Assessing the Impact of Deficit Irrigation on Yield and Phenology of *Bt* Cotton (*Gossypium hirsutum* L.)

ABSTRACT

Aims: To Evaluate the Impact of Different Irrigation Levels on Cotton Yield and Phenological Traits and To Determine the Optimal Fertigation Level for Cotton Cultivation.
Study design: Factorial Randomized Block Design.
Place and Duration of Study:: Department of Agronomy, CCSHAU, Hisar, Haryana, India between June 2019 and July 2020.
Methodology: The experiment was set up in open fields with replicated plots to ensure the reliability of the results. The study included three irrigation levels: I1 (1.0 Etc), I2 (0.8 Etc), and I3 (0.6 Etc). Additionally, four fertigation levels were tested: F1 (control), F2 (50% Recommended Dose of Fertilizers, RDF), F3 (75% RDF), and F4 (100% RDF). The factorial randomized block design with three replications was used to manage the plots. Key phenological traits, such as days to squaring, 50% flowering, 50% boll development, and maturity, were recorded. Yield components including seed cotton yield, number of bolls per plant, and individual boll weight were also measured. Statistical analysis was performed to determine the significance of differences between treatments.
Results: The results indicated that the highest irrigation level, I1 (1.0 Etc), led to prolonged phenological stages but achieved the highest seed cotton yield of 3854 kg/ha. In contrast, the lowest irrigation level, I3 (0.6 Etc), resulted in the lowest yield at 3327 kg/ha. Additionally, I1 outperformed I3 in terms of boll number and individual boll weight. Regarding fertigation treatments, F4 (100% RDF) produced the highest seed cotton yield (4404 kg/ha), boll weight (4.09 g), and number of bolls per plant (53/Plant). These findings suggest that both irrigation and fertigation significantly influence cotton yield and its components.
Conclusion: This study concluded that deficit irrigation, particularly at the I2 level (0.8 Etc), can optimize water use efficiency without significantly compromising yield. The highest fertigation level (F4) was found to produce the best yield outcomes. These optimized irrigation and fertigation practices are recommended for enhancing cotton production in arid regions like Haryana, with further validation needed to ensure their reliability and effectiveness in different environmental conditions.

Keywords: Bt Cotton, Drip irrigation, Fertigation levels, Phenological traits, Yield

1. INTRODUCTION

The production of cotton is essential to the health of both the agricultural and industrial sectors. It provides millions of people with job opportunities and serves as the main raw material used in the textile industry. Around 250 million people worldwide receive income from its cultivation, which accounts for 7% of total agricultural labor (World Wide Fund, 2020). Approximately 80 countries grow cotton, with China, India, the United States, Brazil, and Pakistan producing 75% of the crop. With 130.61 lakh hectares under cultivation and a 5.84 million metric tonnes of output, India ranked first in the world for cotton acreage (Ministry of Textiles, 2022).

As one of the most significant cash crops grown in India, cotton (Gossypium hirsutum L.) feeds the country's largest organized textile sector. Despite India providing the world's largest area and maximum production of cotton, its mean productivity is quite poor (Blaise, 2021). Except for the northwest cotton belt, which includes the states of Punjab, Haryana, and Rajasthan, more than 65% of Indian cotton is grown as rainfed (Vaddula & Singh, 2023). Since cotton is primarily grown in dry and semiarid regions across the country, water is the main production limitation in most of these areas. However, from an environmental viewpoint, cotton growing is unsustainable due to current production techniques like excessive fertilizer application and inadequate irrigation methods. One of the main concerns in modern crop cultivation is achieving water sustainability while satisfying future food and fiber demands. Given cotton's high water use, improper management could lead to water wastage and subsequent water scarcity (Brar & Singh, 2022).

The productivity of cotton is low in comparison to other states due to the arid climate. Therefore, specialized irrigation techniques like drip irrigation can be adopted for cotton. The drip system is continuously gaining popularity among farmers, owing to benefits such as potential savings in water and fertilizers, besides better yield (Kang et al., 2012; Singh et al., 2018). It has been discovered that several irrigation techniques, including sprinkler irrigation, sub-surface drip irrigation, and surface drip irrigation (SDI), increase irrigation efficiency (Singh et al., 2022). Various literatures on drip irrigation suggest that the water budget can be altered by giving different levels of irrigation through the drip system (Ranjith et al., 2014; Zonta et al., 2015; Choudhary et al., 2016). Tailored irrigation levels and fertigation can improve water use efficiency without compromising yield. Kashid (2002) observed that the yield and yield contributing characters, such as the number of bolls per plant, lint weight, seed weight, and seed cotton weight, were significantly higher under the drip irrigation system as compared to other methods of irrigation. Singh et al. (2018) concluded that drip irrigation at different levels, including deficit irrigation, resulted in higher yield and was on par with the 100 percent irrigation level. Singh and Bhati (2018) revealed that drip irrigation at different levels saved 25% water.

In Punjab and Haryana, cotton is irrigated through the flood method, leading to significant water loss through evaporation due to the arid climate. A scientific approach towards irrigation and fertilizer management can improve the productivity of cotton. Therefore, a study was conducted to optimize the irrigation and fertilizer needs of cotton in Haryana.

The present investigation implements an experimental approach to explore the effect of different drip irrigation and fertigation levels on cotton in Haryana. The focus was to study the different irrigation and fertilizer treatments on crop phenology.

2. MATERIAL AND METHODS

The present investigation was carried out during Kharif season of 2019 at cotton research farm of Chaudhary Charan Singh Haryana Agricultural University (CCSHAU). The details of the experimental methods adopted during the research are described below:

2.1 Study area

Hisar is situated in the semi-arid, sub-tropical region of north western India in Haryana state of India. The climate of Hisar is typical semi-arid with very hot summer and severe cold during winter season. During both the season summer as well as winter, the mean monthly temperature shows a wide range of fluctuation in minimum and maximum temperature. In December and January, the minimum temperature may fall up to 0˚C. The normal annual rainfall of Hisar is 450 mm and its distribution in the region is subjected to large variations. Mainly 80 % of the rainfall is received from south-west monsoon during July to September and rest 20 % rainfall is received during non-monsoon period

2.2 Experimental details

The experiment was conducted in an open field with replicate plots subjected to different irrigation and fertigation treatments. Three irrigation levels were applied using drip irrigation system, delivering 100%, 80%, and 60% of crop evapotranspiration (ETc), respectively. Four fertigation levels were administered through the irrigation system, including control, 50% Recommended Dose of Fertilizer (RDF), 75% RDF, and 100% RDF. The experiment was laid out in a Factorial Randomized Block Design (FRBD). The treatment details have given in the table below (Table-1).

Table-1 Treatment details

Sl No	Treatments	Factor 1 Irrigation levels (I)	Factor 2 Fertigation levels (F)

1.	I1F1	1.0 Etc	Control
2.	I1F2	1.0 Etc	50% RDF
3.	I1F3	1.0 Etc	75% RDF
4.	I1F4	1.0 Etc	100% RDF
5.	I2F1	0.8 Etc	Control
6.	I2F2	0.8 Etc	50% RDF
7.	I2F3	0.8 Etc	75% RDF
8.	I2F4	0.8 Etc	100% RDF
9.	I3F1	0.6 Etc	Control
10.	I3F2	0.6 Etc	50% RDF
11.	I3F3	0.6 Etc	75% RDF
12.	I3F4	0.6 Etc	100% RDF
Design		**Factorial Randomized Block Design (FRBD)**	
Replications		**3**	
RDF		**175:60:60:25 N, P, K and ZnSO4 kg ha-1**	

2.3 Crop management practices

Management practices of experimental crop were followed according to the package of practices of cotton crop recommended by the CCS Haryana Agricultural University. A primary harrowing tillage operation was performed with the tractor drawn disc harrow followed by cultivator and planking to prepare a fine seed bed. Bt cotton genotype RCH 776 was sown on 1 May 2019 by dibbling method, by putting 2 seeds per hill at a depth of 3-5 cm to maintain optimum plant population. Gap filling was done five days after germination of cotton crop to obtain optimum plant stand in each plot. Thinning had been done to keep one plant per hill. Weeding in the field was done manually whenever needed. In case of different drip irrigation treatments, the irrigation scheduling was done on the basis of climatological approach. Irrigation was scheduled at every three days interval in all drip irrigated treatments during crop period and volume of water was calculated as per pan evaporation (E0). The volume of irrigation water applied was computed by using following formula (Allen et al., 1998) as given below,

Water Requirement (WR) = EPan x Kp x Kc

Where,
EPan = Pan evaporation (mm/3 days)
Kp = Pan factor (0.70)
Kc = Crop coefficient
Table-2 : The Kc value of cotton was described

Sl. No	Crop age	Kc
1	Up to 25 Days after sowing (DAS)	0.45
2	26-70 DAS	0.75
3	71-120 DAS	1.15
4	121- Harvest	0.70

2.4 Observations recorded

Five plants from each plot were selected randomly and tagged for the recording of different observations till maturity of the crop. The following observations have recorded during the experimental period.

2.4.1 Days to squaring

When the first „square" of a size recognizable with naked eye appeared on 50 % of the plants, number of days from planting to this date was recorded. Average number of days taken to attain squaring from planting was calculated.

2.4.2 Days to 50% flowering

It is the total number of days taken when 50 % of plants begin flowering. Days were recorded from the date of planting from each individual plant to the date when 50% plants begin flowering.

2.4.3 Days to 50% boll opening

It is the total number of days taken when 50 % of plants begin boll opening. Days were recorded from date of sowing to the date when 50 % plants begin boll opening from the individual plots.

2.4.4 Days to maturity

Maturity of cotton is indicated when the bolls crack open and the fluffy white cotton is exposed or when the cotton is ready to be picked. Days were noted from the sowing to first picking

2.4.5 Numbers of bolls per plant

Total numbers of bolls per plant harvested were counted from 5 tagged plants in each plot by adding the mean number of good and poor opened bolls harvested per plant

2.4.6 Seed cotton yield (kg/ha)

Total seed cotton harvested from two pickings per plot was registered and expressed as seed cotton yield in kg ha-1

2.5 STATISTICAL ANALYSIS

Data used in the study are the mean values of the replicated observations. For the statistical analysis of all the research field data, online computer programme OPSTAT (http://hau.ernet.in/sheoranop/) was used.

3. RESULTS AND DISCUSSION

The data on the number of days taken for the four phenological stages, i.e., days to squaring, days to 50% flowering, days to 50% boll opening, and maturity under different irrigation and fertigation levels, are presented in Table 3. The experiment's findings showed that deficit irrigation had a significant impact on cotton's phenological stages. Variations in irrigation intensity significantly affected the duration that Bt cotton took to squaring. Comparing the I1 level of irrigation to all other levels, it took 63 days to achieve squaring, which was longer than other treatments. The irrigation levels I2 and I3 reached the squaring stage in only 58 days. Conversely, there was no discernible difference in the number of days required for squaring based on fertigation levels. However, the F4 (60) treatment took an extra day to reach the squaring stage compared to other treatments.

The amount of irrigation at each level had a substantial impact on the number of days required for 50% flowering. Compared to all other irrigation levels, a notably greater number of days (84) were required to reach 50% flowering at the I1 (1.0 Etc) level. The fertigation levels did not significantly affect the number of days required for 50% flowering.

In terms of boll opening, the I1 (1.0 Etc) level of irrigation required 119 days, a significantly longer period than other irrigation levels. On the other hand, significantly fewer days (115) were needed for the I2 (0.8 Etc) level. The time needed for 50% of the bolls to open did not considerably change depending on the fertigation level. The I1 (1.0 Etc) level of irrigation required notably more days (183) to reach maturity than other irrigation levels, whereas the I3 (0.6 Etc) level required the fewest days (172) to reach maturity. The various fertigation levels had no apparent impact on the total number of days required to reach maturity.

Reduced irrigation levels might affect crop phenology. Under water stress, cotton plants prioritize reproductive growth such as flowering and fruiting (Maniçoba et al., 2021). Water stress can hasten the maturation process, leading to earlier flowering, fruit set, and ripening. By accelerating these stages, deficit irrigation can shorten the overall growing period required for a crop to reach maturity (Sarto et al., 2017). The phenology of cotton was impacted by deficit irrigation levels as reported by Himanshu et al. (2019). Different irrigation regimes affected the number of days to flowering and maturity (Sorensen et al., 2021).

Table 4 contains the results of the study investigating the effects of different irrigation and fertigation levels on yield characters of cotton. This table represents the average values for bolls per plant, boll weight, and seed cotton yield under various treatments. Among the irrigation levels, I1 exhibited the highest seed cotton yield of 3854 kg per hectare, and I3 yielded the lowest value of 3327 kg. Similarly, the number of bolls per plant and individual boll weight were higher in I1 irrigation and lower in I3 irrigation level. However, statistical analysis revealed no significant difference in individual boll weight among the irrigation levels.

When considering the fertigation levels, treatment F4, which received the full recommended dose of fertilizer, resulted in the highest seed cotton yield (4404 kg), boll weight (4.09 g), and the highest number of bolls (53). The F4 and F3 treatments were statistically on par, with not much difference in results. The control treatment showed the lowest values in all the yield characters. Nevertheless, similar to the irrigation levels, no significant differences were observed in individual boll weight. Overall, both irrigation and fertigation significantly influenced boll production, boll weight, and seed cotton yield.

The significant increase in the number of bolls per plant in I1 and I2 levels of irrigation resulted from the increased rate of irrigation water applied. Cotton yield is a function of many yield-attributing parameters such as the number of bolls per plant, boll weight, and water availability. The results revealed that different drip irrigation levels had a significant effect on seed cotton yield. A study by Hussein et al. (2011) also pointed out that the highest number of bolls was observed in fully irrigated cotton compared to deficit-irrigated plants. These findings are in conformity with Yadav et al. (2014). However, Shekar et al. (2016) reported that different irrigation levels had no significant effect on the seed index. The highest boll weight was observed in fully irrigated plots, and the lowest boll weight was observed under 60% irrigated plots (Singh et al., 2018)

Table-3 Effect of Irrigation and Fertigation levels on cotton phenology

Treatment	Days to Squaring (DAS)	Days to 50% Flowering (DAS)	Days to 50% Boll Opening (DAS)	Days to Maturity (DAS)
Irrigation Levels				
I1 - 1.0 Etc	63	84	119	183
I2 - 0.8 Etc	58	80	115	178
I3 - 0.6 Etc	58	80	116	172
SE (m)	**± 0.3**	**± 0.37**	**± 0.48**	**± 1.43**
CD at 5% level	**0.9**	**1.08**	**1.43**	**4.23**
Fertigation Levels				
F1 - Control	59	81	117	176
F2 - 50% RDF	59	81	116	177
F3 - 75% RDF	59	81	117	178
F4 - 100% RDF	60	82	117	179
SE (m)	**± 0.34**	**± 0.42**	**± 0.56**	**± 1.65**
CD at 5% level	**NS**	**NS**	**NS**	**NS**

Table-4 Effect of Irrigation and Fertigation levels on yield attributes of Cotton

Treatment	Bolls plant-1	Boll wt. (g)	Seed cotton yield (kg ha-1)
Irrigation Levels			
I1 - 1.0 Etc	48	4.02	3854
I2 - 0.8 Etc	45	3.99	3816

I3 - 0.6 Etc	43	3.98	3327
SE (m)	**± 1.17**	**0.06**	**154**
CD (5% level)	**3.47**	**NS**	**453**
Fertigation Levels			
F1 - Control	28	3.84	2022
F2 - 50% RDF	50	3.99	3984
F3 - 75% RDF	51	4.07	4251
F4 - 100% RDF	53	4.09	4404
SE (m)	**± 1.36**	**0.07**	**177**
CD (5% level)	**4**	**NS**	**524**

4. CONCLUSION

The research investigated the impact of different irrigation and fertigation levels on cotton crop focusing on phenology and yield attributes. The findings indicated that increasing irrigation rates marginally influenced boll production and boll weight, although these changes did not translate into significant improvements in seed cotton yield. Similarly, fertigation levels showed a positive influence on boll production, boll weight, and seed cotton yield with increasing fertilizer doses. Moreover, the study detailed into phenological aspects, shedding light on how irrigation influences critical stages of cotton growth, such as Squaring, flowering, ball opening and maturity phases. The study proved that the amount of irrigation plays an important role in determining phenology of crop by reducing the number of days taken to maturity with respect to the deficit in irrigation. Therefore, the study concludes that deficit irrigation could potentially enhance yields in regions with limited water availability. Specifically, the irrigation level represented by I2 demonstrates the potential to reduce cotton's water requirements while still maintaining adequate yield levels.

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