Research Article

Response of Cotton (*Gossypium Hirsutum* L.) Cultivars to Different Irrigation Regimes in Zero Tillage System

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Abstract | Water shortage is becoming a serious concern for all crops and particularly for cotton, which has been a major export contributor of Pakistan. In this scenario, drought-tolerant cotton cultivars with zero tillage could be the best option. This research aims to quantify the impact of limited water on lint yield and quality of cotton genotypes. An experiment was managed in a split plot, randomized complete block design, replicated thrice at the Agricultural Research Institute, Dera Ismail Khan. The experiment was conducted in 2016 using treatments irrigation intervals (10, 15, 20 and 25 days) and Bt cotton varieties (MNH-886, CRIS-342, and CRIS-134) as main- and sub-plots treatments, respectively. Total irrigation water used in irrigation treatments, 10, 15, 20, and 25 days intervals were 1125, 750, 560, and 450 mm, respectively. Each experimental unit was 10 × 3 m^2. Results showed that all the parameters under study had a significant response to the treatments irrigation intervals. Irrigation intervals of 10 days produced more sympodial branches (14) and higher plant height (131cm) as compared to other irrigation intervals. Higher bolls (19 / plant), boll weight (2.9 g), seed cotton (2424 kg ha^{-1}), ginning out turn (GOT, 37%), fiber length (28.1mm), fiber strength (29.5 g per tex) and micronaire value (3.5 µg per inch) were achieved from irrigation interval of 25 days. Interaction effects (irrigation x varieties) revealed that variety CRIS-134 in combination with 25 days irrigation interval conserved 60 % more water, produced 60.5% more bolls per plant, 21.1% higher GOT, 48.7% higher seed cotton yield, and 12.4% higher fiber length compared to all other combinations. Results indicate that CRIS-134 with 25 days irrigation interval in zero tillage system is more advantageous and adaptable in agro-ecological conditions of Dera Ismail Khan.

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Introduction

Cotton (*Gossypium hirsutum* L.) is an important cash crop of Pakistan (Ibrahim et al., 2007; Ashraf et al., 2018). It supplies raw materials to textile industries and is called silver-fiber due to its unique quality (Arshad and Anwar, 2007). Cotton is used in garments, medicines and furnishings of homes. Pakistan is the 5th biggest cotton producers after India, China, United States, and Brazil (Statista, 2018). However, Pakistan is not producing sufficient raw materials for national textile mills. Accordingly, Pakistan is the first among leading cotton importing countries of the world such as Bangladesh, Turkey, Vietnam, China, and Indonesia (APTMA, 2018). In Pakistan cotton cultivated area has reached to 3 million hectares; share in GDP to 1.5% and value added to agriculture 7.0% (MNFSR, 2015). The present area under cotton cultivation with low production per unit area cannot meet even the domestic requirement of the growing population. Since extension of the existing area under cotton may not be possible as already occupied by major crops such as wheat, rice, maize, and sugarcane, the possible alternative is to increase cotton yield on the existing area. There are several factors that affect cotton productivity; however, genotype and water are the two key factors that can affect cotton more seriously than all other factors. Cotton yield can be optimized with suitable genotype and optimum use of irrigation water; however, there is acute shortage of irrigation water and of high yielding genetically pure genotype. Current water crisis in agriculture, gives emphasis on efficient use of water resources (Azevedo et al., 2012). Cotton is a deep rooted crop and the growers consider soil inversion deep tillage necessary for the previous crop residues management. With this practice they also intend to create favorable environment for cotton roots penetration. This practice not only incurs the tillage cost but also causes more use of irrigation water by increasing soil water evaporation. Unlike the prevailing practice, cotton grown with zero tillage in the standing stubbles of the previous wheat crop improves water management for cotton by reducing soil water evaporation (Balkcom et al., 2007). Roots of the previous wheat crop decompose and create channels through compacted soil layers, which enable subsequent crop roots to grow through the compacted zone and thus improve infiltration (Williams and Weil, 2004). Since, water consumption is more in conventional tillage than in conservation tillage (Hearn, 2000); drought tolerant genotype grown with conservation practices may give economic yield with limited irrigation water at reduced cost of cultivation (Xi-ping et al., 2004; Hackwell et al., 1991; CTIC, 2004; Shipitalo and Owens, 2006; Usman et al., 2013). Increasing water use efficiency by potential genotype grown with conservation tillage can be an important criterion for enhancing yield under water stressful environment. Several researchers have confirmed positive impact of zero tillage system on cotton quality, economics and water use efficiency (Hulugalle et al., 2004; Tursonov, 2009). More recent studies revealed that increased cotton yield and quality under zero tillage system might be due to improved water use efficiency (WUE), soil fertility, and nutrient status (Hulugalle et al., 2004).

Cotton is a warm season crop that needs regular supply of water, either from irrigation or rainfall. Successful cotton production depends on availability of water. The world scientists are in search of low inputs agriculture including wise use of irrigation water to optimize production from existing limited water (Xi-Ping et al., 2004). Using inadequate water for enhancing cotton productivity is one of the major challenges for agriculturists (Tennakoon and Milroy, 2003) Tang et al. (2005). WUE can be improved by adopting best irrigation management practices (Goyne and Mcintyre, 2001). Effective agronomic practice needs to be explored which has the potential to enhance WUE and cotton yield (Mcalavy, 2004). Since the study area, Dera Ismail Khan, is an arid region and has limited rainfall in addition to low organic matter status of the soil, high yielding genotype grown with zero tillage could be a viable option for efficient use of inadequate irrigation water. Moreover, a drought-tolerant cotton cultivar should be searched being well fit in the region, particularly genetically modified high yielding and drought tolerant variety (Bt). CRIS-342 is an early maturing drought tolerant genotype which takes about 40-45 days to appearance of first flower followed by CRIS-134 (Baloch et al., 2014). It is also high yielding Bt variety and performs well even in adverse environmental conditions. MNH-886 (Bt.) is an upland cotton cultivar (*Gossypium hirsutum* L.) developed through hybridization of three parents [(FH - 207 × MNH- 770) × Bollgard-1] at Central Cotton Research Station Multan, Pakistan. It is high yielding and disease resistant (CLCuVD) variety. CRIS-134 is an early maturing Bt variety having higher bolls per plant, seed cotton yield, and more lint index. Since a little research was done before to investigate the effect of irrigation intervals on different transgenic cultivars under zero tillage; therefore, the present research was aimed to examine the response of cotton cultivars under limited water condition, and to look for best performing Bt. variety of cotton under no-tillage system.

Materials and Methods

Experimental site

An experiment was carried out at Agriculture Research Institute, Dera Ismail Khan in 2016. Five soil samples were collected randomly from 0-30cm soil depth from the study area. The soil samples were analyzed for physico-chemical characteristics. The study area is characterized by hard calcareous soils, high summer temperature (35-40°C), low annual rainfall 180-250 mm) and a pH (>7.0). Total rainfall during the study year was 215 mm (Table 1).

Table 1: *Weather conditions at agricultural research institute, Dera Ismail Khan, Pakistan.*

Year 2016				
Month	**Temperature °C**			**R.F. (mm)**
	Max.	**Min.**	**Avg.**	
May	38.9	23.4	31.1	15.0
June	41.8	27.0	28.5	6.0
July	45.0	27.2	31.5	126.0
Aug.	41.0	20.0	30.5	43.0
Sept.	40.0	18.0	29.0	40.0
Oct.	36.0	17.9	27.0	-
Nov.	27.8	10.4	19.1	3.0
Total rainfall (mm)				233.0

Experimental procedure

The experiment was laid out in a randomized complete block design with split-plot arrangement replicated thrice. Irrigation was given according to treatment detail with 10, 15, 20, and 25 days interval each at a depth of 7.5cm. In this way, the quantity of irrigation used in 10, 15, 20, and 25 days interval during the growing season was 1125, 750, 560, and 450 mm, respectively. Irrigation intervals (10, 15, 20, and 25 days) and varieties viz. CRIS-134, MNH-886, CRIS-342) were kept in the main plots and subplots, respectively. Subplot size was 10m × 3m bearing 4rows of 10m length. Fertilizer i.e. N, P and K fertilizers were given at the rate of 150:60:50 kg/ha. Whole P and potash as TSP and SOP sources, respectively, were given during field preparation, whereas N as urea was given in three equal splits i.e. at thinning, flowering and boll formation stage. Lines were drawn with cotton seed planter in the field previously occupied with wheat and cotton was sown with dibbling method into wheat residues without land preparation. Sowing was done on May 28, 2016, with a seed rate of 20 kg ha^{-1}. Four seeds were sown $hill^{-1}$ with 75cm in rows spaced 22.5cm. Thinning was done 20 days after emergence. One healthy seedling $hill^{-1}$ was left while weak and diseased plants were removed. Agronomic practices such as weeds and insect pest management were adopted equally in the experimental plots. Harvesting was done on 30th November 2016.

Procedure for data recording

The parameters studied were plant height (cm), sympodia per plant, bolls per plant, boll weight (g), seed cotton yield (kg ha^{-1}), GOT (%), fiber length (mm), fiber strength (g tax^{-1}) and fiber micronaire (g $inch^{-1}$). Six randomly selected plants were tagged in each subplot at maturity for measuring plant height and recorded average plant height (cm), Sympodial branches, bolls per plant. Total bolls on each plant were counted manually and then averaged. Fifty bolls were randomly collected from each plot and were weighed for recording average boll weight. Seed cotton yields per plot were weighed with an electronic balance and converted into kg ha^{-1} as given.

$$\text{Seed cotton yield (kg}^{-1}) = \frac{\text{Plot yield (kg)}}{\text{plot area (m}^2)} \times 10000$$

Ginning out turn was recorded by taking seed cotton samples from each plot. After cleaning and sun drying the samples were then ginned with electric ginning machine. The lint attained was weighed and GOT was calculated by the following formula.

$$\text{GOT (\%)} = \frac{\text{Lint yield (kg)}}{\text{Seed cotton yield (kg)}} \times 100$$

Fiber quality such as fiber length, fiber strength (g/tex), and fiber micronaire (µg/inch) was found out through high-volume instrument system taking 50 g sample of lint from each treatment.

Statistical analysis

Statistical analyses of the data were performed as per ANOVA techniques (Steel et al., 1997) and significant results were subjected to LSD test for mean comparison using MSTATC software (MSTATC, 1991).

Results and Discussion

Plant height (cm)

Plant height showed a significant response to irrigation intervals; however, it did not respond to varieties and irrigation × varieties interaction significantly. Results revealed that irrigation applied with 10 days interval produced highest plant height (131 cm) compared to 15, 20, and 25 days irrigation intervals (Table 2). Regression analysis revealed that plant height had a quadratic response to increasing irrigation intervals (Figure 1a), that is, plant height decreased as the irrigation interval increased from 10 to 25. However, if irrigation interval is further increased from 25 to 30, the trend shows much lower plant height indicating negative growth rate. The higher plant height with frequent irrigations might be due to the growing of more nodes and reduced canopy temperature as reported by Wiggins (2012). Siskani et al. (2015) communicated similar findings who reported that water stress reduced plant height of cotton. They further reported that irrigation applied as per requirement of the crop resulted in higher plant height.

Table 2: *Irrigation intervals and cultivars effects on sympodia per plant, plant height, bolls/plant, boll weight and seed cotton yield under zero tillage system.*

Irrigation intervals(I)	Plant height (cm)	Sympodia/ plant	bolls/ plant	Boll weight (g)	Seed cotton yield (kg/ha)
10 days	131 a	14a	12 c	2.3 c	1647 d
15 days	124 b	11b	14 b	2.5 b	1891 c
20 days	114 c	8c	15 b	2.6 b	2095 b
25 days	105 d	7c	19 a	2.9 a	2424 a
$LSD_{0.05}$	5.71	1.76	1.27	0.13	67.38
Varieties (V)					
MNH-886	114	8 b	13 c	2.5	1740 c
CRIS-342	119	10 b	15 b	2.7	2027 b
CRIS-134	122	13 a	19 a	2.6	2275 a
$LSD_{0.05}$	-	1.73	0.64	-	47.94
I x V interaction	NS	NS	*	NS	**

Note: *Means followed by different letter (s) differ significantly at P≤5%.*

Sympodial branches per plant

Effect of irrigation intervals and cultivars were significant while interaction was not significant regarding sympodial branches per plant. Crop irrigated with 25 days interval produced more sympodia (14 plant^{-1}) as compared to the rest of the given treatments i.e. 10, 15 and 20 days intervals (Table 3). Cultivar CRIS-134 had a higher number of sympodia (13 plant^{-1}) as compared to CRIS-342 and MNH-886 both having a similar number of sympodial branches. Regression analysis showed that sympodia plant^{-1} had a quadratic response to irrigation intervals (Figure 1b). The trend line showed a similar pattern as mentioned for plant height. Sympodia per plant decreased with the increase in irrigation interval from 10 to 25 days. Variations in the cultivars genetic makeup might be the reason for the variation in sympodial branches. Copur (2006) reported that sympodial branches per plant were different for different varieties. Pedroza and Flores (1998) arrived at analogous results and concluded that irrigation intervals affected sympodial branches substantially, whereas cotton varieties of different genetic makeup produced great variation in the number of sympodia.

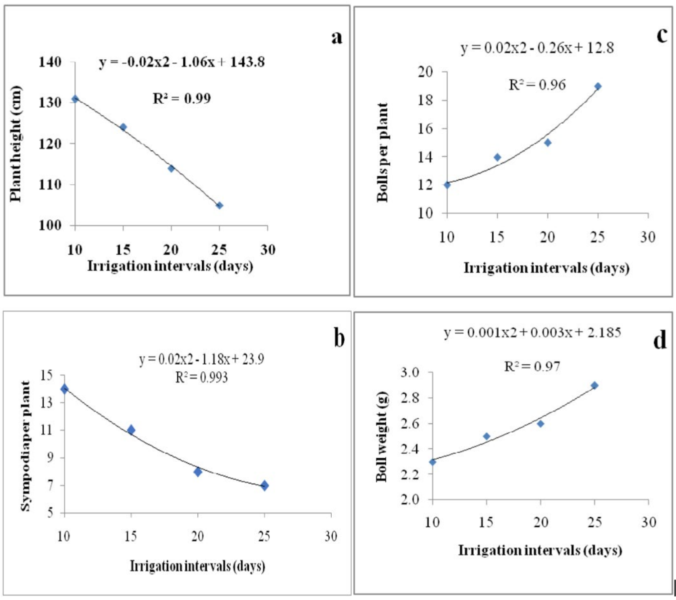

Figure 1: *Plant height (cm); (a): sympodia per plant, (b): bolls per plant, (c) and boll weight (g) as affected by irrigation intervals (days).*

Bolls plant^{-1}

Bolls plant^{-1} showed a significant response to irrigation intervals, cultivars, and their interaction. Irrigation with 25 days interval produced significantly more bolls per plant compared to all other irrigation intervals. Varietal mean revealed that CRIS-134 produced higher bolls count per plant compared with CRIS-342 and MNH-886. Interaction effect revealed that CRIS-134 in combination with 25 days irrigation interval had the highest number of bolls per plant. Irrigation with 25 days interval had probably more favorable moisture content than lower or higher irrigation interval under ZT cotton which resulted in the development of more fruiting bodies (Mcvay et al., 2006). Bolls per plant showed a curvilinear response to different irrigation intervals (Figure 1c). Bolls per plant increased with an increase in irrigation intervals from 10 to 25, however, further increase beyond 25 days interval may not be productive for the reduced rate of boll growth. These findings tallied with those of Ertek and Kanber (2001) who reported that an optimum number of irrigations could result in more boll formation. Further, they reported the number of bolls as a genetic parameter that differed for different cultivars (Ehsan et al., 2008). Copur (2006) and Anwar et al. (2002) also had similar findings who reported that different varieties had the different number of bolls plant^{-1} due to differences in their genetic potential.

Boll weight (g)

Boll weight showed a significant response to irrigation intervals whereas interaction was not significant. Boll weight was higher (2.9 g) with 25 days irrigation interval compared with other irrigation intervals (Table 2). Irrigation with 25 days interval resulted in heavier bolls compared to 10, 15, and 20 days intervals. Regression analysis revealed that boll weight had a quadratic response to irrigation intervals (Figure 1d). Boll weight fluctuates between values of 2.3 and 2.9 with irrigation interval from 10 to 25 days. The regression equation indicates that 25 days irrigation interval is optimum for boll weight as a further increase in irrigation interval up to 30 days may result in reduced growth rate. This was probably because of increased translocation of photosynthates from source to sink (boll) due to more favorable soil environment for uptake of nutrients compared to all other irrigation regimes (as more moisture favored more vegetative growth rather than reproductive growth) (Dumka et al., 2004). Heavier boll weight with 25 days irrigation interval was perhaps due to more favorable moisture condition for lesser evaporative losses from zero tillage cotton as reported by Silburn et al. (2007).

Seed cotton yield (kg ha^{-1})

Results revealed that varieties, irrigation intervals, and varieties x irrigation interaction had significant effects on seed cotton yield. Results revealed that 25 days irrigation interval proved to be more productive regarding seed cotton yield than all other intervals (Table 2). Irrigation intervals 10 to 20 days had lower seed cotton yield perhaps due to excessive soil moisture that led to more dynamic vegetative growth rather than seed cotton yield. Besides higher seed cotton yield, irrigation with 25 days interval was cost-effective as it saved more water (60%) when compared with 10 days interval (check treatment for comparison). Varietal means revealed that CRIS-134 produced higher seed cotton yield while MNH-886 produced lower seed cotton yield. Interaction effect revealed that CRIS-134 in combination with 25 days irrigation interval produced higher seed cotton yields (Figure 2a). Trend line drawn for seed cotton yield in relation to irrigation intervals showed a quadratic response to an incremental increase in irrigation intervals (Figure 2b). It can be predicted from regression analysis that irrigation interval beyond 25 days may not be productive for the reduced rate of growth as a consequence of low moisture stress. Lower seed cotton yield with shorter irrigation intervals (10 to 20 days) might be due to excess moisture stress that led to flowers and bolls dropping (Ertek and Kanber, 2001). Similar findings were conveyed by Sahito et al. (2015).

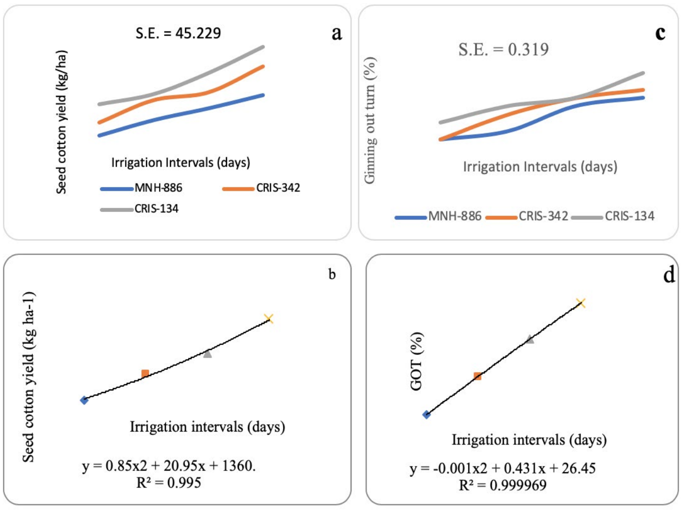

Figure 2: *(a): Interactive effect of genotypes x irrigation intervals on seed cotton yield; (b): Irrigation effect on seed cotton yield; (c): interactive effect of genotypes x irrigation intervals on GOT and (d): irrigation effect on GOT.*

who reported that irrigation interval more than 20 days produced higher seed cotton yield. Encisco et al. (2003), Guerra et al. (2002) and El-Shahawy and Abd-El-Malik (2005) had comparable findings who reported that moderate volume of irrigation would be more economical than excessive use of water. Furthermore, they reported that varieties with different genetic background had different seed cotton yields.

Ginning out turn (%)

GOT was significantly affected by irrigation intervals, cultivars, and their interaction. It is evident from the values shown in Table 3 that irrigation with 25 days interval produced highest GOT (37%) among all other irrigation intervals. Varietal means revealed that CRIS-134 produced higher GOT while MNH-886 produced lower GOT. Interaction effect revealed that CRIS-134 in combination with 25 days interval produced highest GOT of 38% (Figure 2c). Regression analysis revealed that there was an increase in GOT with the incremental increase in irrigation interval showing quadratic trend line (Figure 2d). Got had the almost similar response to irrigation intervals as mentioned for seed cotton yield. Arshad et al. (2003) and Wang et al. (2004) recorded variable GOT among different varieties and reported that variation might be due to environmental or genetic factors/heterosis. The results of the present investigation are in line with previous findings by El-Shahawy and Abd-El-Malik (2005) and Abdel-Malak and Radwan (1998) who reported that GOT was associated with the genetic makeup of a variety.

Fiber length (mm)

Data pertaining to fiber length was affected significantly by irrigation intervals, cultivars, and their interaction. Mean values revealed that irrigation with 25 days interval produced lengthier fibers (28.1 mm) compared to other irrigation intervals (Table 3). Varietal means revealed that CRIS-134 produced higher fiber length while MNH-886 produced lower fiber length. Interaction effect revealed that CRIS-134 in combination with 25 days interval produced maximum fiber length of 28.8 mm (Figure 3a). Regression analysis showed that fiber length had a curvilinear response to irrigation intervals (Figure 3b). Ashokkumar and Ravikesavan (2011) reported that fiber length differed widely with genotypes and environment.

Fiber strength (g tex^{-1})

Irrigation intervals affected fiber strength whereas varieties and irrigation intervals × varieties interaction were not significant. Mean values shown in Table 3 revealed that irrigation intervals of 25 days had more fiber strength (29.5 g tex^{-1}) compared with 10, 15, and 20 days interval (Table 3). Fiber strength showed a quadratic trend line with respect to different irrigation intervals (Figure 3c). Trend line showed maximum value for fiber strength at 25 days irrigation interval. It can be predicted from regression analysis that increasing irrigation interval beyond 25 days may not result in significantly higher fiber strength for reduced growth rate. It is evident from the results that excess moisture stress negatively affected fiber strength. Gutstein (1997) had also analogous results who reported that water in excess of cotton crop water requirement reduced fiber strength. Faircloth (2007) reported that fiber strength (g tex^{-1}) varied among cultivars.

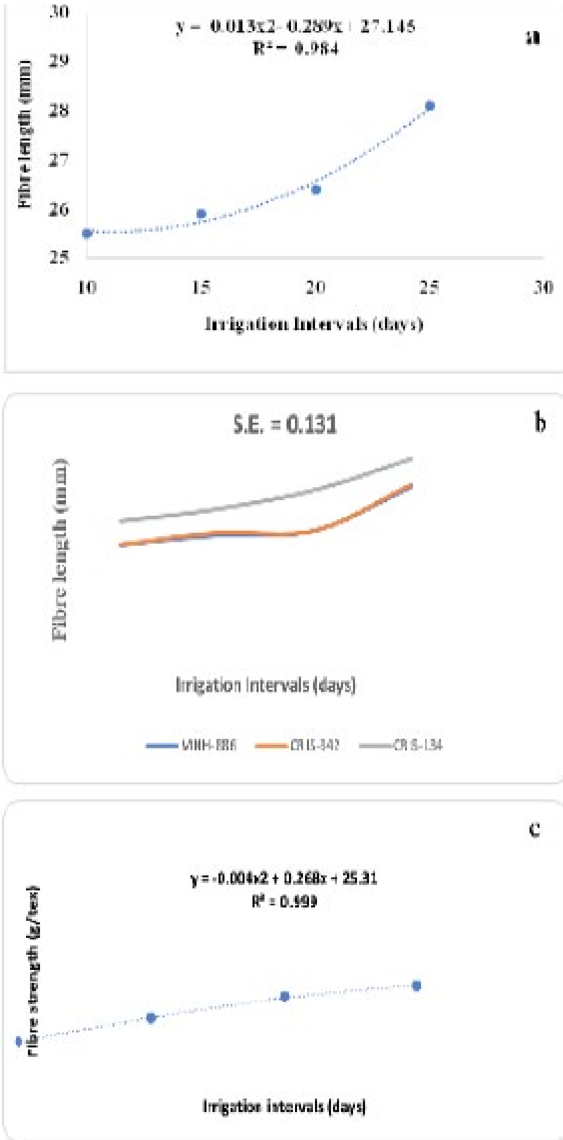

Figure 3: *(a): Effect of irrigation on fiber length; (b): interactive effect of genotypes x irrigation on fiber length, and (c): irrigation effect on fiber strength.*

Fiber micronaire (µg inch^{-1})

Fiber micronaire values were significant for irrigation intervals whereas non-significant for varieties and their interaction with irrigation intervals. Irrigation interval of 25 days produced higher fiber micronaire (3.5 µg inch^{-1}) compared with irrigation intervals of 10, 15 and 20 days (Table 3). Other researchers had also identical results who communicated that different irrigation regimes significantly affected fiber micronaire (Balkcom et al., 2006). Moreover, they reported that longer irrigation interval caused more fineness of the fiber. Although genotypes in the present study did not differ regarding micronaire value, however, Ehsan et al. (2008) and Copur (2006) remarked that varieties might be different in fiber fineness in different environments.

Table 3: *Irrigation intervals and varietal effects on ginning out turn, Fiber length, Fiber micronaire and Fiber strength of cotton under zero tillage conditions.*

Irrigation intervals (I)	GOT (%)	Fiber length (mm)	Fiber strength (g /tex)	Fiber micronaire (µg inch^{-1})
10 days	31 d	25.5 d	27.6 d	3.1 c
15 days	33 c	25.9 c	28.4 c	3.2 bc
20 days	35 b	26.4 b	29.1 b	3.3 b
25 days	37 a	28.1 a	29.5 a	3.5 a
$LSD_{0.05}$	0.39	0.16	0.31	0.12
Varieties (V)				
MNH-886	33 c	26.1 b	28.7	3.3
CRIS-342	34 b	26.2 b	28.7	3.2
CRIS-134	35 a	27.3 a	28.6	3.3
$LSD_{0.05}$	0.34	0.14	-	-
I×V interaction	**	**	NS	NS

Note: *Means followed by different letter (s) differ significantly at P≤5%.*

Conclusions and Recommendations

Cotton transgenic variety (CRIS-134) at zero tillage produced 60.5% more bolls per plant, 48.7% higher seed cotton yield, 21.1% higher GOT and12.4% higher fiber length. Irrigation with 25 days interval can conserve 60% water compared to usual application of irrigation with 10 days interval for the crop life cycle of growth and development.

Author's Contribution

Muhammad Waqas Imam Malik: Conducted this research and prepared draft of the paper.
Khalid Usman: Was a supervisor of the research scholar and corresponding author who gave final shape to the manuscript.
Tahir Amin: Helped in lab analysis and literature collection.
Muhammad Riaz: Helped in initial draft of the paper.
Zafar Iqbal and Fiaz Hussain: Helped in lab work and analysis.

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