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Evaluating the Influence of Legume and Cereal Intercropping on Bt Cotton Traits in Rainfed Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates how various intercropping systems involving cereals and legumes affect the phenotypic characteristics of *Bt* cotton. Understanding that intercropping can improve agricultural sustainability and production, we grew *Bt* cotton alongside various cereal and leguminous crops in several field tests. The study aimed to evaluate the effects of different cotton based intercropping systems under rainfed conditions on important phenotypic characteristics of cotton, including dry matter accumulation, crop growth rate (CGR), relative growth rate (RGR) and boll weight in black calcareous soil under rainfed conditions. The experiment conducted at Junagadh Agricultural University, Junagadh, Gujarat during *kharif* 2022-23 and 2023-24 with randomized block design with fifteen treatments, involving sole and intercropping systems of groundnut, sunflower, pearl millet, maize and soybean with cotton in 1:1 row proportion. According to our research, intercropping legumes like green gram, black gram and groundnut significantly improved cotton phenotypic characteristics as compare to other intercropping systems by increasing soil fertility and lowering insect burden. Dry matter per plant at 60, 90 DAS, at harvest and average boll weight were found significantly higher under sole cotton except 30 DAS during both the years of experimentation and in pooled results. Among different intercropping systems, the cotton + green gram (T_{14}) intercropping recorded the highest dry matter, CGR and average boll weight while the lowest was recorded with the cotton + maize (T_{12}) intercropping system. Overall, the findings show that while cereal-based systems necessitate careful management to balance competition and resource consumption, incorporating legumes into *Bt* cotton agriculture can provide significant agronomic benefits, including higher growth and yield. This study emphasises how crucial it is to choose the right intercrops in order to maximise the productivity and efficiency of *Bt* cotton systems.

Keywords: CGR; cotton; dry matter; intercropping; legume; phenotypic traits, RGR.

1. INTRODUCTION

Cotton (*Gossypium* spp. L.) is one of the predominant fibre crops playing a pivotal role in agriculture, industrial development, employment generation and the economy of India. The current crisis in cotton production revolves around the rising cost of production and is mainly due to the extraneous use of pesticides without adequate pest suppression. Even though several cotton cultivars with a fair amount of tolerance to sucking pests have been developed, tangible resistance to most important pest, the bollworm has not been obtained through traditional plant breeding. Hence genetically modified (GM) cotton widely known as *Bt* cotton due to the delta endotoxin gene from the ubiquitous soil fact crisis *Bacillus thuringenesis* developed to manage bollworm. There is ambiguity of raising of *Bt* cotton around the non *Bt* cotton and related crops, as it may sterilize the embryo when *Bt* cotton pollen cross the non *Bt* cotton and other crop stigmas which eventually may reduce the yields.

Intercropping is the practice of growing two or more crops together with a specific row proportion in a single field. The main purpose of intercropping is to produce a greater yield on a given piece of land by making the use of available resources [1]. Intercropping being a unique property of tropical and sub-tropical areas is becoming popular day by day among small farmers. Other benefits of intercropping are related to better soil cover, which reduces soil erosion and nutrients leaching [2]. In this system, root interaction could increase the root activity and microbial quantity in the rhizosphere [3]. On-farm biodiversity, if correctly assembled in time, can lead to agro ecosystems capable of maintaining their own soil fertility. Now-a-days, the practice of intercropping of green gram and black gram in cotton is very popular with farmers and many dry land farmers are adopting it. Soil quality indicates the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health, improves with suitable intercropping as compared to pure stand [4].

In tropical and subtropical countries, intercropping is expected as it creates favourable micro-climates, has low labour requirements, higher yield stability and productivity [5]. For several decades in India, intercropping has been practising particularly under rainfed conditions. Throughout the past, it has been taken up primarily as a risk minimizing activity in tradition-bound dryland agriculture, simultaneously growing two or more crops varying in growth, period and nutrient requirements in such a way that the productivity of the major component is not reduced compared to its productivity as a single crop and that it can be grown with the least competition by using more effective ways of using environmental and labour capital to increase overall returns. The main objective of the study is to find out suitable component crops for intercropping in *Bt* cotton and to study the effect of different intercrops on cotton.

2. MATERIALS AND METHODS

The field experiment with fifteen treatments was conducted at Instructional Farm, Department of Agronomy, College of Agriculture, JAU, Junagadh during the *kharif* season of 2022-23 and 2023-24. Randomized Block Design (RBD) was used to carry out present investigation with three replications. Total fifteen treatments were replicated thrice in three tires. The treatments were assigned randomly in each plot within replications.

The sowing of crops was considerably delayed in both years due to the continuous and heavy rainfall experienced throughout the months of June and July, which severely impacted the timeliness of sowing and crop management. The furrows were opened at different row spacing and lines were marked as per the distance mentioned in treatments in each row with the help of marker. The graded and healthy fungicide treated seeds of cotton, groundnut, sunflower, pearl millet, maize, black gram, green gram and soybean were sown during 2022-23 and 2023-24, respectively using the recommended seed rate of each crop. The seeds of crops were sown by dibbling in previously fertilizers furrows and covered with the soil.

2.1 Dry Matter Accumulation at 30, 60, 90 and at Harvest

The plant growth is represented by the weight of dry matter accumulated (g) in plant. Five plants were uprooted from each ring plot area and used for dry matter. After removing the soil from roots, the remaining plant parts were air dried in sun first and then kept in thermostatic oven at $65^{o} \pm 5^{o}C$ till they were completely dried. The final constant dry weight was recorded at 30, 60, 90 DAS and at harvest.

2.2 Crop Growth Rate (CGR)

The crop growth rate is widely used for determination of production efficiency of plant stand and enables comparison to be made between stand and communities of different types in different habitat. The values for CGR were calculated between 0-30 DAS, 30-60 DAS, 60-90 DAS and 90-harvest with the help of the following formula [6].

$$CGR\ (g\ m^{-2}\ day^{-1}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where;

W_1 and W_2 = Weight of dry matter of plant (g) at first and second stages

t_1 and t_2 = Time in days of first and second stages

P = Land area

2.3 Relative Growth Rate (RGR)

According to Blackman [7] the increase in dry matter of the plant is a process of continuous compound interest, wherein, the increment in any interval adds to the capital for subsequent growth. This rate of increment is known as RGR which was worked out between 30-60 DAS, 60-90 DAS and 90-harvest as per the formula given by Fisher [8].

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

Where;

Log_e = Natural logarithm (base e),

W_1 and W_2 = Weight of dry matter of plant (g) at first and second stage, respectively,

t_1 and t_2 = Time in days of first and second stages.

Log_e = Natural logarithm to the base 'e' = 2.3026.

2.4 Average Boll Weight (g)

Ten picked bolls were randomly selected from five plants from each net plot with each picking and their average weight was recorded for respective treatments.

2.5 Statistical Analysis

The statistical analysis of the data of various characters studied in the investigation was carried out as per randomized block design. Significance of difference was tested by F test.

The two years data was pooled after conducting homogeneity test as prescribed by Gomez and Gomez [9].

3. RESULTS AND DISCUSSION

3.1 Dry Matter Accumulation Per Plant

The data pertaining to mean dry matter accumulation per plant at 30, 60, 90 DAS and at harvest of the *Bt* cotton as influenced by various *Bt* cotton based intercropping systems with cereal, pulse and oilseed at different growth stages are presented in Tables 1, 2, 3 and 4.

3.1.1 Dry matter accumulation per plant at 30 DAS

Effect of different *Bt* cotton based intercropping systems on dry matter accumulation per plant at 30 DAS was observed non-significant during both individual years and also in pooled results.

3.1.2 Dry matter accumulation per plant at 60 DAS

The data furnished in Table 2 indicated that *Bt* cotton based intercropping systems had significant effect on dry matter accumulation of cotton at 60 DAS. Among different *Bt* cotton based cropping systems sole cotton gave significantly higher dry matter accumulation 35.39, 39.20 and 37.29 g plant^{-1} during the year of 2022-23, 2023-24 and in pooled results, respectively which was remained statistically at par with cotton intercropped with green gram (T_{14}), black gram (T_{13}) and soybean (T_{15}) during in both years and pooled results. Conversely, significantly the lower dry matter accumulation per plant of 23.49, 26.72 and 25.10 g plant^{-1} were observed under cotton intercropped with maize (T_{12}) during 2022-23, 2023-24 and pooled analysis respectively.

3.1.3 Dry matter accumulation per plant at 90 DAS

The cereal, pulse and oilseed as intercrop with *Bt* cotton significantly influenced dry matter accumulation per plant at 90 DAS during the years 2022-23, 2023-24 as well as in pooled results (Table 3). The data clarified that sole cotton produced significantly higher dry matter accumulation of 130.08, 138.05 and 134.07 g plant^{-1} during both the years and in pooled results, respectively being at par with cotton intercropped with green gram (T_{14}), black gram (T_{13}), groundnut (T_9) and soybean (T_{15}) during first and second years results. The lower dry matter accumulation per plant (90.29, 92.54 and 91.42 g plant^{-1}) was recorded under cotton intercropped with maize in 2022-23, 2023-24 and in pooled results, respectively.

3.1.4 Dry matter accumulation per plant at harvest

Various *Bt* cotton based intercropping systems with cereal, pulse and oilseed exhibit their significant influence on dry matter accumulation per plant at harvest (Table 4). Among different cropping systems sole cotton (T_1) gave significantly the higher dry matter accumulation of 293.59, 292.48 and 293.03 g plant^{-1} at harvest in during both the years and in pooled results, respectively and being at par with cotton intercropped with green gram (T_{14}), black gram (T_{13}) and groundnut (T_9) during the year of 2022-23 and 2023-24. On the other hand, significantly the less dry matter accumulation per plant (193.16, 193.58 and 193.37 g plant^{-1}) were recorded under cotton intercropped with maize (T_{12}) followed by cotton intercropped with sunflower during 2022-23, 2023-24 and in pooled results, respectively.

3.2 Crop Growth Rate (CGR)

The data regarding crop growth rate (g m^{-2} day^{-1}) of *Bt* cotton recorded during 0-30, 30-60, 60-90 DAS and 90 DAS- harvest as influenced by the different *Bt* cotton based intercropping system with cereal, pulse and oilseed crops are presented in Tables 5, 6, 7, 8.

3.2.1 Crop growth rate at 0-30 DAS

The data (Table 5) regarding crop growth rate recorded during 0-30 DAS showed that crop growth rate (g m^{-2} day^{-1}) of cotton remained statistically unaffected with the intercropping of cereals, pulses and oilseeds during both the individual years and in pooled result.

3.2.2 Crop growth rate during 30-60 DAS

The data furnished in Table 6 indicated that *Bt* cotton based intercropping systems with cereal, pulse and oilseed crops had a significant effect on crop growth rate (g m^{-2} day^{-1}) of cotton during 30-60 DAS. Among different cropping systems sole cotton (T_1) gave significantly the higher crop growth rate 1.68, 1.85 and 1.77 g m^{-2} day^{-1} during the year of 2022-23, 2023-24 and in pooled results, respectively which was remained statistically at par with cotton intercropped with green gram, black gram and soybean during in first year, whereas in the year 2023-24 it was at par with cotton + green gram (T_{14}), cotton + black gram (T_{13}), cotton + groundnut (T_9) and cotton + soybean (T_{15}) intercropping system. In pooled results intercropping of cotton with green gram (T_{14}) and black gram (T_{13}) found at par with sole cotton (T_1). Conversely, significantly the lower crop growth rate of 1.03, 1.20 and 1.11 g m^{-2} day^{-1} were recorded under cotton intercropped with maize (T_{12}) during 2022-23, 2023-24 and pooled analysis respectively.

3.2.3 Crop growth rate during 60-90 DAS

The *Bt* cotton based intercropping systems with cereal, pulse and oilseed crops significantly influenced crop growth rate (g m^{-2} day^{-1}) during 60-90 DAS during the years 2022-23, 2023-24 as well as in pooled results (Table 7). The data clarified that sole cotton (T_1) recorded significantly higher crop growth rate of cotton 5.84, 6.10 and 5.97 g m^{-2} day^{-1} during both the years and in pooled results, respectively and being at par with intercropping of cotton + green gram (T_{14}), cotton + black gram (T_{13}), cotton + groundnut (T_9) and cotton + soybean (T_{15}) during the year 2022-23 and in pooled results.

The lower crop growth rate (4.12, 4.06 and 4.09 g m^{-2} day^{-1}) were recorded under cotton intercropped with maize (T_{12}) in 2022-23, 2023-24 and in pooled results, respectively.

Table 1. Effect of different cotton based intercropping systems on dry matter accumulation per plant of cotton at 30 DAS

Tr. No.	Treatment Details	Dry matter accumulation at 30 DAS (g $plant^{-1}$)		
		2022	**2023**	**Pooled**
T_1	Sole cotton	8.21	9.15	8.68
T_9	Cotton + groundnut (1:1)	7.58	8.10	7.84
T_{10}	Cotton + sunflower (1:1)	7.24	7.48	7.36
T_{11}	Cotton + pearl millet (1:1)	7.08	7.55	7.32
T_{12}	Cotton + maize (1:1)	6.81	7.29	7.05
T_{13}	Cotton + black gram (1:1)	8.02	7.79	7.91
T_{14}	Cotton + green gram (1:1)	7.33	8.67	8.00
T_{15}	Cotton + soybean (1:1)	7.72	8.43	8.07
S. Em.±		0.43	0.53	0.34
C. D. (P=0.05)		NS	NS	NS
C. V. %		9.89	11.28	10.67

Table 2. Effect of different cotton based intercropping systems on dry matter accumulation per plant of cotton at 60 DAS

Tr. No.	Treatment Details	Dry matter accumulation at 60 DAS (g $plant^{-1}$)		
		2022	**2023**	**Pooled**
T_1	Sole cotton	35.39	39.20	37.29
T_9	Cotton + groundnut (1:1)	28.25	33.71	30.98
T_{10}	Cotton + sunflower (1:1)	25.15	27.75	26.45
T_{11}	Cotton + pearl millet (1:1)	25.61	27.85	26.73
T_{12}	Cotton + maize (1:1)	23.49	26.72	25.10
T_{13}	Cotton + black gram (1:1)	31.71	34.61	33.16
T_{14}	Cotton + green gram (1:1)	32.90	36.17	34.53
$\mathbf{T_{15}}$	Cotton + soybean (1:1)	30.36	33.00	31.68
S. Em.±		2.01	2.03	1.43
C. D. (P=0.05)		6.10	6.15	4.14
C. V. %		11.97	10.84	11.37

Table 3. Effect of different cotton based intercropping systems on dry matter accumulation per plant of cotton at 90 DAS

Tr. No.	Treatment Details	Dry matter accumulation at 90 DAS (g plant^{-1})		
		2022	**2023**	**Pooled**
T_1	Sole cotton	130.08	138.05	134.07
T_9	Cotton + groundnut (1:1)	119.65	120.17	119.91
T_{10}	Cotton + sunflower (1:1)	96.71	102.50	99.61
T_{11}	Cotton + pearl millet (1:1)	100.43	107.89	104.16
T_{12}	Cotton + maize (1:1)	90.29	92.54	91.42
T_{13}	Cotton + black gram (1:1)	119.90	129.63	124.77
T_{14}	Cotton + green gram (1:1)	125.68	133.18	129.43
T_{15}	Cotton + soybean (1:1)	115.32	118.09	116.70
S. Em.±		5.74	6.70	4.41
C. D. (P=0.05)		17.41	20.31	12.78
C. V. %		8.86	9.85	9.39

Table 4. Effect of different cotton based intercropping systems on dry matter accumulation per plant of cotton at harvest

Tr. No.	Treatment Details	Dry matter accumulation at harvest (g plant^{-1})		
		2022	**2023**	**Pooled**
T_1	Sole cotton	293.59	292.48	293.03
T_9	Cotton + groundnut (1:1)	252.94	250.38	251.66
T_{10}	Cotton + sunflower (1:1)	204.13	199.86	202.00
T_{11}	Cotton + pearl millet (1:1)	208.21	213.25	210.73
T_{12}	Cotton + maize (1:1)	193.16	193.58	193.37
T_{13}	Cotton + black gram (1:1)	274.09	270.16	272.12
T_{14}	Cotton + green gram (1:1)	280.00	277.27	278.63
T_{15}	Cotton + soybean (1:1)	247.56	240.10	243.83
S. Em.±		15.13	14.19	10.37
C. D. (P=0.05)		45.88	43.04	30.04
C. V. %		10.73	10.15	10.45

Table 5. Effect of different cotton based intercropping systems on crop growth rate (CGR) of cotton during 0-30 DAS

Tr. No.	Treatment Details	Crop Growth Rate during 0-30 DAS (g m^{-2} day^{-1})		
		2022	**2023**	**Pooled**
T_1	Sole cotton	0.507	0.565	0.536
T_9	Cotton + groundnut (1:1)	0.468	0.500	0.484
T_{10}	Cotton + sunflower (1:1)	0.447	0.462	0.454
T_{11}	Cotton + pearl millet (1:1)	0.437	0.466	0.452
T_{12}	Cotton + maize (1:1)	0.421	0.450	0.435
T_{13}	Cotton + black gram (1:1)	0.495	0.481	0.488
T_{14}	Cotton + green gram (1:1)	0.453	0.535	0.494
T_{15}	Cotton + soybean (1:1)	0.476	0.520	0.498
S. Em.±		0.026	0.032	0.021
C. D. (P=0.05)		NS	NS	NS
C. V. %		9.89	11.28	10.67

Table 6. Effect of different cotton based intercropping systems on crop growth rate (CGR) of cotton during 30-60 DAS

Tr. No.	Treatment Details	Crop Growth Rate during 30-60 DAS ($g\ m^{-2}\ day^{-1}$)		
		2022	**2023**	**Pooled**
T_1	Sole cotton	1.68	1.85	1.77
T_9	Cotton + groundnut (1:1)	1.28	1.58	1.43
T_{10}	Cotton + sunflower (1:1)	1.11	1.25	1.18
T_{11}	Cotton + pearl millet (1:1)	1.14	1.25	1.20
T_{12}	Cotton + maize (1:1)	1.03	1.20	1.11
T_{13}	Cotton + black gram (1:1)	1.46	1.66	1.56
T_{14}	Cotton + green gram (1:1)	1.58	1.70	1.64
T_{15}	Cotton + soybean (1:1)	1.40	1.52	1.46
S. Em.±		0.12	0.12	0.08
C. D. (P=0.05)		0.36	0.35	0.24
C. V. %		15.43	13.34	14.32

Table 7. Effect of different cotton based intercropping systems on crop growth rate (CGR) of cotton during 60-90 DAS

Tr. No.	Treatment Details	Crop Growth Rate during 60-90 DAS ($g\ m^{-2}\ day^{-1}$)		
		2022	**2023**	**Pooled**
T_1	Sole cotton	5.84	6.10	5.97
T_9	Cotton + groundnut (1:1)	5.64	5.34	5.49
T_{10}	Cotton + sunflower (1:1)	4.42	4.61	4.52
T_{11}	Cotton + pearl millet (1:1)	4.62	4.94	4.78
T_{12}	Cotton + maize (1:1)	4.12	4.06	4.09
T_{13}	Cotton + black gram (1:1)	5.44	5.87	5.65
T_{14}	Cotton + green gram (1:1)	5.73	5.99	5.86
T_{15}	Cotton + soybean (1:1)	5.24	5.25	5.25
S. Em.±		0.35	0.37	0.26
C. D. (P=0.05)		1.08	1.11	0.74
C. V. %		11.98	12.06	12.01

Table 8. Effect of different cotton based intercropping systems on crop growth rate (CGR) of cotton during 90 DAS-harvest

Tr. No.	Treatment Details	Crop Growth Rate during 90 DAS-harvest ($g\ m^{-2}\ day^{-1}$)		
		2022	**2023**	**Pooled**
T_1	Sole cotton	3.52	3.11	3.31
T_9	Cotton + groundnut (1:1)	2.87	2.62	2.75
T_{10}	Cotton + sunflower (1:1)	2.31	1.96	2.14
T_{11}	Cotton + pearl millet (1:1)	2.32	2.12	2.22
T_{12}	Cotton + maize (1:1)	2.22	2.03	2.12
T_{13}	Cotton + black gram (1:1)	3.32	2.83	3.07
T_{14}	Cotton + green gram (1:1)	3.32	2.90	3.11
T_{15}	Cotton + soybean (1:1)	2.85	2.46	2.65
S. Em.±		0.25	0.23	0.17
C. D. (P=0.05)		0.75	0.70	0.49
C. V. %		14.99	16.03	15.48

Table 9. Effect of different cotton based intercropping systems on relative growth rate (RGR) of cotton during 30-60 DAS

Tr. No.	Treatment Details	Relative Growth Rate during 30-60 DAS (g g^{-1} day^{-1})		
		2022	**2023**	**Pooled**
T_1	Sole cotton	0.049	0.049	0.049
T_9	Cotton + groundnut (1:1)	0.044	0.047	0.046
T_{10}	Cotton + sunflower (1:1)	0.041	0.044	0.042
T_{11}	Cotton + pearl millet (1:1)	0.043	0.044	0.043
T_{12}	Cotton + maize (1:1)	0.041	0.043	0.042
T_{13}	Cotton + black gram (1:1)	0.046	0.050	0.048
T_{14}	Cotton + green gram (1:1)	0.050	0.048	0.049
T_{15}	Cotton + soybean (1:1)	0.046	0.046	0.046
S. Em.±		0.003	0.002	0.002
C. D. (P=0.05)		NS	NS	NS
C. V. %		10.37	9.28	9.82

Table 10. Effect of different cotton based intercropping systems on relative growth rate (CGR) of cotton during 60-90 DAS

Tr. No.	Treatment Details	Relative Growth Rate during 60-90 DAS (g g^{-1} day^{-1})		
		2022	**2023**	**Pooled**
T_1	Sole cotton	0.044	0.042	0.043
T_9	Cotton + groundnut (1:1)	0.048	0.042	0.045
T_{10}	Cotton + sunflower (1:1)	0.045	0.043	0.044
T_{11}	Cotton + pearl millet (1:1)	0.046	0.045	0.045
T_{12}	Cotton + maize (1:1)	0.045	0.042	0.043
T_{13}	Cotton + black gram (1:1)	0.044	0.044	0.044
T_{14}	Cotton + green gram (1:1)	0.045	0.044	0.044
T_{15}	Cotton + soybean (1:1)	0.045	0.042	0.043
S. Em.±		0.003	0.002	0.002
C. D. (P=0.05)		NS	NS	NS
C. V. %		11.14	8.01	9.77

Table 11. Effect of different cotton based intercropping systems on relative growth rate (RGR) of cotton during 90 DAS-harvest

Tr. No.	Treatment Details	Relative Growth Rate during 90 DAS-harvest (g g^{-1} day^{-1})		
		2022	**2023**	**Pooled**
T_1	Sole cotton	0.0094	0.0081	0.0088
T_9	Cotton + groundnut (1:1)	0.0087	0.0080	0.0084
T_{10}	Cotton + sunflower (1:1)	0.0088	0.0073	0.0081
T_{11}	Cotton + pearl millet (1:1)	0.0085	0.0074	0.0079
T_{12}	Cotton + maize (1:1)	0.0089	0.0080	0.0085
T_{13}	Cotton + black gram (1:1)	0.0096	0.0080	0.0088
T_{14}	Cotton + green gram (1:1)	0.0093	0.0080	0.0086
T_{15}	Cotton + soybean (1:1)	0.0088	0.0077	0.0083
S. Em.±		0.0005	0.0006	0.0004
C. D. (P=0.05)		NS	NS	NS
C. V. %		8.97	14.15	11.52

Table 12. Effect of different cotton based intercropping systems on average boll weight of cotton

Tr. No.	Treatment Details	Average boll weight (g)		
		2022	2023	Pooled
T_1	Sole cotton	3.47	3.53	3.50
T_9	Cotton + groundnut (1:1)	3.00	3.15	3.08
T_{10}	Cotton + sunflower (1:1)	2.75	2.85	2.80
T_{11}	Cotton + pearl millet (1:1)	2.68	2.90	2.79
T_{12}	Cotton + maize (1:1)	2.41	2.65	2.53
T_{13}	Cotton + black gram (1:1)	3.14	3.18	3.16
T_{14}	Cotton + green gram (1:1)	3.35	3.44	3.40
T_{15}	Cotton + soybean (1:1)	2.87	3.05	2.96
S. Em.±		0.21	0.17	0.13
C. D. (P=0.05)		0.64	0.51	0.45
C. V. %		12.30	9.40	10.88

3.2.4 Crop growth rate during 90 DAS-harvest

Various *Bt* cotton based intercropping systems exhibit their significant influence on crop growth rate (g m^{-2} day^{-1}) during 90 DAS-harvest (Table 8). Among different cropping systems sole cotton gave significantly the higher crop growth rate of cotton 3.52, 3.11 and 3.31 g m^{-2} day^{-1} at harvest during both the years and in pooled results, respectively and being at par with cotton + green gram (T_{14}), cotton + black gram (T_{13}), cotton + groundnut (T_9) and cotton + soybean (T_{15}) during the year of 2022-23 and 2023-24. On the other hand, significantly the less crop growth rate (2.22, 2.03 and 2.12 g m^{-2} day^{-1}) were recorded under cotton intercropped with maize (T_{12}) during 2022-23, 2023-24 and in pooled results, respectively.

3.3 Relative Growth Rate (RGR)

The data on RGR of cotton as influenced by cereal, pulse and oilseed as intercrops with cotton recorded during, 30-60 DAS, 60-90 DAS and 90 DAS-harvest are presented Tables 9, 10 and 11.

3.3.1 Relative growth rate (g g^{-1} day) during 30-60 DAS

An examination of data indicated that relative growth rate (g g^{-1} day) during 30-60 DAS remained statistically unaffected by intercropping of cereal, pulse and oilseed crops with cotton during both the years and pooled analysis (Table 9).

3.3.2 Relative growth rate (g g^{-1} day) during 60-90 DAS

An appraisal of data showed that intercropping of cereals, pulses and oilseeds did not influence relative growth rate (g g^{-1} day) during 60-90 DAS in both the years and in pooled analysis (Table 10).

3.3.3 Relative growth rate (g g^{-1} day) during 90 DAS-harvest

Various *Bt* cotton based intercropping systems not exhibit significant influence on relative growth rate (g g^{-1} day) recorded at 90 DAS-harvest during 2022-23, 2023-24 and in pooled analysis (Table 11).

3.4 Average Boll Weight

The data on average boll weight as influenced by cereal, pulse and oilseed as intercrop with cotton during 2022-23, 2023-24 and in pooled analysis are presented in Table 12.

The data in Table 4. indicated that the intercropping of cereals, pulses and oilseeds was significantly affected the single boll weight (g) of *Bt* cotton during 2022-23 and 2023-24 and in pooled results. The data revealed that the sole cotton (T_1) recorded significantly highest single boll weight (3.47, 3.53 and 3.50 g) during 2022-23, 2023-24 and pooled results respectively which was at par with intercropping of cotton with black gram (T_{13}), green gram (T_{14}), groundnut (T_9) and soybean (T_{15}). The lowest single boll weight (2.41, 2.65 and 2.53 g) was observed under cotton + maize (T_{12}) intercropping system during both the years and in pooled results, respectively.

4. DISCUSSION

The results revealed that dry matter per plant at 30 DAS (Table 1), CGR during 0-30 DAS

(Table 6), RGR during 30-60 DAS, RGR during 60-90 DAS, RGR during 120 DAS-harvest (Table 9, 10 and 11) failed to show perceptible variation under the influence of different intercropping.

Dry matter production per plant at 60 DAS (Table 2), 90 (Table 3) and harvest (Table 4), crop growth rate during 30-60 (Table 6), 60-90 (Table 7) and 90 to harvest (Table 8) were influenced significantly due to different intercropping systems. During initial growth stages there was no much variation in dry matter production per plant and CGR under different intercropping. Further it was observed that sole cotton recorded significantly higher dry matter production per plant and CGR at 60, 90 DAS and harvest which was found at par with cotton + green gram (T_{14}), cotton + black gram (T_{13}), cotton + groundnut (T_9) and cotton + soyabean (T_{15}). This might be due to lack of inter-specific competition, increased habitat population coupled with better microclimate, taller plants and thick stems. The lowest dry matter accumulation and CGR by cotton was recorded when it was intercropped with maize at different growth stages. This might be due to fast growing nature and ultimate smothering effect of sunflower in comparison to green gram, black gram and groundnut. At all the stages of crop growth, intercropping treatments were statistically comparable among each other. These results are in consonance with the work done by Jayakumar et al. [10], Singh et al. [11], Daisy et al. [12], Kumar et al. [13] and Saleem et al. [14].

The higher bolls weight might be due to the cotton under sole cropped situation that received all benefits and gained more boll weight from environmental and below ground resources without any competition. Similar results were reported by Satish et al. [15] and Tabib et al. [16]. Reduction in boll weight in different intercropping systems can be due to an intensive competition between the component crops in different intercropping systems for the factors such as water, nutrients, light *etc.,* which are required for boll formation.

5. CONCLUSIONS

Dry matter per plant, CGR at 60, 90 DAS and at harvest and bolls weight were found significantly higher under sole cotton during both the years of experimentation and in pooled results. Among different intercropping systems, the cotton + green gram (T_{14}) intercropping recorded the higher phenotypic attributes while the lowest was recorded with the cotton + maize (T_{12}) intercropping system.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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