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Effect of weed control treatments on weeds and physiology of *Bt* cotton grown under North Gujarat agroclimatic conditions of India

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ABSTRACT

Weeds are major obstacles in the successful cultivation of cotton. Many weeds have fast growth; hence they offer severe competition with crops especially in the initial stage. Manual weeding is time-consuming, expensive and tedious. A judicious combination of chemical and cultural methods of weed control seems necessary for effective control of weeds and for the best possible utilization of costly inputs which would ultimately result in higher yields. Therefore, a field experiment was planned and conducted at Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat (India) during kharif 2022 to study the "Effect of weed control treatments on weeds and physiology of Bt cotton grown under North Gujarat agroclimatic conditions of India" on loamy sand soil. The experiment was conducted in a randomized block design with three replications and ten treatments. The Btcotton variety GTHH 49 was sown manually at a row-to-row distance of 120 cm and 45 cm between plant to plant. Different weed control treatments significantly affected the dry weight of total weeds across the crop growth stages. After weed free plot, the minimum dry weight of total weeds at 25 and 50 DAS was observed under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS (T_5). After weed free plot, the dry weight of total weeds at 75 DAS was found minimum under pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC fb HW at 50 DAS (T_8), which had significantly reduced the dry weight of total weeds compared to all other treatments except weed free plot. The maximum dry weight of total weeds at 25, 50, and 75 DAS was observed under a weedy check plot and was significantly higher than all other weed control treatments. Physiological parameters of the crop viz., leaf area index, leaf area duration, chlorophyll content index, and PS Ⅱ quantum were reported maximum under weed-free plot followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) $^{g/ha}$ as PoE at 25 DAS + IC fb HW at 50 DAS. The seed cotton yield was reported significantly higher under weed free plot over all other weed control treatments except T_8 which was adjudged at par with weed-free plot. Based on the results of the experiment, it is concluded that T_8 controlled weeds effectively in Bt cotton and gave higher seed cotton yield and net return under North Gujarat conditions.

Keywords: *Cotton, weeds, weed dry weight, weed control efficiency, nutrient uptake, physiological parameters, yield*

Introduction

Cotton *(Gossypium hirsutum* L.) is one of the predominant fibre crops belongs to family Malvaceae. It is grown under diverse conditions around the world and plays an important role in agricultural growth. It is also called as "King of fiber" and "White gold " due to its higher economic value among all cash crops in India. India is the second largest producer of cotton after China, contributing 23.48 percent to the total cotton production of the world. The area, production and productivity of cotton in India during 2022-23 was 13.05 million hectares, 33.72 million bales and 439 kg lint per ha, respectively [4]. Gujarat, Maharashtra and Telangana are the major cotton-growing states in the country.

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Gujarat is the leading cotton producer in India and a major state for the textile industry due to its huge cotton production. During 2021-22, the cotton area, production, and productivity of Gujarat was 2.26 million hectares, 8.10 million bales, and 610 kg lint per ha, respectively [3]. Cotton supplies products such as lint, oil, seed meal, hulls, and linter, out of which lint and oil are the most important products. In India, an estimated 4 million farmers and about 60 million people depend on cotton production and textile industry to make their livelihood. Cotton is the most important cash and commercial crop contributing nearly 75 percent to the total raw material requirement of the textile industry in India. The textile industry is one of the major export enterprises in the country earning revenue of over $ 8.5 billion. Hence, it is also called 'White gold' and plays a vital role in the economic development of the country [29].

Weeds are major obstacles in the successful cultivation of cotton. Cotton is highly vulnerable to weed competition, especially in the initial stage of growth. As cotton is slow slow-growing crop while the growth of many weeds is very fast, therefore, they offer competition and also suppress the growth

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of cotton. Weeds compete with the crop for nutrients, moisture, space, and sunlight, thus, affecting the growth and development of crop during the early stages of growth. In cotton, the critical period of weed competition prevails up to 60 to 90 DAS and during this period the crop needs weed-free conditions for better results [31]. Losses caused by weeds in cotton range from 50 to 85 per cent depending upon the nature and intensity of weeds [26]. Thus, if proper weed control measures are followed, there would be greater availability of nutrients and moisture for the benefit of crop [13].

Manual weeding is a common practice to control weeds in cotton. But the scarcity of labor and high soil moisture conditions due to frequent irrigation or heavy rains during *Kharif* make the farmers unable to take up timely cultural practices including hand weeding, such operations are time-consuming, expensive and tedious. Hence, it has become imperative to control weeds by using herbicides to get higher yields. Weeds in cotton fields can be effectively killed or paralyzed at the germination stage itself by the use of suitable herbicides. Herbicides are capable of giving the crop a relatively better weed-free situation in the early stage of the crop. Pre-emergence application of pendimethalin will control the weeds at early stages and thereby ensure efficient utilization of inputs by the crop, but the weeds (annual and perennial) that appear in the later period of crop growth need to be controlled efficiently for minimum crop weed competition and obtain good yield. Therefore, a judicious combination of chemical and cultural methods of weed control seems necessary for effective control of weeds and for the best possible utilization of costly inputs which would ultimately result in higher yields. Considering the above facts and views, the present experiment was planned and conducted.

Materials and Methods

Experimental site description

A field experiment was conducted at the Agronomy Instructional Farm, Department of Agronomy, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Banaskantha (Gujarat) to evaluate the effect of weed control treatments on weeds and physiology of *Bt* cotton grown under North Gujarat agroclimatic conditions of India during *Kharif* season of the year 2022. Geographically, Sardarkrushinagar is situated at 24°19' North latitude and 72°19' East longitude with an elevation of 154.52 m above the mean sea level in the North Gujarat Agro-climatic region (AES IV) of Gujarat. This region is characterized by a semi-arid climate with extremely cold winters and hot and dry summers. Generally, monsoon commences by the third week of June and retreats from the middle of September, but there is an uncertain and uneven distribution of rainfall during the monsoon. The partial failure of rain once in three or four years is very common. Most of the precipitation is received from the South-West monsoon, concentrating in the months of July and August. The total rainfall received during the experimental period was 1346.1 mm. The winter season is fairly cold and dry starting from the end of October and continuing till the end of February. The minimum temperature of the year is reached in the months of December and January. The summer season (March-June) is generally hot and dry. The wind velocity is very high during summer. The temperature starts rising in February and reaches the maximum in the months of April or May.

Experimental details

The soil samples of the experimental field were taken randomly from different spots to a depth of 0-15 cm before lay out of experiment and composite soil sample was prepared. The soil sample was analyzed for physical as well as chemical properties of soil. The soil of the experimental field was loamy sand in texture. The details of the soil physical and chemical properties of the experimental plot are given in Table 1. The experiment was laid out in a randomized block design with three replications. The cotton variety GTHH 49 was used in this investigation. There were ten treatments *viz.*, pendimethalin 1000 g/ha as PE (T_1), quizalofop ethyl 50 g/ha as PoE at 25 DAS (T_2), pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS (T_3), pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS (T_4), pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS (T_5), quizalofop ethyl 50 g/haas PoE at 25 DAS + IC *fb* HW at 50 DAS (T_6), pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_7), pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8), weed free (T_9) and weedy check (T_{10}).

Observations recorded

Five plants were randomly selected and labeled from each net plot. These plants were used for recording different observations and also the bolls were harvested separately according to plucking for post-harvest observations. The leaf area index was worked out by dividing the leaf area per plant by the land area occupied by the plant at 25, 50, and 75 DAS.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Area occupied by plant}}$$

A = (L×W×0.771) n

Where,

A = Leaf area

L = Length of leaf

W = Maximum width of leaf

0.771 = Leaf area constant [6]

n = number of leaves per plant

Leaf area duration *i.e.,* relationship of LAI with time, was worked out by the formula given below-

$$\text{LAD} = \frac{\text{LAI}_1 + \text{LAI}_2}{2} \times t_2 - t_1$$

Where,

LAI_1 = leaf area index at t_1

LAI_2 = leaf area index at t_2

t_1 = time of first observation

t_2 = time of second observation

Chlorophyll concentration was estimated with the help of instrument MC-100 at 25, 50 and 75 DAS. PS Ⅱ quantum yield was estimated with the help of instrument LI-600 at 25, 50 and 75 DAS. The number of busted bolls was counted and collected from previously tagged five plants from the net plot and each value was sum up of all picking and the average value per plant was worked out and recorded for each treatment. Fully matured healthy and open bolls from each tagged plant were collected randomly, weighed, averaged and recorded as boll weight in gram. Seed cotton was picked from each net plot and its weight was recorded picking-wise. Then it was converted into kilogram/hectare and expressed as seed cotton yield (kg/ha).

After recording the density of weeds at 25, 50 and 75 DAS from each plot using 50 cm × 50 cm quadrate (0.25 m^2/plot), the same weeds samples were sun-dried to estimate the dry weight of total weeds and expressed in g/m^2.

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The weed control efficiency was calculated by using the below given formula [16].

$$WCE\ (\%) = \frac{DWC - DWT}{DWC} \times 100$$

Where,
DWC = Dry weight of weeds in weedy check
DWT = Dry weight of weeds in the treated plot
Nitrogen, phosphorus, and potassium content was analyzed in weeds at 50 days after sowing by adopting micro Kjeldahl's digestion [12], Vanadomolybdo phosphoric acid yellow colour [12], and flame photometric [12] method, respectively. The nutrient uptake (kg/ha) by weeds was calculated by using nitrogen, phosphorus and potassium content values and dry matter of weeds on a hectare basis.
Nutrient uptake by weeds (kg/ha)

Nutrient content in dry matter of weeds (%) × dry matter of weeds (kg/ha) x 100

Since the data on related to weeds were not normally distributed, the data were transformed by using the $\sqrt{x+0.5}$ transformation [9]. The transformed data were and analyzed statistically. The statistical analysis of the data collected for different parameters was carried out following the standard procedures [22], using a computer system at the Computer Centre, Department of Agricultural Statistics, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar. The values of calculated 'F' are taken at 5 percent level of significance. The standard errors of the mean (S.Em.), the critical difference (C.D.) at 5 percent and the co-efficient of variance percentage (C.V.%) were also calculated.

Results

Dry weight of total weeds

Data pertaining to the dry weight of total weeds (g/m^2) in *Bt* cotton at 25, 50 and 75 DAS are presented in Table 2 revealing that the different weed control treatments significantly affected the dry weight of total weeds across the crop growth stages. The weed-free plot significantly reduced the dry weight of total weeds compared to all other treatments at 25, 50 as well as 75 DAS. After weed free plot, the minimum dry weight of total weeds at 25 DAS was observed under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS *i.e.,* T_5 (3.81) followed by pendimethalin 1000 g/ha as PE *i.e.,* T_1 (4.01). These two treatments adjudged at par with each other and reduced the dry weight of total weeds significantly than all other weed control treatments except weed-free plots.

At 50 DAS, the dry weight of total weeds after weed free plot was observed minimum under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS *i.e.,* T_5 (3.60) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS *i.e.,* T_8 (4.36) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS *i.e.,* T_4 (4.53). These three treatments remained at par with respect to dry weight of total weeds at 50 DAS. The maximum dry weight of total weeds was observed under the weedy check plot *i.e.,* T_{10} (9.40), which was significantly higher over all other weed control treatments. After weed free plot, the dry weight of total weeds at 75 DAS was found minimum under pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS *i.e.,* T_8 (4.13) which had significantly reduced the dry weight of total weeds compared to all other treatments except weed free plot. Treatments 7, 6, 5 and 4 remained at par with each other in reducing the dry weight of total weeds at 75 DAS. The maximum dry weight of total weeds at 75 DAS was observed under the weedy check plot (11.61), which was significantly higher than all other weed control treatments.

Weed control efficiency (WCE)

Data related to the weed control efficiency (%) of different weed control treatments in *Bt* cotton are presented in Table 2 indicating that the weed-free plot resulted in 100% weed control efficiency across all the crop growth stages. After free plot, the maximum weed control efficiency at 25 DAS was recorded under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS *i.e.,* T_5 (64.09%) followed by pendimethalin 1000 g/ha as PE *i.e.,* T_1 (60.9%). Whereas, at 50 DAS, maximum WCE after weed-free plot was observed under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS (85.83 %) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (78.74%). Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS *i.e.,* T_8 had resulted in maximum WCE after weed-free plot at 75 DAS (87.66%).

Nutrients content and uptake by weeds in *Bt* cotton

Data pertaining to nitrogen, phosphorus, and potassium content and uptake by weeds at 50 DAS as affected by different weed control treatments are presented in Table 3. In weed-free plots, weeds were not observed therefore no value of nutrient content was reported. Maximum N, P and K content in weeds at 50 DAS was observed under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS. The minimum N, P, and K content in weeds at 50 DAS was recorded under the weedy check plot. Contrary to the nutrients content, maximum nutrient uptake by weeds at 50 DAS was observed under the weedy check plot *i.e.,* 3.45, 1.62, and 3.36 kg N, P and K/ha, respectively, which was found significantly higher over the rest of the weed control treatments. Minimum nutrient uptake by weeds at 50 DAS was observed under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS. These two treatments were found at par with respect to nutrient uptake by weeds.

Physiology of cotton

The data pertaining to the different physiological parameters of cotton are presented in Figures 1 to 4.

Leaf area index (LAI)

Results revealed that the leaf area index at 25 DAS was not influenced significantly by the different weed control treatments (Fig. 1). The weed control treatments significantly affected the leaf area index of cotton at 50 and 75 DAS. The maximum leaf area index *i.e.,* 0.671 and 1.091 was observed under weed-free plot (T_9) at 50 and 75 DAS, respectively followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8) which was found at par with weed free.

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These two treatments had resulted significantly higher leaf are index over all other weed control treatments at 50 as well as 75 DAS. The T_7, T_6, T_5 and T_4 were found at par with each other. The lowest leaf area index *i.e.,* 0.398 and 0.701 was observed under the weedy check plot at 50 and 75 DAS, respectively which was significantly lower than all other weed control treatments.

Leaf area duration (LAD)

Leaf area duration during 25-50 and 50-75 DAS was significantly affected by the different weed control treatments as indicated through the result (Fig. 2). The maximum leaf area duration *i.e.,* 9.49 and 22.48 was observed under weed free plot (T_9) during 25-50 and 50-75 DAS, respectively followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8) which was found at par with weed free. These two treatments had resulted from significantly higher leaf area duration over all other weed control treatments during 25-50 and 50-75 DAS. The T_7, T_6, T_5 and T_4 found at par with each other. The lowest leaf area duration *i.e.,* 5.90 and 13.76 was observed under the weedy check plot during 25-50 and 50-75 DAS, respectively which was significantly lower than all other weed control treatments.

Chlorophyll content index (CCI)

The different weed control practices have shown variation in chlorophyll content index (SPAD meter value) as presented in Fig. 3. At 25 and 50 DAS, the different weed control treatments did not affect the chlorophyll content index significantly but maximum and minimum CCI was observed under weed free and weedy check plot, respectively. The different weed control treatments significantly affected the chlorophyll content index at 75 DAS. The maximum chlorophyll content index was observed under weed free plot (17.9) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (17.7) which was found at par with weed free. These two treatments had resulted significantly higher chlorophyll content index over all other weed control treatments during 75 DAS. The T_7, T_6, T_5 and T_4 were found at par with each other. The lowest chlorophyll content index *i.e.,* 12.9 was observed under a weedy check plot during 75 DAS.

PS Ⅱ quantum yield

PS Ⅱ quantum yield at 25 DAS did not influence significantly, but it was significantly affected at 50 and 75 DAS by the different weed control treatments (Fig. 4). At 50 DAS, the maximum PS Ⅱ quantum yield *i.e.,* 0.708 was observed under weed free plot (T_9) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8), pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_7), quizalofop ethyl 50 g/haas PoE at 25 DAS + IC *fb* HW at 50 DAS (T_6). All these treatments were found at par with weed-free with respect to the PS Ⅱ quantum yield at 50 DAS. At 75 DAS, the maximum PS Ⅱ quantum yield was observed under weed free plot (0.752) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (0.743) which was found at par with weed free. These two treatments resulted in significantly higher PS Ⅱ quantum yield over all other weed control treatments at 75 DAS. The T_7, T_6, T_5 and T_4 were found at par with each other. The lowest PS Ⅱ quantum yield at 75 DAS was observed under the weedy check plot (0.457) which was significantly lower than all other weed control treatments.

Number of bolls per plant

The data pertaining to the number of bolls per plant of *Bt* cotton as influenced by different weed control treatments are presented in Table 4. Results indicated that different weed control treatments significantly affected the number of bolls per plant. Maximum number of bolls per plant was observed under weed free plot (31.40) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (30.07) which remained at par with weed-free plot. These two treatments resulted significantly higher number of bolls per plant over all other weed control treatments. The T_7, T_6, T_5 and T_4 were found at par with each other. The least number of bolls per plant was recorded under the weedy check plot (15.40) which was significantly lower than all other weed control treatments.

Boll weight

The data related to the single boll weight (g) are presented in Table 4. Results indicated that different weed control treatments significantly affected the boll weight. Maximum boll weight was observed under weed-free plot (5.03 g) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (4.90 g) which remained at par with weed-free plot. These two treatments had resulted in significantly higher boll weight over all other weed control treatments. The T_7, T_6, T_5 and T_4 were found at par with each other with respect to the single boll weight. The lowest single boll weight was observed under the weedy check plot (2.43 g) which was significantly lower than all other weed control treatments.

Seed cotton yield

Seed cotton yield was significantly affected by different weed control treatments as indicated by the data presented in Table 4. Maximum seed cotton yield *i.e.,* 3066 kg/ha was obtained under weed-free plot (T_9) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8) which had resulted 2981 kg/ha seed cotton yield and remained at par with weed-free plot with regard to seed cotton yield. These two treatments produced significantly higher seed cotton yield over the rest of the weed control treatments. The T_7, T_6, T_5 and T_4 were found at par with each other. The lowest seed cotton yield was recorded under the weedy check plot (T_{10}) *i.e.,* 1608 kg/ha which was significantly lower than all other weed control treatments. The seed cotton yield was reduced by 47.5 per cent in the weedy check plot as compared to weed free.

Correlation study

The correlation between total weed dry weight versus cotton physiology (CCI and PS II quantum yield) and seed cotton yield was negative, whereas, the correlation between crop physiological parameters and seed cotton yield was found positive (Fig. 5 and 6). The regression equation indicated that every one g/m^2 increase in total weed dry weight at 75 DAS reduced the seed cotton yield by 11.51 kg/ha (Fig. 6).

Discussion

Different weed control treatments significantly affected the dry weight of total weeds across the crop growth stages. The minimum dry weight of total weeds in T_5 and T_1 at 25 DAS was observed due to a minimum number of weeds because of the pre-emergence application of herbicides in these treatments.

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After weed free plot, the minimum dry weight of total weeds at 50 DAS was observed under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS (T_5) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS (T_4) because of post emergence application of herbicides which had controlled the weeds emerged at later stages. The dry weight of total weeds after weed free plot at 75 DAS was found minimum under pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8) due to efficient weed control with the integrated approach *i.e.,* after post-emergence application of herbicide, intercultural and hand weeding operations was done, which had significantly reduced the dry weight of total weeds. The maximum WCE after weed-free plot at 75 DAS under pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS *i.e.,* T_8 (87.66%) was observed because of overall good weed control due to integrated approach.

The minimum N, P, and K content in weeds at 50 DAS was recorded under a weedy check plot which might be due to huge competition for nutrients. Contrary to the nutrient content, the maximum nutrient uptake by weeds at 50 DAS under the weedy check plot was due to the maximum dry matter accumulation by weeds in the weedy check plot. The minimum nutrient uptake by weeds at 50 DAS under pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS was observed because of lowest dry matter accumulation by weeds due to better weed control.

The maximum leaf area index at 50 and 75 DAS under weed-free plot (T_9) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8) was the result of zero and minimum competition for resources in T_9 and T_8, respectively. The lowest leaf area index at 50 and 75 DAS under weedy check plot might be due to the severe weed competition for light and nutrients resulting in the production of small leaves and thus leading to the reduction in leaf area. The results are in conformity with the findings of different researchers [7, 10, 27]. Similar to LAI, the lowest leaf area duration under weedy check plot during 25-50 and 50-75 DAS, might be due to the reduction of leaf area index which had affected leaf area duration since it is positively correlated with leaf area index.

The chlorophyll content index at 75 DAS was observed maximum under weed weed-free plot followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS. These two treatments had resulted significantly higher chlorophyll content index over all other weed control treatments during 75 DAS. Weed-free treatment quantified with greater CCI value may be due to no competition for light between crop and weeds as the light has a major influence on chlorophyll development in plant systems. The lowest chlorophyll content index at 75 DAS was observed under weedy check plot, which might be due to weed flora that shaded the crop plant and hinders the light penetration into the crop canopy which ultimately reduced the chlorophyll content. Similar results were obtained by different researchers [2, 14, 20].

PS Ⅱ quantum yield did not influence significantly by the different weed control treatments at 25 DAS but it was significantly affected at 50 and 75 DAS. During 50 and 75 DAS, the maximum PS Ⅱ quantum yield was observed under weed-free plot (T_9) followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS (T_8). Higher PS Ⅱ quantum yield indicated that all the light captured by chlorophyll contributes towards electron transport chain under weed free plot. Effective weed control leads to higher PS Ⅱ quantum yield without compromising with the photochemistry of the plant, which is an indicator of photosynthesis. The lowest PS Ⅱ quantum yield at 50 and 75 DAS was observed under a weedy check plot which was significantly lower than all other weed control treatments. The Least PS Ⅱ quantum yield under the weedy check plot was due to competition of resources leads to stress, which ultimately decreased the PS Ⅱ quantum yield. Decrease in PS Ⅱ quantum yield was observed under nutrient deficiency [11, 19].

Maximum number of bolls per plant under weed free plot followed by pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS was the result of efficient weed control, which resulted in zero and minimum crop weed competition in above-said treatments, respectively. The least number of bolls per plant under weedy check plot might be due to severe competition by weeds for resources, which made the crop plant incompetent to take up adequate moisture and nutrients, consequently, growth was adversely affected. Poor growth and less uptake of nutrients with a weedy check might have produced fewer photosynthates and partitioned less assimilates to numerous metabolic sinks and ultimately poor development of bolls. These results are in conformity with the findings of other researchers [5, 15, 18]. Similar to a number of bolls per plant, maximum and minimum boll weight was observed under weed-free and under weedy check plot, respectively. This might be due to zero and maximum crop-weed competition under weed-free and under weedy check plot, respectively, that had affected the overall crop performance.

The maximum seed cotton yield in weed-free plot is due to improved yield attributes *viz.,* number of bolls per plant, boll weight and seed cotton yield, this in turn was because of improvement in plant height, leaf area index and number of sympodial branches. The increased seed cotton yield in this treatment could also be attributed to the efficient utilization of growth resources and other environmental factors. This was the outcome of reduced crop-weed competition due to good control of weeds. Whereas, it was the reverse for the weedy check plot. Analogous findings have been reported by many researchers [1, 7, 8, 17, 23, 25, 28].

Conclusions

Based on the results of the experiment, it is concluded that application of pyrithiobac sodium + quizalofop 100 (60+40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS controlled weeds effectively in *Bt* cotton and gave higher seed cotton yield north Gujarat conditions similar weed free situation. Thus, in future, this integrated weed control approach will be helpful in sustainable cotton cultivation.

Abbreviations

PE: Pre-emergence
PoE: Post-emergence
DAS: Days after sowing

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GTHH: Gujarat Talod Hirsutum Hybrid
IC: Interculturing
fb: Followed by
HW: Hand weeding
LAI: Leaf area index
LAD: Leaf area duration
WCE: Weed control efficiency
WI: Weed index
CCI: Chlorophyll content index
PS Ⅱ: Photosystem II

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Authors' contributions
Presha Mukeshkumar Parmar: Conceptualization, investigation, data analysis and preparation of the original draft.
Vikash Kumar: Conceptualization, methodology, writing original draft and editing
Jugal Kishor Malav: Methodology
Anuj Kumar Singh: Methodology and editing
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Conflict of interest
The authors declare that they have no conflict of interests.

Table 1: Physico-chemical properties of the experimental field

Sr. No.		Particulars	Content
[A]			
	(a)	Sand (%)	86.44
	(b)	Silt (%)	7.20
	(c)	Clay (%)	6.24
	(d)	Textural class [24]	Loamy sand
[B]			
	(a)	Soil pH (1:2.5 soil:water) [12]	7.58
	(b)	$EC_{1:2.5}$ (dS/m) [12]	0.16
	(c)	Organic carbon (%) [32]	0.34
	(d)	Available N(kg/ha) [30]	162.80
	(e)	Available P_2O_5 (kg/ha) [21]	39.20
	(f)	Available K_2O (kg/ha) [12]	254.30

Table 2: Effect of different weed control practices on dry weight of total weeds and weed control efficiency in Bt cotton

Treatment		Dry weight of total weeds (g/m²)			Weed control efficiency (%)		
		25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS
T_1	Pendimethalin 1000 g/ha as PE	4.01 (15.60)	6.80 (46.27)	8.55(72.90)	60.90	47.68	45.92
T_2	Quizalofop ethyl 50 g/ha as PoE at 25 DAS	5.75 (32.93)	5.40 (28.73)	8.15 (66.33)	17.47	67.51	50.79
T_3	Pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS	5.72 (32.33)	5.17 (26.37)	7.98 (63.57)	18.97	70.18	52.84
T_4	Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS	6.08 (36.63)	4.53 (20.20)	6.78 (45.87)	08.20	77.16	65.97
T_5	Pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS	3.81 (14.33)	3.60 (12.53)	6.52 (42.13)	64.09	85.83	68.74
T_6	Quizalofop ethyl 50 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	6.05 (36.17)	5.54 (30.23)	6.16 (37.80)	09.35	65.82	71.96
T_7	Pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	6.20 (38.03)	5.29 (27.70)	5.86 (33.97)	04.69	68.68	74.80
T_8	Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	6.31 (39.57)	4.36 (18.80)	4.13 (16.63)	00.83	78.74	87.66
T_9	Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100.00	100.00	100.00
T_{10}	Weedy check	6.34 (39.90)	9.40 (88.44)	11.61(134.80)	00.00	00.00	00.00
S.Em. ±		0.30	0.33	0.36	-	-	-
C.D. at 5%		0.88	0.97	1.07	-	-	-
C.V. %		10.11	11.09	9.41	-	-	-

Table 3: Effect of different weed control treatments on nutrients content and uptake by weeds in Bt cotton at 50 DAS

Treatment		Nutrient content (%)			Nutrient uptake (kg/ha)		
		N	P	K	N	P	K
T_1	Pendimethalin 1000 g/ha as PE	1.36	0.260	1.25	2.58 (6.21)	1.30 (1.21)	2.49 (5.78)
T_2	Quizalofop ethyl 50 g/ha as PoE at 25 DAS	1.37	0.283	1.28	2.11 (3.94)	1.14 (0.81)	2.04 (3.67)
T_3	Pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS	1.42	0.293	1.29	2.06 (3.78)	1.13 (0.78)	1.97 (3.39)
T_4	Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS	1.43	0.300	1.34	1.84 (2.90)	1.05 (0.60)	1.78 (2.69)
T_5	Pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS	1.48	0.313	1.37	1.53 (1.86)	0.94 (0.39)	1.49 (1.72)

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T_6	Quizalofop ethyl 50 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	1.39	0.250	1.32	2.17 (4.20)	1.12 (0.76)	2.11 (3.95)
T_7	Pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	1.41	0.280	1.31	2.10 (3.93)	1.15 (0.82)	2.03 (3.70)
T_8	Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	1.45	0.307	1.35	1.79 (2.75)	1.04 (0.58)	1.74 (2.58)
T_9	Weed free	-	-	-	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_{10}	Weedy check	1.31	0.247	1.23	3.45 (11.44)	1.62 (2.13)	3.36 (10.81)
S.Em. ±		0.08	0.02	0.09	0.12	0.05	0.12
C.D. at 5%		NS	NS	NS	0.35	0.14	0.34
C.V. %		9.52	12.79	11.43	10.04	7.44	10.15

Note: Square root transformation ($\sqrt{x+0.5}$) was applied to the original values which are given in the parenthesis

Table 4: Effect of different weed control treatments on yield of cotton

Treatment		Number of bolls per plant	Boll weight (g)	Seed cotton yield (kg/ha)
T_1	Pendimethalin 1000 g/ha as PE	19.60	3.13	2005
T_2	Quizalofop ethyl 50 g/ha as PoE at 25 DAS	20.80	3.30	2107
T_3	Pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS	21.40	3.50	2207
T_4	Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS	23.87	3.83	2392
T_5	Pendimethalin 1000 g/ha as PE + pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS	24.47	4.00	2448
T_6	Quizalofop ethyl 50 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	25.13	4.13	2508
T_7	Pyrithiobac sodium 62.5 g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	25.80	4.20	2592
T_8	Pyrithiobac sodium + quizalofop ethyl 100 (60 + 40) g/ha as PoE at 25 DAS + IC *fb* HW at 50 DAS	30.07	4.90	2981
T_9	Weed free	31.40	5.03	3066
T_{10}	Weedy check	15.40	2.43	1608
S.Em. ±		1.38	0.22	129.23
C.D. at 5%		4.10	0.67	383.96
C.V. %		10.04	10.10	9.36

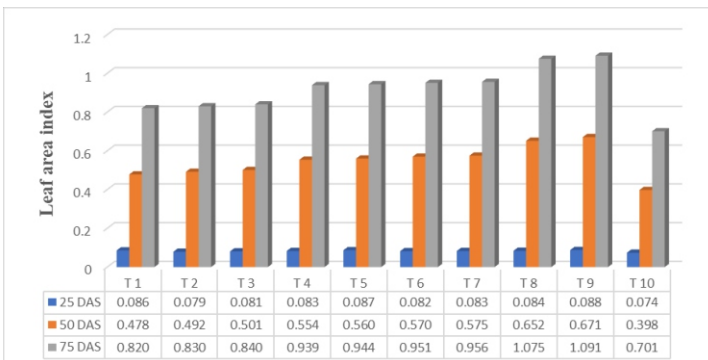

Fig. 1 Leaf area index (LAI) of cotton as affected by different weed control treatments

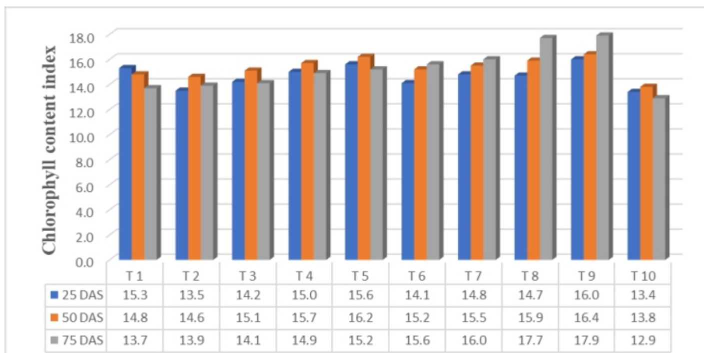

Fig. 3 Chlorophy ll content index (CCI) of cotton as affected by different weed control treatments

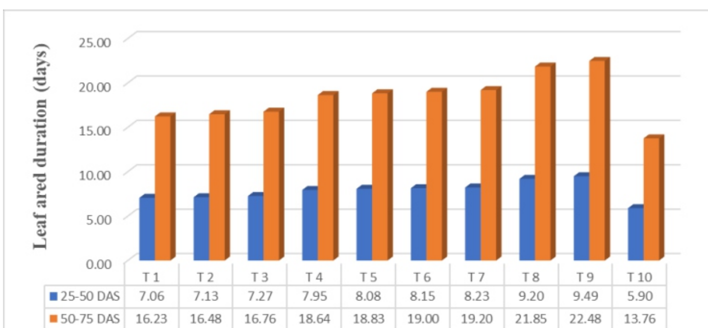

Fig. 2 Leaf area duration (days) of cotton as affected by different weed control treatments

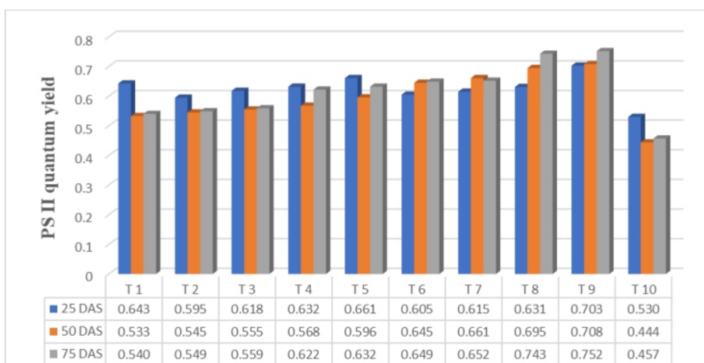

Fig. 4 PS ll quantum yield of cotton as affected by different weed control treatments

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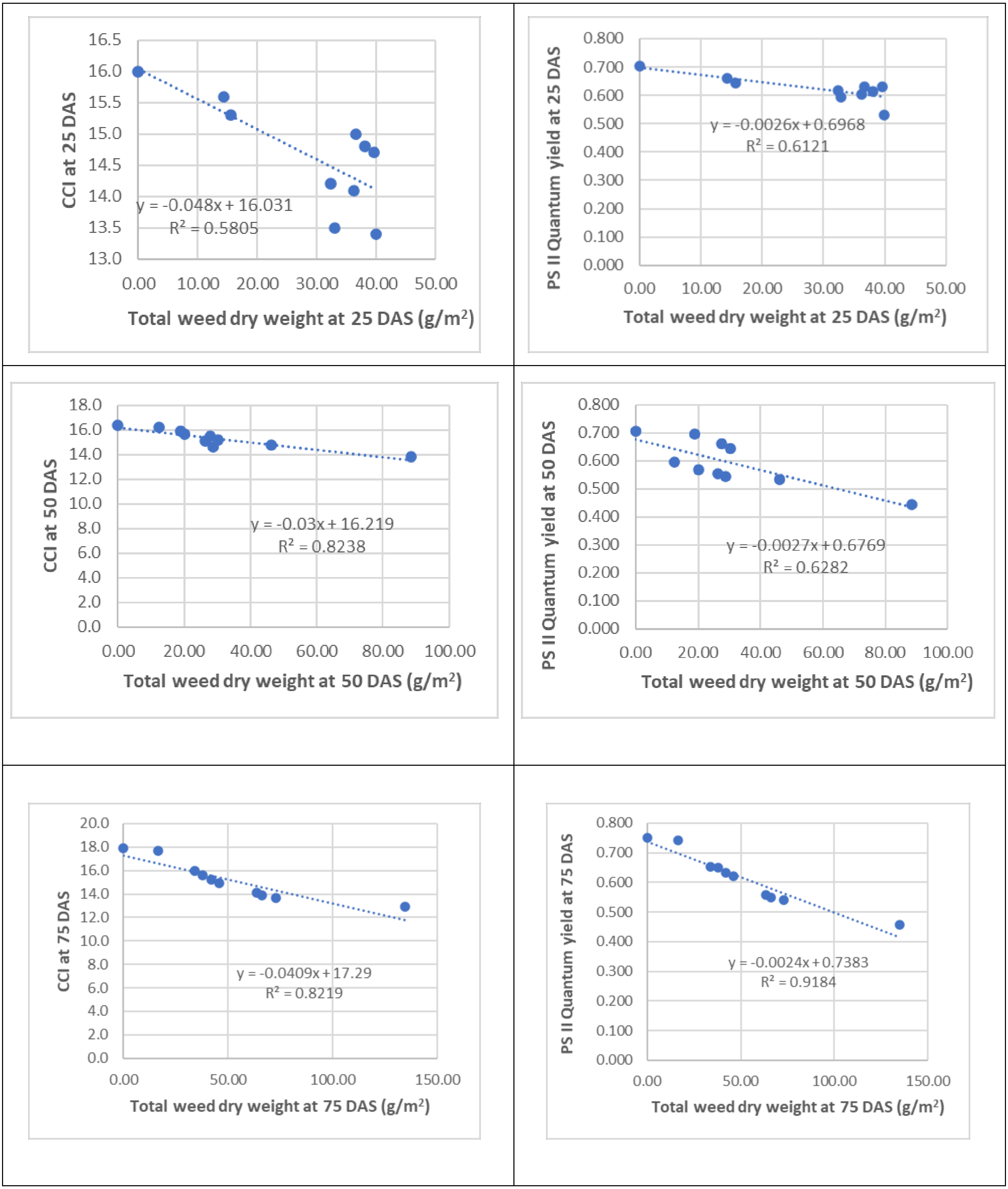

Fig. 5 Regression analysis of total weed dry weight versus CCI and PS II quantum yield at various crop growth stages in cotton

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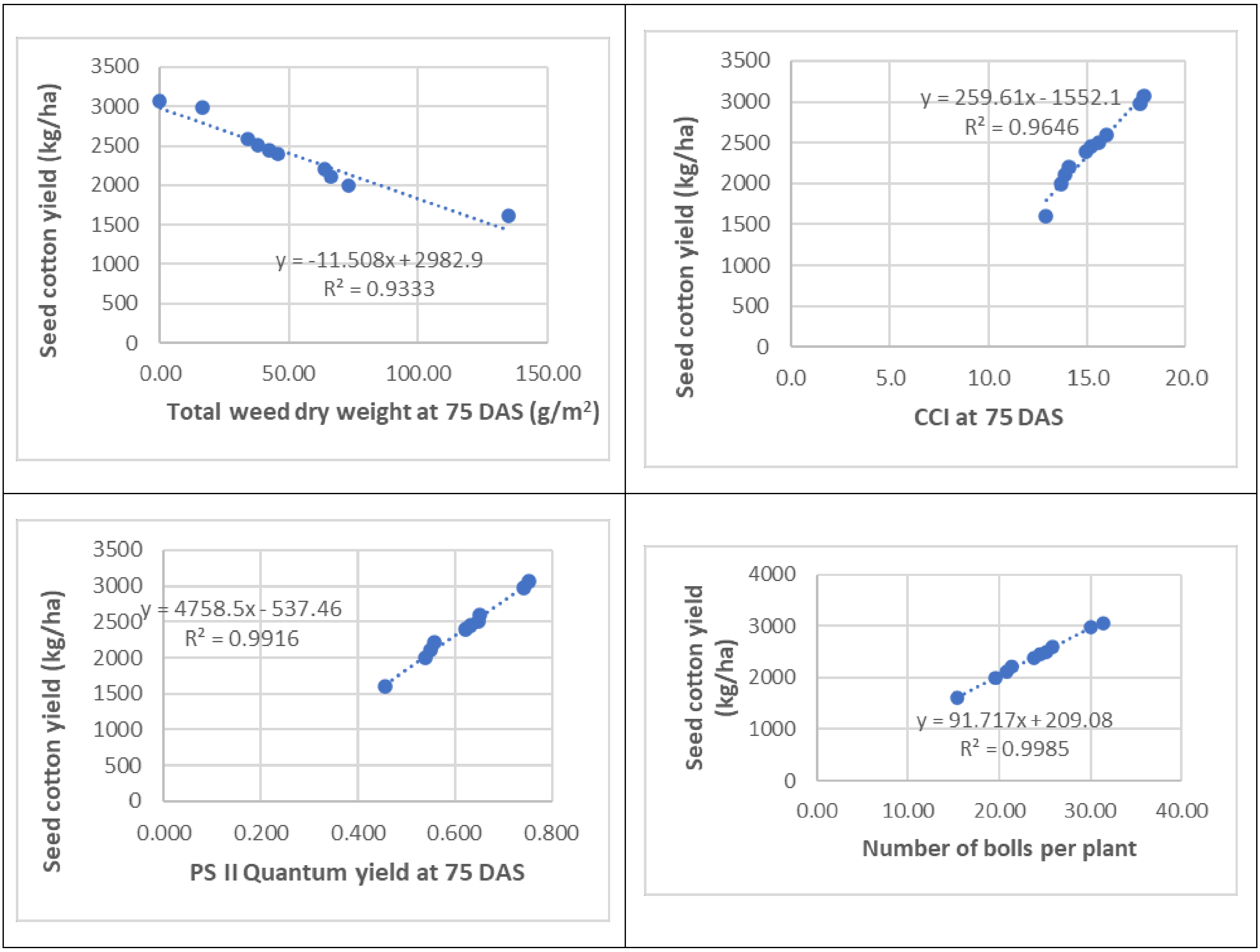

Fig. 6 Regression analysis of total weed dry weight, CCI, PS II quantum yield and Number of bolls per plant versus seed cotton yield.

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