REGULATED DEFICIT IRRIGATION AND COTTON PRODUCTION RESPONSES IN SOUTHWEST TEXAS

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ABSTRACT

The urban water demand in Southwest Texas has grown rapidly in recent years due to large population increase. Regulated deficit irrigation (RDI) is one important measure for saving water while maintaining crop yield/ net benefit. An RDI field experiment was conducted at the Texas AgriLIFE Research and Extension Center at Uvalde in the summer of 2008 to examine the water saving potential. Seven irrigation schemes and four varieties were assigned to the experimental field to test their effects on lint yield.

The results showed that: 1) The threshold of the replacement ratio is between 0.7 and 0.8 in fixed ratio irrigation schemes. Dynamic irrigation schemes showed a higher potential to save irrigation water. 2) The fiber quality was affected more by varieties than by irrigation schemes. A 50X (fixed 50% ratio) scheme has the potential risk to produce relatively lower quality cotton fiber by affecting fiber length and fiber yellowness. Considering its negative effect on lint yield as well, the 50X scheme is definitely not recommended. The two dynamic irrigation schemes, 50D and 70D, showed no negative effect on fiber quality. The 70D scheme has some potential to increase the fiber quality in fiber length, uniformity, fiber strength and reflectance; however, this scheme uses more irrigation water that the 50D scheme. Although further research is needed before making definitive conclusions, both dynamic schemes could be applied to maintain lint yield and fiber quality while saving more water, compared to the fixed ratio irrigation schemes.

INTRODUCTION

The urban water demand in Southwest Texas has grown rapidly in recent years due to the fast population increase. Since the water resources in this area are limited, making a good plan for the available water supply is crucial. One possible way to assist in solving this problem is to reduce the agricultural water use through irrigation scheduling. However, the economic crop yield, or growers' profit, should at least be maintained.

Regulated deficit irrigation (RDI) is one important measure for saving water and maintaining crop yield and growers' net benefit (Goodwin, 2000; Jones, 2004; Fereres et al.,2007). Another advantage of deficit irrigation, according to Cull et al. (1981), is to permit utilization of precipitation. Some RDI studies were done over the last decades in North China (Zhang et al., 1998b; Zhang et al., 1999; Kang et al., 2000), Australia

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(French and Schultz, 1984), West Germany (Ehlers, 1989), North Syria (Zhang et al., 1998a), Turkey (Mert,2005; Basal et al., 2009; Dagdelen et al., 2009) and North Texas, USA (Howell et al., 2004). Several different irrigation regimes were tested, and the water use efficiency and transpiration efficiency of both dry matter of shoot and grain yield were discussed in details. However, these results cannot be applied directly to South Texas, as the climatic and hydrologic conditions are not the same, and the different crops may have different responses. Most of the irrigation regimes mentioned in the literature are relatively simple - the irrigation frequency was controlled without considering much about the irrigated water amount - which weakens the ability of the results to recommend irrigation improvement and predict crop responses.

The objectives of this study are: 1) to find the maximum water saving potential for cotton production in Southwest Texas; and 2) provide suggested irrigation schedules based on the lint yield and fiber quality.

MATERIALS AND METHODS

The Cotton RDI Experiment in 2008

A field experiment was conducted at the Texas AgriLIFE Research and Extension Center at Uvalde in the summer of 2008. A split-split-plot design experiment was assigned in a 90^{o} wedge (approximately 16.2 ha) of a 250m long center pivot field. The wedge was divided into four spans (48.8 m width each) and two "buffer zones" (filler spans). Each span had 48 rows, which were sub-divided into four 12-row plots to which a cotton variety (DP555, DP164, FM9063, and 989B2R) was randomly assigned. The cotton was planted on April 15, 2008, and harvested on September 25 (162 days after planting /162 DAP)).

Irrigation was applied by a center pivot with a low energy precision application (LEPA) system with 95% efficiency. Seven irrigation regimes were selected, including the fully irrigated (100X) as reference; four fixed deficit irrigation regimes: 80X, 70X, 60X and 50X; and two dynamic irrigation regimes: 70D and 50D. The treatments refer to the percentage of the net evapotranspiration of the well-watered crop (ΔET), which equals to the difference between evapotranspiration (ET) and rainfall (P) in a certain period that is replaced:

$$\Delta ET = ET - P$$

For instance, the number 50 in 50X stands for 50% replacement; that is, for each 1 mm water loss in the net evapotranspiration, we provide 0.5 mm water back to the field through irrigation. In practice, we recorded the daily ET and P to calculate the daily net water loss (ΔET), and then accumulated the net water loss day by day until it reached a certain limit (we used 38 mm in 2008), at which time irrigation was applied. In the fixed scheme (marked as X), the replacement rate (as percentage of ΔET) was kept constant regardless of the growth stages; e.g., 50X means that in each irrigation application we compensated the field with 50% of the water loss. In the dynamic scheme (marked as D), the irrigation was applied in different replacement ratios at each growth stages.In the beginning of growing season, deficit irrigation is applied to make better root establishment; at blooming and fruit-set stages, the field is fully irrigated (Meng et al., 2007); from 25-50% open boll to harvest, again, deficit irrigation is applied due to less water use by plant (Cohen et al., 1995). In our case, the ratios in each stage of the 50D scheme were: starting with 50% till first bloom, then changing to 100% till 50%-open boll, and then 10% thereafter until harvest. The ratios of 70D scheme in each stage were: starting with 70% till first bloom, then increasing to 100% until 50%-open boll, and reducing to 15% from then on. Our intent was to maintain the actual water use at 45-55% for 50D, and 65-75% for 70D, assuming little effect from precipitation. However, if intensive rainfall was received, especially at the end of the growing season, the total ratio may reach a higher than expected number.

The Data Collection and Analysis

On September 25, 2008, 12 m^2 areas were randomly selected in each experimental unit and all seed cotton was harvested in these sample areas with a cotton picker. Then small sub-samples were selected from each harvested sample, and ginned in the Cotton Improvement Lab (Texas A&M Univ., College Station, TX). According to the weight ratio of lint to seed cotton of the small samples, the lint yield in each experimental unit was estimated (in kg/ ha).

The small samples then were sent to the Fiber & Biopolymer Research Institute (Texas Tech Univ., Lubbock, TX) for USDA standard HVI test. The micronaire, fiber length, fiber uniformity index, fiber strength, elongation, fiber reflectance and fiber yellowness were tested as fiber quality parameters.

The lint yield and fiber quality data were analysed with PROC GLM (for MANOVA test) and PROC MIXED in SAS 9.2 (SAS Inc., NC), against two factors: irrigation schemes (7 levels) and varieties (4 levels). Both equal and unequal variance situations were considered and the best fit was selected based on AIC values as final results.

RESULTS AND DISCUSSIONS

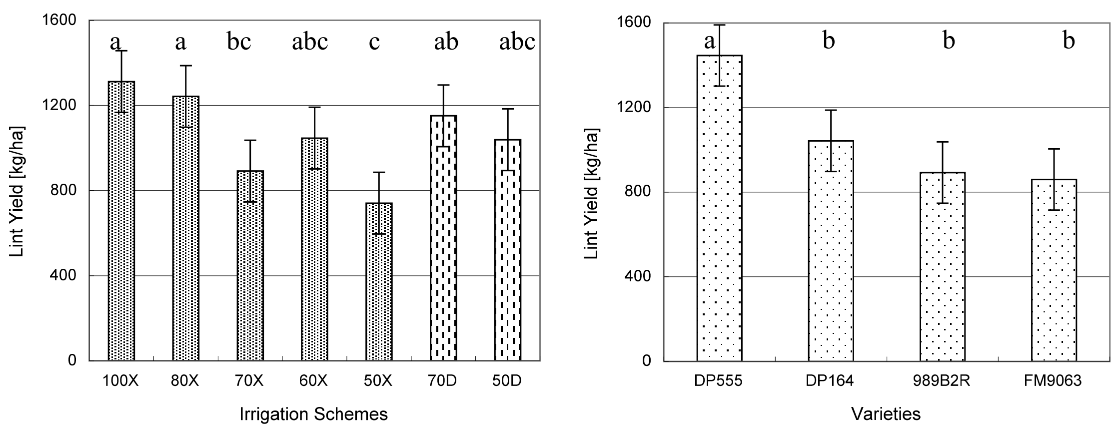
Lint Yield

The effects of irrigation scheme and variety on lint yield were first tested in the full statistical model to determine the significance of the interaction between the two factors. The interaction term was not significant, and thus was removed from the model. The main effect model indicated that both main effects were significant. The pairwised comparison results of irrigation scheme effect and variety effect are shown in Figure 1.

For fixed irrigation schemes, the lint yield of 80X and 100X were not different, but were significantly higher than that of 70X and 50X (Fig. 1(a)). Due to some technical failure the 60X treatment was over-irrigated twice in mid-July, which may have caused the abnormally high yield relative to 70X. It appears that the threshold of maintaining lint yield is between 70% and 80%. As the previous year research in Uvalde center showed that 75% replacement did not decrease lint yield significantly (result has not been published yet), and in some articles such as Basal et al. (2009) and Dagdelen et al. (2009) similar results were also reported, we conclude that the threshold was somewhere between 70% and 75%. It is not clear whether the threshold value is sensitive to the annual precipitation, which needs to be further studied.

The lint yield of the two dynamic schemes were not significantly lower than that of the 100% replacement. Thus, it appeared to be possible to save up to 50% of the irrigation water. However, our data were affected by two heavy rainfalls that occurred in mid-August, 2008, which brought 68.6 mm (Aug. 17, 2008) and 55.9 mm (Aug. 22-23, 2008) of precipitation, respectively. In this case there was no need to apply irrigation during the late growing season, but total ratios of 50D and 70D were raised to 80% and 85%, respectively. It is not possible to assume the possibility of 50% saving at this moment, but the 70% dynamic scheme could be applicable, which could potentially save up to 30% irrigation water, especially in late growing season.

The varietal response demonstrated in Fig. 1(b) showed that the lint yield of DP555 was approximately 50% higher than those of other varieties. No yield difference was found among the other three varieties.



(a) Irrigation Schemes (b) Varieties

Figure 1. Lint yield comparison among different irrigation schemes and varieties. The fixed schemes (100X, 80X, 70X, 60X, and 50X) are illustrated in dot-shaded bars, and dynamic schemes (70D and 50D) are shown in vertical-dashed bars in (a). The ranking results of the Tukey pairwised comparison are shown on the top of each bar. The bars with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

Fiber Quality

Balkcom et al. (2006) reported that irrigation regimes affected several fiber quality parameters, such as fiber length, fiber uniformity and micronaire. The similar results were expected in our study. Before analyzing each fiber quality parameter individually, we ran MANOVA (through PROC GLM) to test the significance of the main effects (irrigation schemes, varieties) and their interaction (irrigation scheme by variety). The result (Table 1) showed that the irrigation-variety interaction was not significant, and both main effects were significant. Thus, the initial statistical model of each parameter analysis was set as two main effects only. As mentioned in the previous section, both equal and unequal variance models were considered while fitting the data, and the better fit was selected as the final model. Table 2 gives a summary of the final model selection for each parameter. We concluded that based on Table 2, the irrigation scheme had effects on all parameters except micronaire (fiber fineness) and elongation; variety effects were present in all parameters. The elongation and yellowness (Hunter's +b) showed unequal variance, while the variances of the other parameters could be assumed equal. These parameters were discussed below in details.

Table 1. MANOVA test result of fiber quality parameters

	Irrigation Scheme	Variety	Irrig * Var
Wilk's Lambda	0.3154	0.02613	0.2308
F-value	2.11	23.45	0.89
Degree of Freedom	48 / 382.93	24 / 223.92	144 / 580.13
Pr > F	< 0.0001	< 0.0001	0.8054

Table 2. Summary of the final model selection for each fiber quality parameter

Parameter	Irrigation Scheme	Variety	Equal Variance
Micronaire	NS	*	Yes
Fiber Length	*	*	Yes
Fiber Uniformity Index	*	*	Yes
Fiber Strength	*	*	Yes
Elongation	NS	*	No
Reflectance	*	*	Yes
Yellowness	*	*	No

*: significant at 0.05 level. NS: not significant

Micronaire/ Fiber Fineness. There was no micronaire difference among the seven irrigation schemes (Table 2). DP555 had the highest micronaire value, and FM9063 had the lowest (Fig. 2). According to the fiber quality classification criteria provided by the National Cotton Council (www.cotton.org), FM9063's fibers were desirable (4.7 falls into 3.5-4.9), and the other three varieties' fibers were coarse (5.0 or higher).

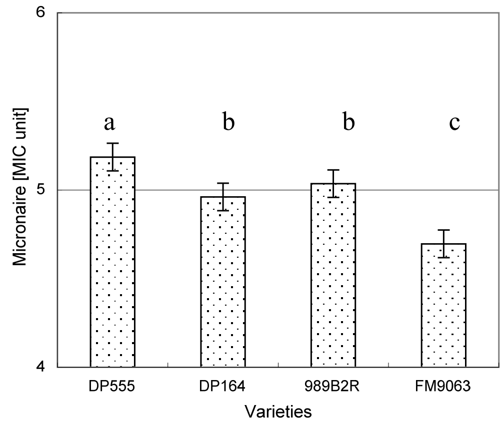
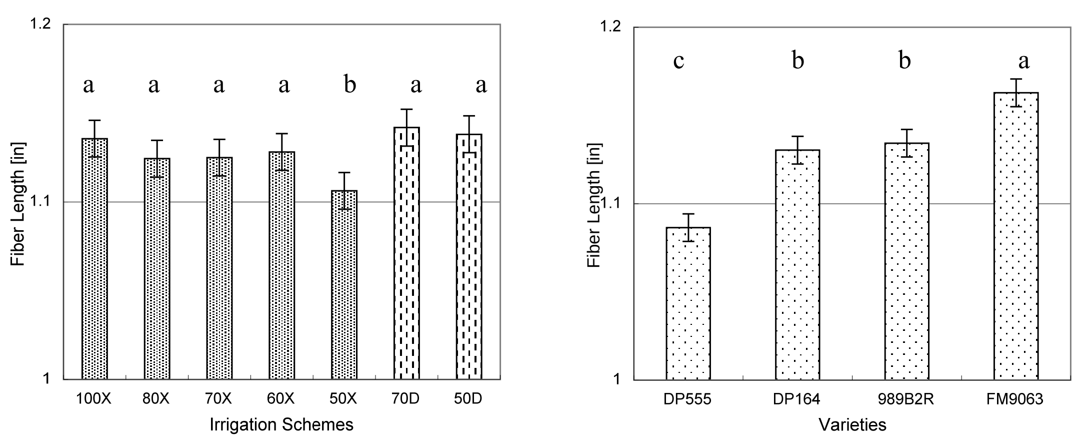


Figure 2. Micronaire comparison among four varieties. The line mark above/ below each bar is the confidence interval of each mean value.

<u>Fiber Length</u>. The 50X irrigation scheme significantly reduced the fiber length (Fig. 3(a)). Other fixed ratio schemes were not different. The two dynamic ratio schemes, especially the 50D, did not reduce fiber length. Although not significant, the mean fiber length of 70D is slightly higher than that of 100% irrigation, indicating that there might be potential to increase fiber length by the dynamic irrigation treatment. In general, all fiber length of each irrigation scheme showed long fiber (1.11 - 1.28). However, the mean fiber length of 50X is very close to the lower boundary, which may bring the risk of reducing fiber quality in length. In other words, 50X irrigation scheme may reduce fiber length, thus affecting the fiber quality.

The shortest fiber length was produced by DP555 and the longest by FM9063 (Fig. 3(b)). Besides DP555, the fiber length of the other three varieties exhibited long fibers. The mean fiber length of DP555 is 1.09, which is slightly lower than the lower boundary of the long fiber category, thus being classified into the medium group.



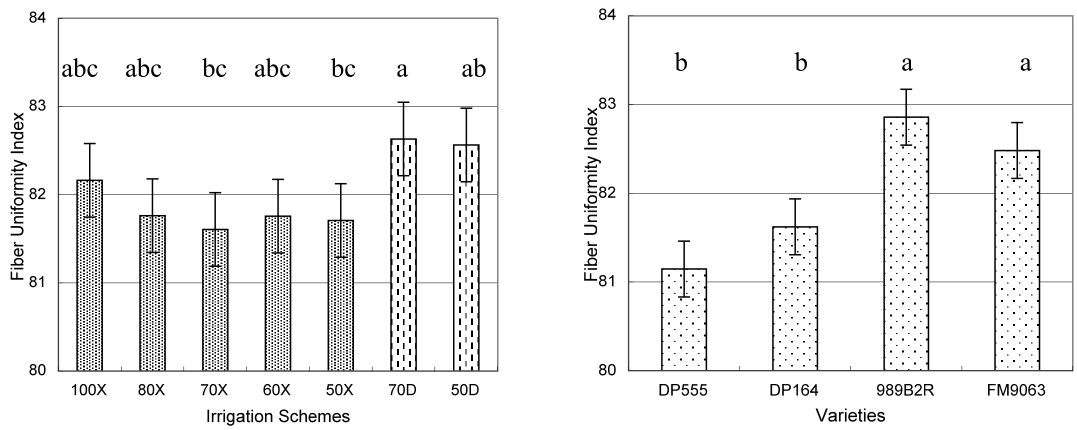
(a) Irrigation Schemes (b) Varieties

Figure 3. Fiber length comparison among different irrigation schemes and varieties. The two vertical-dash shaded bars in (a) are the two dynamic irrigation schemes. The ranking results of the Tukey pairwised comparison are shown on the top of each bar. The bars

with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

Fiber Uniformity Index (FUI). The fiber uniformity among five fixed ratio irrigation schemes were not different (Fig. 4(a)). Although not all significant, the two dynamic irrigation schemes illustrated higher uniformity than the fixed ratio ones, especially 50X and 70X. Both FUI means of the dynamic schemes were around 82.5, which is close to the lower boundary of the *high uniformity* classification (83 - 85). Other FUIs were between 80 and 82, which is classified as average uniformity. It seems that potentially, the dynamic irrigation schemes could improve the fiber uniformity.

Among four varieties, 989B2R showed the highest uniformity (classified as high according to NCC criteria), followed by FM9063; the uniformities of DP555 and DP164 were average, which were significantly lower than 989B2R and FM9063 (Fig. 4(b)).

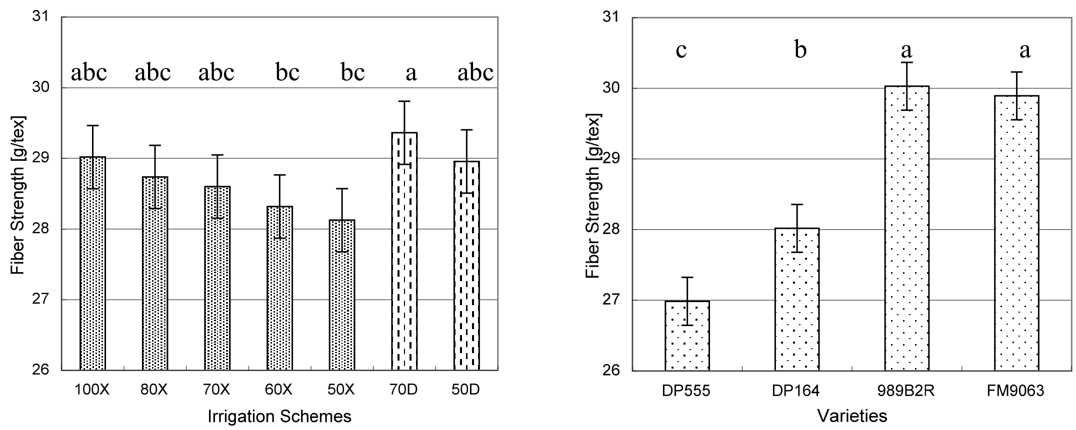


(a) Irrigation Schemes (b) Varieties

Figure 4. Fiber uniformity index (FUI) comparison among different irrigation schemes and varieties. The two vertical-dash shaded bars in (a) are the two dynamic irrigation schemes. The ranking results of the Tukey pairwised comparison are shown on the top of each bar. The bars with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

Fiber Strength. The fiber strength of 70D was significantly higher than that of 60X and 50X, while other treatments showed no difference (Fig. 5(a)). The fiber strength of all seven irrigation schemes were classified as "high" (27-29 for long fiber). It seems that 70D has the potential to increase fiber strength.

The fiber strength of 989B2R and FM9063 were classified as "very high" (30-32 for long fiber). DP555 and DP164 had lower fiber strength values, which were still classified as "high" (27-29 for long fiber).



(a) Irrigation Schemes (b) Varieties

Figure 5. Fiber strength comparison among different irrigation schemes and varieties. The two vertical-dash shaded bars in (a) are the two dynamic irrigation schemes. The ranking results of the Tukey pairwised comparison are shown on the top of each bar. The bars with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

Elongation. No effect on elongation was found among the seven irrigation treatments. DP164 showed the highest elongation and DP555 the lowest (Fig. 6). The fiber elongation of all four varieties was classified as "average" (5.9-6.7).

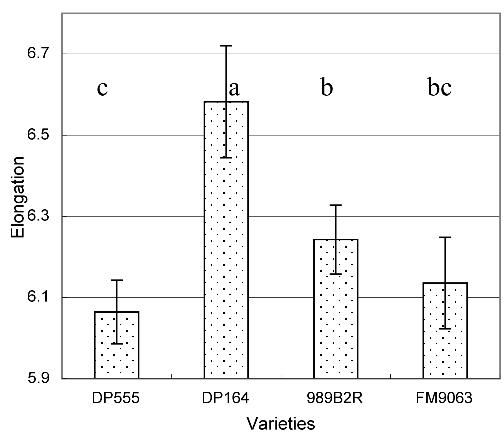
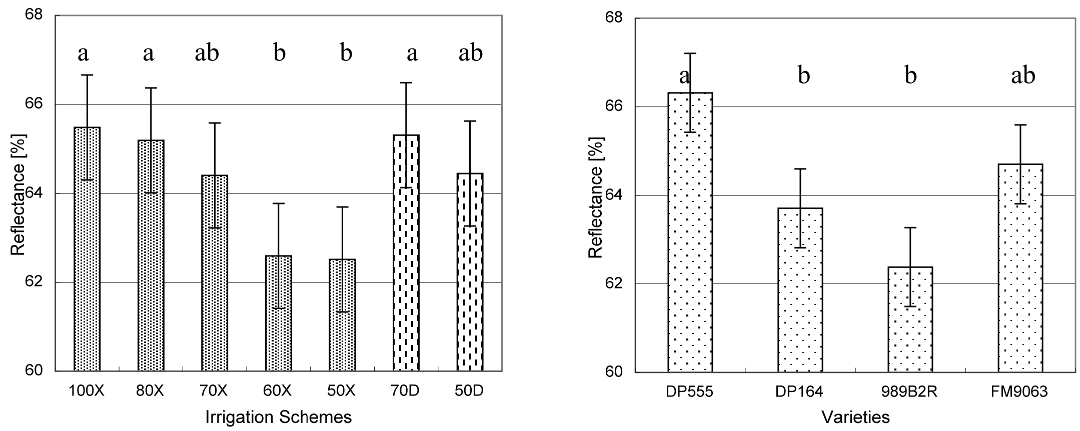


Figure 6. The fiber elognation comparison among four varieties. The ranking results of the Tukey pairwise comparison are shown on the top of each bar. The bars with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

Fiber Greyness/ Percent Reflectance. The fibers of 60X and 50X had lower reflectance than 100X, 80X and 70D. In general, dynamic irrigation schemes did not reduce the fiber quality by affecting reflectance. The two dynamic schemes were not different than 100X

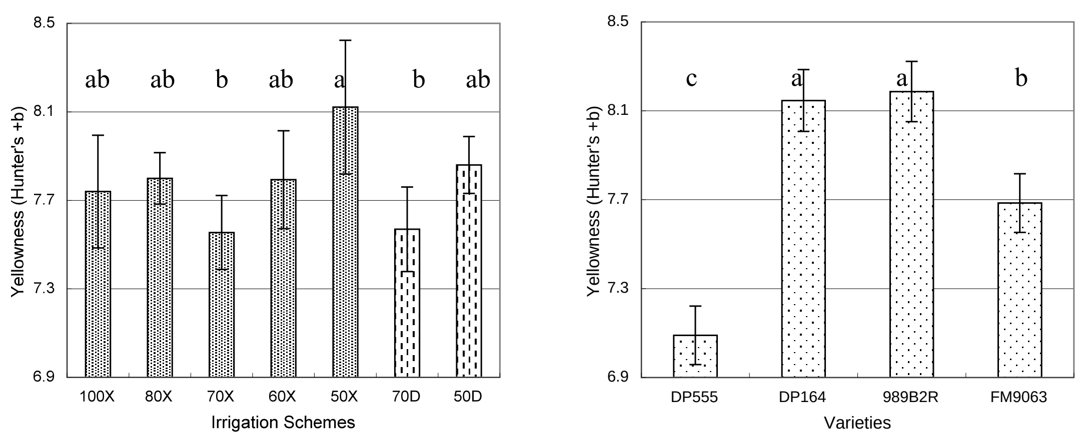
(Fig. 7(a)). DP555 and FM9063 showed higher reflectance than DP164 and 989B2R (Fig. 7(b)).



(a) Irrigation Schemes (b) Varieties

Figure 7. Fiber greyness/ reflectance [%] comparison among different irrigation schemes and varieties. The two vertical-dash shaded bars in (a) are the two dynamic irrigation schemes. The ranking results of the Tukey pairwised comparison are shown on the top of each bar. The bars with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

Fiber Yellowness (+b). 70X and 70D had lower yellowness indices compared to other irrigation schemes. 50X showed the highest yellowness with a larger variation than other treatments, indicating a potential risk of fiber quality reduction by increasing the yellowness (Fig. 8(a)). The fiber of DP555 was the least yellow fiber among all four varieties. DP164 and 989B2R produced the most yellow fiber (Fig. 8(b)).



(a) Irrigation Schemes (b) Varieties

Figure 8. Fiber yellowness (+b) comparison among different irrigation schemes and varieties. The two vertical-dash shaded bars in (a) are the two dynamic irrigation schemes.

The ranking results of the Tukey pairwised comparison are shown on the top of each bar. The bars with common letters are not significantly different. The line mark above/ below each bar is the confidence interval of each mean value.

CONCLUSIONS

In summary, the following conclusions can be drawn:

1) The threshold of the replacement ratio is between 0.7 and 0.8 in fixed ratio irrigation schemes. Dynamic irrigation schemes showed a higher potential to save irrigation water and still maintain yield and quality.

2) The fiber quality is affected more by variety than by irrigation scheme. The 50X scheme has the potential risk to produce relatively lower quality cotton fiber by affecting fiber length and fiber yellowness. Considering its negative effect on lint yield as well, the 50X scheme is not recommended. The two dynamic irrigation schemes, 50D and 70D, showed no negative effect on fiber quality. The 70D scheme may have some potential to increase the fiber quality in fiber length, uniformity, fiber strength and reflectance. Further research is needed before making conclusive recommendations, but it appears both dynamic schemes could be used to maintain lint yield and fiber quality while saving water.

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