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Physiological growth parameters of cotton under mulching with varying fertigation schedules

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Abstract
A field trial was conducted during the kharif season of 2021-2022 at the Agronomy Research Farm, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (M.S.), to evaluate the impact of different fertigation schedules and mulching practices on the growth indices of Bt. cotton (*Gossypium hirsutum* L.). The site, situated in the Marathwada region of Maharashtra at 19°16' N latitude and 76°46' E longitude with an elevation of 408.46 m above mean sea level, had a fairly uniform and level topography. The soil type was medium black, classified as vertisol. The experiment followed a split plot design with three replications. Treatments included four fertigation levels: 80:40:40 NPK kg ha^{-1} (S1), 100:50:50 NPK kg ha^{-1} (S2), 120:60:60 NPK kg ha^{-1} (S3), and 140:70:70 NPK kg ha^{-1} (S4), assigned to main plots, and four mulching options: no mulch (M1), organic mulch (M2), black polyethylene mulch (M3), and silver polyethylene mulch (M4), allocated to subplots. Findings indicated that the combination of fertigation at 140:70:70 NPK kg ha^{-1} with silver polyethylene mulch (S4M4) achieved the highest values for physiological growth parameters such as leaf area index, leaf area duration, and crop growth rate.

Keywords: Cotton, mulching, fertigation scheduling, physiological growth indices

Introduction
Cotton, widely referred to as the "King of Fibre" and "White Gold," is the most important fibre and commercial crop of global importance. It is cultivated in tropical and subtropical regions across more than seventy countries. In India, cotton has been deeply intertwined with culture and heritage for centuries and continues to play a pivotal role in the agricultural economy. The crop provides employment to nearly 70 million people and supplies about 75% of the raw material required by the textile industry (Ushanandini *et al.*, 2017) [12]. Notably, India is the only country in the world where all four cultivated cotton species and their hybrids are grown under diverse agro-climatic conditions.

India ranks first globally in terms of cotton acreage. Out of 33.16 million hectares under global cotton cultivation with a production of 25.89 million tonnes, India accounts for 12.06 million hectares (36% of world area) and produces 5.36 million tonnes (21% of global production) (Anonymous, 2021a) [1]. Despite this, the national average yield remains low at around 445 kg ha^{-1} compared to the global average of 781 kg ha^{-1} (Anonymous, 2021b) [2]. Moreover, only about 35.8% of the cotton-growing area in India is under irrigation.

Post-Green Revolution, Indian agriculture has transitioned from focusing solely on yield enhancement to addressing emerging challenges such as efficient input use and resource conservation (Himoud *et al.*, 2022) [6]. Several factors contribute to the low productivity of Bt cotton, including delayed sowing, imbalanced fertilizer application, and inadequate irrigation practices. The commercialization of Bt cotton hybrids marked the beginning of India's transgenic era, with the introduction of the Bt gene in *Gossypium hirsutum* to combat bollworms. Adoption of Bt cotton has considerably improved productivity over the past decade, particularly under irrigated conditions. Since Bt cotton performs better with irrigation than non-Bt varieties, drip irrigation has emerged as a promising technology for expanding irrigated area and boosting yields (Manjunatha *et al.*, 2010) [8].

The productivity of Bt cotton is strongly influenced by efficient and timely application of water and nutrients. However, rising fertilizer costs have made input management a concern for farmers.

Agronomic practices, alongside high-yielding cultivars, play a key role in improving productivity. Hence, proper scheduling of irrigation and fertilizer application considering the right amount, timing, and method is essential. Drip fertigation, which combines irrigation with fertilizer delivery, ensures precise and uniform placement of nutrients in the active root zone. Compared to conventional methods, it saves significant amounts of both water and fertilizers while improving nutrient-use efficiency. Moreover, fertigation using liquid or fully water-soluble fertilizers not only reduces fertilizer input but also enhances application efficiency.

Consequently, fertigation lowers production costs, minimizes groundwater pollution, and reduces environmental and health risks associated with nitrate leaching. Thus, fertigation holds great potential for Indian agriculture by optimizing the use of costly and limited fertilizers. Against this backdrop, the present study was undertaken to examine the impact of fertigation schedules and mulching on the growth performance of Bt cotton.

Materials and Methods

A field experiment was carried out during the kharif season of 2021 at the Agronomy Research Farm, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (M.S.). The site is located in the Marathwada region of Maharashtra at 19°16' N latitude and 76°46' E longitude, with an elevation of 408.46 m above mean sea level. The topography of the field was fairly level and uniform, with medium black soil classified as vertisol. Initial soil analysis revealed low available nitrogen (164.65 kg/ha), medium phosphorus (13.38 kg/ha), and high potassium (506.24 kg/ha).

The experiment was laid out in a split-plot design with three replications, where fertigation schedules were allotted to main plots and mulching treatments to subplots. The main plot treatments included four fertigation levels: 80:40:40 NPK kg ha^{-1} (S1), 100:50:50 NPK kg ha^{-1} (S2), 120:60:60 NPK kg ha^{-1} (S3), and 140:70:70 NPK kg ha^{-1} (S4). The subplot treatments comprised four mulching options: no mulch (M1), organic mulch (M2), black polyethylene mulch (M3), and silver polyethylene mulch (M4).

Raised beds of 1.2 m width were prepared with a tractor, and drip lateral lines were laid before applying polyethylene mulch. A silver/black polyethylene sheet of 25 µ thickness and 120 cm width was placed over the beds, with the respective color side facing up as per the treatment. The sheet edges were buried along the slopes of the beds. Sowing lines were marked at 30 cm intervals, and holes were created using a 2-inch GI pipe, into which cotton seeds were dibbled. For the organic mulch treatment, mulching was applied at 5 t ha^{-1} at 30 days after sowing (DAS).

The cotton hybrid RCH-659 was sown manually on 18 June 2021, maintaining a spacing of 150 cm between rows and 30 cm between plants, resulting in a plant density of 22,222 plants per hectare. Fertilizers were supplied as per treatment schedules using water-soluble sources: urea, 19:19:19 NPK, mono potassium phosphate (0:52:34), and potassium nitrate (13:0:45). Data on growth parameters were collected at 30-day intervals from sowing to harvest, and growth indices were calculated using standard formulae.

Leaf area index (LAI): From each treatment plot, five representative plants were selected, and observations were recorded on the third fully expanded leaf from the top. The leaf length and maximum width were measured, and the total number of leaves per plant was counted. These measurements were taken at 30, 60, 90, 120, and 150 days after sowing (DAS). Based on these observations, the Leaf Area Index (LAI) was calculated using the formula proposed by Ashley *et al.* (1963) [3].

$$LAI = \frac{L \times W \times N \times K}{\text{Land area (cm}^2\text{) occupied by one plant}}$$

Where,

- L = Length of the leaf in cm W = Width of the leaf in cm
- N = Number of the leaves per plant and K = Constant factor (0.775 for cotton)

Leaf area duration (LAD)

The mean Leaf Area Duration (LAD) was estimated using the formula proposed by Power *et al.* (1967) [10] and later modified by Kvet *et al.* (1971) [7].

$$LAI = \frac{L_1 + L_2}{2} \times (t_2 - t_1)$$

Where,

L_1 and L_2 are the LAI at time t_1 and t_2.

Crop growth rate (CGR)

Crop Growth Rate (CGR) refers to the rate of increase in dry matter production per unit land area per unit time. It was calculated using the formula proposed by Watson (1958) [13] and expressed as g m^{-2} day^{-1}.

$$CGR = \frac{W_2 - W_1}{(t_2 - t_1)}$$

Where,

- W_1 and W_2 - dry weight of plants in g at times t_1 and t_2 respectively.
- t_2 - t_1 - time intervals in days between stages

Relative growth rate (RGR)

According to Blackman (1919) [4], the increase in plant dry matter follows the principle of continuous compound interest, wherein the increment during any growth interval contributes to the biomass available for subsequent growth. This rate of increment is termed the Relative Growth Rate (RGR), which was calculated using the formula suggested by Fisher (1921) [5].

$$RGR \ (g\,g^{-1}\,day^{-1}) = \frac{Log_e W_2 - Log_e W_1}{t_2 - t_1}$$

Where,

- W_1 and W_2 are the weights of dry matter in g per plant at times t_1 and t_2, respectively and t_2- t_1 is the time interval in days.
- Log_e = natural logarithm to the base „e" = 2.3026.

Absolute growth rate (AGR)

The rate of increase in a growth variable, such as plant height (H) or dry weight (W), within a given time interval (t), is termed the Absolute Growth Rate (AGR). It is expressed as cm day⁻¹ for plant height and g day⁻¹ for dry matter accumulation per plant. The AGR for plant height and total dry matter per plant was calculated using the formula suggested by Richards (1969) [11].

$$\text{AGR (Height) (cm day}^{-1}) = \frac{H_2 - H_1}{t_2 - t_1}$$

$$\text{AGR (Dry matter) (g day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

H_2 and H_1 are plant heights, while W_2 and W_1 are dry matter weights per plant at t_2 and t_1 times, respectively.

Results and Discussion

Leaf Area Index

The Leaf Area Index (LAI), expressed as the leaf area per unit ground area, was calculated at different growth stages and is presented in Table 1. This foliar parameter is an important determinant of light interception and photosynthetic potential. In the experimental year, the mean LAI increased progressively up to the 91-120 DAS stage, after which it declined until 150 DAS. The maximum LAI (4.3741) was recorded during the 91-120 DAS stage, while the minimum value (2.1792) was observed during 121-150 DAS.

Fertigation schedules significantly influenced the LAI of Bt cotton. Each increment in fertilizer dose under fertigation resulted in a corresponding increase in LAI. This trend may be attributed to enhanced light interception and greater leaf expansion under higher fertigation levels. Among the treatments, the highest fertigation schedule of 140:70:70 NPK kg ha^{-1} (S4) consistently recorded superior LAI values across all growth stages.

Mulching treatments also had a notable effect on LAI. The application of silver polyethylene mulch (M4) resulted in the highest LAI values from 0-30 DAS up to 121-150 DAS, followed by black polyethylene mulch (M3).

Leaf area duration (Days)

Table 1 presents the mean values of Leaf Area Duration (LAD) as influenced by fertigation schedules and mulching. LAD increased gradually from 0-30 DAS, reached its peak during 91-120 DAS (126.06), and then declined steadily between 121-150 DAS, when the lowest values were recorded.

Fertigation schedules significantly affected LAD in Bt cotton. Higher fertilizer levels under fertigation consistently produced longer LAD compared to lower levels across all growth stages. The fertigation schedule of 140:70:70 NPK kg ha^{-1} (S4) recorded the maximum LAD, followed by 120:60:60 NPK kg ha^{-1} (S3) and 100:50:50 NPK kg ha^{-1} (S2). The lowest values were observed under 80:40:40 NPK kg ha^{-1} (S1). The improved LAD under higher fertigation levels can be attributed to increased leaf area, which sustained photosynthetic activity for a longer duration.

Mulching treatments also showed a marked influence on LAD. The application of silver polyethylene mulch (M4) produced the highest LAD (131.67) during 91-120 DAS, followed by black polyethylene mulch (M3) with 128.14.

Crop Growth Rate (g day^{-1} m^{-2}): Table 2 presents the Crop Growth Rate (CGR) for dry matter accumulation (g m^{-2} day^{-1}) in Bt cotton as influenced by fertigation schedules and mulching during the study year. The CGR was initially low between 0-30 DAS, reached its maximum between 61-90 DAS (6.9896 g m^{-2} day^{-1}), and then gradually declined up to 150 DAS.

Fertigation schedules significantly affected CGR values. The highest CGR was consistently recorded under the fertigation schedule of 140:70:70 NPK kg ha^{-1} (S4), followed by 120:60:60 NPK kg ha^{-1} (S3) and 100:50:50 NPK kg ha^{-1} (S2), while the lowest values were obtained with 80:40:40 NPK kg ha^{-1} (S1). Between 61-90 DAS, the maximum CGR (7.1925 g m^{-2} day^{-1}) was observed in S4, closely followed by S3 (7.0217 g m^{-2} day^{-1}) and S2 (6.9791 g m^{-2} day^{-1}). This trend was consistent across all growth stages.

Mulching treatments also influenced CGR performance. Silver polyethylene mulch (M4) produced the highest values, followed by black polyethylene mulch (M3), organic mulch (M2), and no mulch (M1). During 61-90 DAS, M4 recorded the maximum CGR (7.0767 g m^{-2} day^{-1}), followed by M3 (7.0033 g m^{-2} day^{-1}), M2 (6.9542 g m^{-2} day^{-1}), and M1 (6.9241 g m^{-2} day^{-1}). Overall, silver polyethylene mulch (M4) consistently enhanced CGR across the season, particularly during square formation and flowering stages.

Relative Growth Rate (g g^{-1} day^{-1})

Table 2 shows the Relative Growth Rate (RGR) for dry matter accumulation (g g^{-1} day^{-1}) in Bt cotton as influenced by fertigation schedules and mulching. The RGR increased up to 30 DAS and then gradually declined with crop maturity. The highest mean RGR (0.0881 g g^{-1} day^{-1}) was recorded during 0-30 DAS.

Fertigation schedules significantly affected RGR. The highest values were consistently observed under 140:70:70 NPK kg ha^{-1} (S4), followed by 120:60:60 NPK kg ha^{-1} (S3) and 100:50:50 NPK kg ha^{-1} (S2). The lowest RGR was obtained with 80:40:40 NPK kg ha^{-1} (S1). However, between 31-60 DAS, S1 showed the maximum RGR, followed by S2 and S3, after which values declined with crop advancement. Overall, S4 maintained the highest RGR across most growth stages.

Mulching also had a marked influence on RGR. During 0-30 DAS, silver polyethylene mulch (M4) and black polyethylene mulch (M3) produced the highest RGR values, indicating their positive effect on early crop vigor.

Absolute Growth Rate for plant height (cm day^{-1} $plant^{-1}$)

Table 3 presents the mean values of Absolute Growth Rate (AGR) for plant height (cm $plant^{-1}$ day^{-1}) as influenced by fertigation schedules and mulching. The AGR of plant height was highest between 30-90 DAS and declined progressively thereafter until harvest.

Fertigation schedules significantly affected AGR values. Higher fertilizer levels under fertigation increased AGR for plant height across growth stages. The fertigation schedule of 140:70:70 NPK kg ha^{-1} (S4) recorded the highest AGR at all stages, except during 91-120 DAS. The increase in AGR can be attributed to greater plant height achieved under higher fertigation levels.

Mulching treatments also enhanced AGR compared to no mulch (M1). At all stages, except 61-90 DAS and 121-150 DAS, silver polyethylene mulch (M4) recorded the maximum AGR, followed by other mulching treatments (M3 and M2). The superior performance of mulch treatments may be explained by their ability to conserve soil moisture and improve the microclimatic conditions around the root zone, which promoted better vegetative growth compared to non-mulched plots.

Absolute Growth Rate for dry matter (g day^{-1} $plant^{-1}$)

Table 3 presents the mean values of Absolute Growth Rate (AGR) for dry matter accumulation (g $plant^{-1}$ day^{-1}) in Bt cotton as influenced by fertigation schedules and mulching. AGR was slow up to 30 DAS, increased steadily from 31-90 DAS, and then declined between 91-150 DAS as the crop advanced towards maturity.

Fertigation schedules significantly influenced AGR for dry matter. The highest values were recorded under 140:70:70 NPK kg ha^{-1} (S4), which achieved 3.2693 g $plant^{-1}$ day^{-1} during 61-90 DAS. This was followed by 120:60:60 NPK kg ha^{-1} (S3, 3.1917 g $plant^{-1}$ day^{-1}) and 100:50:50 NPK kg ha^{-1} (S2, 3.1723 g $plant^{-1}$ day^{-1}). The lowest AGR was observed with 80:40:40 NPK kg ha^{-1} (S1), which restricted vegetative growth throughout the season. Similar trends were recorded across all other growth intervals (0-30, 31-60, 91-120, and 121-150 DAS).

Mulching treatments also enhanced AGR values. Silver polyethylene mulch (M4) recorded the maximum AGR (3.2167 g $plant^{-1}$ day^{-1}) during 61-90 DAS, followed by black polyethylene mulch (M3, 3.1833 g $plant^{-1}$ day^{-1}) applied during square formation and flowering. Organic mulch (M2) and no mulch (M1) resulted in comparatively lower AGR values. The observed improvement under polythene mulch treatments may be attributed to their favorable influence on soil moisture, microclimate, and vegetative growth parameters such as plant height and sympodial branching. Similar findings were reported by Naliyani (2007) [9].

Table 1: Mean Leaf Area Duration (Days) and Mean Leaf Area Index (LAI) of *Bt* cotton hybrid as influenced by different treatments at various crop growth period

Treatments	LAD (days)					Leaf area index				
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS
Main plot: Fertigation scheduling (S)										
S_1: 80:40:40 NPK kg ha^{-1}	5.81	49.42	102.14	122.50	94.72	0.3874	2.9074	3.9019	4.2648	2.0500
S_2: 100:50:50 NPK kg ha^{-1}	6.16	51.13	104.83	124.75	96.58	0.4104	2.9981	3.9907	4.3259	2.1130
S_3: 120:60:60 NPK kg ha^{-1}	6.51	52.76	107.42	127.17	99.56	0.4337	3.0833	4.0778	4.4000	2.2370
S_4: 140:70:70 NPK kg ha^{-1}	6.71	53.99	109.50	129.81	102.33	0.4472	3.1519	4.1481	4.5056	2.3167
Sub plot: Mulching (M)										
M_1: No mulch	6.00	49.75	101.86	120.67	92.58	0.4002	2.9167	3.8741	4.1704	2.0019
M_2: Organic mulch	6.15	50.49	103.58	123.75	95.75	0.4103	2.9556	3.9500	4.3000	2.0833
M_3: Black polyethylene mulch	6.43	53.21	108.28	128.14	100.97	0.4285	3.1185	4.1000	4.4426	2.2889
M_4: Silver polyethylene mulch	6.60	53.85	110.17	131.67	103.89	0.4399	3.1500	4.1944	4.5833	2.3426
GM	6.30	51.82	105.97	126.06	98.30	0.4197	3.0352	4.0296	4.3741	2.1792

Table 2: Mean Crop Growth Rate (CGR) (g day^{-1} m^{-2}) and mean Relative Growth Rate (RGR) (g g^{-1} day^{-1}) of *Bt* cotton hybrid as influenced by by different treatments at various crop growth period

Treatments	CGR (g day^{-1} m^{-2})					RGR (g g^{-1} day^{-1})				
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS
Main plot: Fertigation scheduling (S)										
S_1: 80:40:40 NPK kg ha^{-1}	0.8829	3.3704	6.7650	5.1898	2.4383	0.0829	0.0524	0.0317	0.0129	0.0034
S_2: 100:50:50 NPK kg ha^{-1}	0.9240	3.4078	6.9791	5.1407	2.4383	0.0845	0.0515	0.0320	0.0125	0.0036
S_3: 120:60:60 NPK kg ha^{-1}	0.9570	3.4804	7.0217	5.3387	2.5058	0.0856	0.0511	0.0316	0.0127	0.0038
S_4: 140:70:70 NPK kg ha^{-1}	1.0303	3.4980	7.1925	5.4201	2.3892	0.0881	0.0493	0.0317	0.0127	0.0039
Sub plot: Mulching (M)										
M_1: No mulch	0.8822	3.3044	6.9241	5.1781	2.3958	0.0829	0.0519	0.0325	0.0128	0.0037
M_2: Organic mulch	0.9189	3.3704	6.9542	5.1722	2.4567	0.0843	0.0514	0.0321	0.0126	0.0037
M_3: Black polyethylene mulch	0.9959	3.4958	7.0033	5.3453	2.4625	0.0870	0.0502	0.0313	0.0127	0.0037
M_4: Silver polyethylene mulch	0.9973	3.5860	7.0767	5.3937	2.4567	0.0870	0.0508	0.0311	0.0127	0.0036
GM	0.9486	3.4392	6.9896	5.2724	2.4429	0.0847	0.0513	0.0320	0.0127	0.0037

Table 3: Mean Absolute Growth Rate (AGR) for plant height (cm day^{-1} $plant^{-1}$) and for dry matter (gday^{-1} $plant^{-1}$) of *Bt* cotton hybrid as influenced by different treatments at various crop growth period

Treatments	AGR (cm day^{-1} $plant^{-1}$)					AGR (g day^{-1} $plant^{-1}$)				
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS
Main plot: Fertigation scheduling (S)										
S_1: 80:40:40 NPK kg ha^{-1}	1.6560	3.1723	1.6593	0.7990	0.3007	0.4013	1.532	3.0750	2.3590	1.1083
S_2: 100:50:50 NPK kg ha^{-1}	1.7167	3.3140	1.6893	0.8383	0.2473	0.4200	1.549	3.1723	2.3367	1.1083
S_3: 120:60:60 NPK kg ha^{-1}	1.7417	3.5890	1.6910	0.6567	0.3910	0.4350	1.582	3.1917	2.4267	1.1390
S_4: 140:70:70 NPK kg ha^{-1}	1.7793	3.7973	1.6060	0.5983	0.5123	0.4683	1.590	3.2693	2.4637	1.0860
Sub plot: Mulching (M)										
M_1: No mulch	1.6450	3.1750	1.6977	0.6413	0.4287	0.4010	1.502	3.1473	2.3537	1.0890
M_2: Organic mulch	1.6943	3.4140	1.5743	0.7643	0.3753	0.4177	1.532	3.1610	2.3510	1.1167
M_3: Black polyethylene mulch	1.7583	3.6000	1.6893	0.7240	0.3083	0.4527	1.589	3.1833	2.4297	1.1193
M_4: Silver polyethylene mulch	1.7960	3.6833	1.6843	0.7630	0.3387	0.4533	1.630	3.2167	2.4517	1.1167
GM	1.7055	3.4103	1.6529	0.7163	0.3759	0.4239	1.548	3.1694	2.3818	1.1079

Conclusion
From this experiment, it can be concluded that the combination of fertigation scheduling at 140:70:70 NPK kg ha^{-1} along with the application of polyethylene mulch proved to be the most effective treatment for achieving higher growth indices in Bt cotton.

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