full irrigation [FI], RI, and no irrigation [NI]) over the four growing seasons. The FI treatment was managed based on common irrigation practices of the study area, taking advantage of the full capacity of the groundwater well. The center pivot was programmed to apply 75% of the FI amount to the RI treatment. The NI treatment was placed at the corner of the field outside the reach of the center pivot. Tipping bucket rain gauges (Texas Electronics Inc.) were installed at each treatment to measure irrigation and rainfall amounts. The collected data by rain gauges were separated into irrigation and rainfall depths using the NI rain gauge and the data from the nearby Oklahoma Mesonet weather station.

At the end of each season, cotton was harvested from the three treatments by a picker-harvester, and grab samples were sent to the Texas A&M AgriLife Research and Extension Center in Lubbock, TX, for ginning to determine lint and seed yield. Samples of the cleaned cotton lint were sent to the Texas Tech University Fiber and Biopolymer Research Institute in Lubbock for high volume instrument analysis. Based on the fiber quality parameters, the Commodity Credit Corporation upland loan values for each treatment were estimated in U.S. dollars using the 2019/2020 Upland Cotton Loan Calculator from Cotton Incorporated.

A one-way ANOVA with Tukey’s honest significance difference was conducted on cotton yield, fiber quality parameters, and loan values to determine the effects of irrigation level. The IWUE was calculated as the ratio of the yield difference between FI/RI and NI treatments to seasonal irrigation amount (Himanshu et al., 2019; Ibragimov et al., 2007).

3 RESULTS AND DISCUSSION

3.1 Cotton yield

The responses of lint and seed yields to irrigation treatment were significant in every year of the study period (2014–2017). However, the ranking of treatments remained stable, and the year × treatment interaction was not statistically significant. Hence, the results are reported in terms of overall averages. The 4-yr average lint yields were 1,973, 1,866, and 710 kg ha⁻¹ for FI, RI, and NI, respectively (Figure 1). Seed yield averaged 2,558, 2,419, and 903 kg ha⁻¹ for FI, RI,
FIGURE 1 Four-year (2014–2017) average lint and seed yields for full irrigation (FI), reduced irrigation (RI), and no irrigation (NI) treatments and NI, respectively. The ANOVA results showed no significant differences in lint and seed yields ($p = .90$) between FI and RI. However, lint and seed yields for NI were significantly smaller compared with FI and RI ($p < .05$). When benchmarked against FI, there were 5 and 64% reductions in lint yield on average for RI and NI, respectively. Similarly, 5 and 65% of seed yield losses were found for RI and NI, respectively.

The results of this study are in agreement with the findings of other studies that reported lower yields when cotton was grown under RI and NI. For example, Howell, Evett, Tolk, and Schneider (2004) reported lint yields that were 33 and 65% smaller under half-FI and NI, respectively, compared with FI. Additionally, DeLaune, Mubvumba, Ale, and Kimura (2020) reported 7 and 12% reductions in lint yields in treatments that received 33 and 67% less irrigation water than the largest treatment in the Texas Rolling Plains. Pettigrew (2004) reported a 35% yield difference between FI and NI in Stoneville, MS. Several studies have reported that soil moisture deficits reduce the boll weight and ultimately the overall yield due to the induced water stress (Onder, Akiscan, Onder, & Mert, 2009; Ünlü et al., 2011). In Turkey, however, Dağdelen, Başal, Yılmaz, Gürbüz, and Akçay (2009) found no differences in fiber quality properties between FI and 75% RI levels, but fiber length and strength were significantly reduced in the 50 and 25% RI levels.

The estimated average loan values were not significantly different among the three treatments. The overall economic values of lint estimated as a product of the loan value and the lint yield were US$2,398, $2,289, and $843 ha$^{-1}$ for FI, RI, and NI, respectively. This shows 5 and 65% of revenue loss under RI and NI, respectively, compared with FI.

### 3.2 Cotton fiber quality

None of the quality properties was significantly ($p > .05$) affected by irrigation treatment (Table 1). In addition, all measured fiber parameters were within acceptable values based on the classifications by Cotton Incorporated for upland cotton. The results from this study are similar to the findings of several previous studies that reported no significant differences in cotton fiber quality parameters under different irrigation and/or soil moisture deficits levels (Chen et al., 2020; Pettigrew, 2004; Ünlü et al., 2011).

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### 3.3 Irrigation water use efficiency

Seasonal rainfall ranged from 364 to 503 mm during the study period, with an average of 439 mm. Rainfall distributions were different among studied seasons and influenced irrigation scheduling decisions. For instance, 54% of the seasonal rainfall in 2014 was received in the first quarter of the season, after which dry periods occurred. Hence, most irrigation applications took place during the dry periods in that year. The average seasonal irrigation applied was 165 and 137 mm at the FI and RI sites, respectively.
The 4-yr average IWUEs for lint (IWUE_{lint}) were 0.78 and 0.85 kg m\(^{-3}\) for FI and RI, respectively. The average IWUEs for seed (IWUE_{seed}) were 1.06 and 1.14 kg m\(^{-3}\) for FI and RI, respectively. The IWUE_{lint} and IWUE_{seed} values for RI were 9 and 8\% larger than their respective values for FI. The IWUE_{seed} estimates determined in this study were within the range of 0.93–1.27 kg m\(^{-3}\) reported by Chuanjie, Yi, Lin, and Na (2015) in China.

When seed cotton (lint plus seed) was used in computations, IWUEs of 1.84 and 1.99 kg m\(^{-3}\) were obtained for FI and RI, respectively. These values are comparable to the average IWUE of 1.97 kg m\(^{-3}\) determined under variable center pivot irrigation in Missouri (O’Shaughnessy et al., 2018). However, they are considerably larger than those reported in other studies, such as Ibragimov et al. (2007). Another example is Modala et al. (2015), who reported seed cotton IWUEs in the range of 0.58 to 1.25 kg m\(^{-3}\) in the Texas Rolling Plains.

CONCLUSIONS

A 4-yr study was conducted to investigate the impacts of FI, RI at 75\% of FI, and NI on cotton yield, fiber quality, and IWUE at a commercial field under center pivot irrigation located in west-central Oklahoma. The FI and RI treatments achieved larger seed and lint yields compared with the NI treatment. However, lint and seed yield differences were not significant between FI and RI. There were no significant differences in cotton fiber quality parameters among the three irrigation treatments. The lint and seed IWUEs were larger for RI compared with FI. Due to the nonsignificant yield differences, acceptable fiber quality, considerable water saving, and superior IWUE determined in this study, reducing cotton irrigation water applications by 25\% of the full capacity appears to be an effective approach to increase the longevity of groundwater resources while minimizing negative effects on cotton yield and quality in west-central Oklahoma. Implementation of regulated deficit irrigation, which means applying different levels of irrigation reductions at different cotton growth stages to minimize yield losses, should be investigated in future studies.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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