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Chemical defoliants promotes defoliation by altering leaf growth parameters and photosynthetic efficiency in high density cotton

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ABSTRACT: The experiment was conducted to know the physiological mechanism of chemical defoliants in cotton. The effect of different defoliants and time of application on defoliation, leaf growth and gas exchange parameters were studied. Three time of defoliants application for main plot and seven treatment levels for subplot were given at Department of Crop Physiology, TNAU, Coimbatore. Results showed that, defoliation percentage was significantly enhanced from 4 days after defoliants spray to 15 days after defoliants spray. Among the different defoliants, especially Thidiazuron + Diuron (0.03 %) and Sodium chlorate (0.9 %) showed higher percentage of defoliation. Although a significant effect was observed on leaf growth, gas exchange parameters and seed yield. This study aimed to determine the physiological mechanism of defoliants on defoliation and seed cotton yield of cotton.

Key words: Chemical defoliants, cotton, gas exchange parameters, leaf area, leaf area ratio, seed cotton yield, specific leaf weight

Cotton is the most important crop for Indian as well as Tamil Nadu farmers, textile industry and economy of the country. High density cotton cultivation is new production system and CO 17 cotton variety developed with erect, compact plant architecture, offer viable opportunities to increase yield and land use efficiencies. Mechanized harvesting is the new trend of cotton production in some countries like China and Australia. Since it is the key measure to improve harvesting efficiency and solve the problem of labor shortage (Du *et al.,* 2014). Applying chemical defoliants before harvesting can promote the shedding of cotton leaves as well as promote boll opening and reduce the content of trash in cotton and enhance the picking efficiency (Wang *et al.,* 2019). Chemical defoliants which contain Thidiazuron with Diuron that widely used in most of western countries (Nisler *et al.,* 2016). However, the mechanism of Thidiazuron with Diuron and other defoliants inducing cotton leaf dropping is not completely clear still. The effect of defoliants being tightly associated with the application time, type of defoliants used and dosage. So in this study, changes in leaf growth parameters and gas exchange parameters like photosynthesis, stomatal conductance and seed cotton yield were tested.

MATERIALS AND METHODS

Field experiment was conducted at Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore during 2018 to 2019. The experiment was laid out in a split-plot design with four replications. The main plot comprised of three stage of defoliant spray (M_1 - Spray at 120 DAS, M_2 -Spray at 127 DAS and M_3- Spray at 134 DAS) and the sub-plots were seven foliar treatments (S_1 – Control, S_2 – 2, 4 D (0.5 %), S_3 – Ethephon (0.5 %), S_4– Ethephon (0.5 %)+ TIBA (450 ppm), S_5- Sodium chlorate (0.9 %), S_6 – 6-BAP (0.1 %), S_7– Thidiazuron + Diuron (0.03 %). Control treatment was sprayed with water. Plots were arranged accordingly so that each plot could be mechanically harvested without affecting other plots. Recommended cultural practices and plant protection measures were

followed throughout the crop growing season. Treatment effects were detected by counting and recording the number of green leaves remaining on the same tagged plants 4, 8, 12 and 15 Days after Treatment. Defoliation percentage was calculated by following formula,

$$\text{Defoliation (\%)} = \frac{La - Lb}{La} \times 100$$

where;

La = Number of leaves before treatment

Lb = Number of leaves after treatment.

The following growth parameters were measured five days after each defoliants treatment. Leaf area/plant was measured using a Leaf Area Meter (LICOR, Model LI 3000) and expressed as cm^2/plant specific leaf weight (mg/cm) and leaf area ratio (cm^2/g) were calculated by using the formula followed by Sivakumar *et al.,* (2018). Gas exchange parameters were measured using a portable photosynthesis system (LI-6400 XT; LI-COR Inc. Lincoln, Nebraska, USA). The different parameters such as net rate of photosynthesis (µmol CO_2 m^{-2} s^{-1}) and stomatal conductance (mol H_2O m^{-2} s^{-1}) were measured at a light intensity of 1400 µmol m^{-2} s^{-1} PAR, a leaf temperature of 30°C and a constant CO_2 concentration of 400±5 µmol CO_2 mol^{-1} in the sample chamber provided with buffer volume. All measurements for each treatment were made on the fully expanded leaves between 8:00 and 12:00 a.m. on sunny days to avoid effects of photo-inhibition and were repeated at least 3 times using different cotton plants. One week after application of the last defoliation treatments, seed cotton yield was determined in plots by manual harvesting of the center two rows of each plot and calculated kg/ha. The data collected were subjected to statistics of least square design (LSD) in split plot analysis.

RESULTS AND DISCUSSION

Defoliation percentage: The effects of defoliants on the percent defoliation after defoliants spray are given in Table 1. Defoliation starts from 4 days after defoliant application, Thidiazuron + Diuron (0.03 %) treatment registered significantly higher defoliation percentage (66.82, 33.02 and 61.90 %) at three different stages compared to other treatments. Raghavendra and Reddy, (2020) reported that higher leaf defoliation was observed in Dropp ultra @ 200ml/ha spraying. In this results indicated that the defoliation effect was influenced by the time of defoliant application. In 8 days after defoliant application, 134 DAS registered higher defoliation rate. Among the treatments, Thidiazuron + Diuron (0.03%) application of recorded highest defoliation per cent (83.75, 61.32 and 85.71 %) followed by Sodium Chlorate (0.9%). In interaction effect, Thidiazuron + Diuron (TDZ) (0.03%) of 120 and 134 DAS recorded higher defoliation. Thidiazuron is a kind of chemical defoliation agent that significantly induces leaf shedding and the activation of the abscission zone. According to the similar phenotypical and physiological characteristics of cotton seedling leaves under abiotic stress and TDZ treatment, the biological process of TDZ-triggered leaf abscission response appears to be similar to the abiotic stress-triggered leaf abscission (Patharkar and Walker, 2016). The defoliation rate increased further 12 days after defoliants spray and recorded higher defoliation rate at 120 DAS. Application of Thidiazuron + Diuron (0.03 %) (95.94, 85.85 and 93.65%) was recorded highest defoliation rate at 120 DAS. The same trend of Thidiazuron + Diuron (0.03 %) at 120 DAS and 134 DAS works better. At 15 days after defoliants spray, the defoliation process completed and Defoliants spray at 120 DAS registered highest defoliation. Among the treatments, application of Thidiazuron + Diuron (0.03 %) was recorded highest defoliation rate (99.32, 98.11 and 96.83 %) followed by Sodium chlorate (0.9 %). Haliloglu *et al.,* (2020) also reported that the highest defoliation was obtained from the Drop Ultra + Ethephon 3000 ml ha^{-1} treatment. In this we concluded that the Thidiazuron + Diuron (0.03 %) works better in

younger cotton plants (120 DAS) when compared to matured plants (127 and 134 DAS).

Leaf growth parameters: The treatments, time of application, and their interaction effects had a significant relationship with the leaf area, leaf area ratio and specific leaf weight which is given in Table 2. The lowest leaf area was observed at 120 DAS. Among the treatments, the lowest leaf area (641 cm^2/plant) was observed in 6-BAP (0.1 %). In interaction effect, the lower value was observed in 6-BAP (0.1 %) at 120 DAS. Leaf area development aids in the effective interception or penetration of light leading to high dry matter production (Rodrigues *et al.,* 2019). The decline in leaf area due to defoliants application might be due to the loss of cell turgor leads to reduced cell enlargement, transport of assimilates from the leaves to the developing sink which later caused senescence of leaves.

The lowest leaf area ratio (LAR) was recorded was 120 DAS. Among the treatments, the lowest LAR observed in 6-BAP (0.1 %) (8.90 cm^2/g). In interaction effect, the lower value was observed in 6-BAP (0.1 %) at 120 DAS and Ethephon (0.5 %) + TIBA (450 ppm) at 134 DAS. The lowest specific leaf weight (SLW) was recorded at 120 DAS. 2, 4 D (0.5 %) and Sodium chlorate (0.9%) registered lower SLW in defoliants. Defoliants spray at 127 DAS with Sodium chlorate (0.9%) treatment registered lower specific leaf weight in interaction effect. Leaf characters and physiological growth attributes are considered as important criteria for efficient defoliation process. In present study, it was evident that leaf area was reduced in defoliants treated plants. This was also reflected in the leaf area index. Plants with good boll retention and lower leaf area defoliate better due to the better penetration of applied chemicals in to the leaf canopy (Xin *et al.,* 2018).

Gas exchange parameters : Photosynthetic rate is the primary determinant of plant growth and yield. Current study showed that defoliants caused significant reduction in photosynthetic rate than control conditions. This may be due to increase in chlorophyll break down (Kaewsuksaeng *et al.,* 2011). At 4 days after defoliants spray, photosynthetic rate was decreased at 134 DAS. Among the treatments, the lowest was 2, 4 D (0.5 %) (5.66 µmol CO_2 m^{-2}/s). The interaction of 127 DAS with 2, 4 D (0.5 %) and 134 DAS with Thidiazuron + Diuron treatment showed lower photosynthetic rate. The photosynthetic rate also decreased in 8, 12 and 15 days after defoliants spray (Table 3). Finally, the lower photosynthetic rate was recorded at 134 DAS in 15 days after defoliants spray. Among the different treatments, the lowest photosynthetic rate (4.13 µmol CO_2 m^{-2}/s) observed in Sodium chlorate (0.9 %) which is on par with 2, 4 D (0.5 %). Defoliants spray at 134 DAS with 2,4 D (0.5 %), Sodium chlorate (0.9 %) and Thidiazuron + Diuron (0.03 %) recorded lowest photosynthetic rate and it enhance the senescence process. The treatments, time of application and their interaction effects had a significant relationship with stomata conductance (Table 4). The lowest stomata conductance was recorded at 134 DAS. Among the different treatments given, the lowest stomata conductance recorded in 2, 4 D (0.5%) at 4 days after defoliants spray. In interaction effects, Thidiazuron + Diuron (0.03 %) at 134 DAS recorded lower stomatal conductance. The stomatal conductance also decreased in 8, 12 and 15 days after defoliants spray. At 15 after defoliants spray, the lowest stomata conductance was recorded at 120 DAS. Among the different treatments given, the lowest stomata conductance (0.02) recorded in 2, 4 D (0.5%). In interaction effects, 2, 4 D (0.5%) at 134 DAS recorded lower stomatal conductance. One possible reason for this response could be that excessive ROS production and leaf cell structure destruction affect photosynthesis and stomatal conductance. This is consistent with previous studies, which showed that ROS could

Table 1. Effect of defoliants on defoliation percentage of cotton variety CO 17

Treatments	Defoliation (percentage)															
	4 days after defoliants spray				8 days after defoliants spray				12days after defoliants spray				15 days after defoliants spray			
	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**
Control	4.9	6.3	6.1	**5.8**	30.0	17.6	17.8	**21.8**	34.5	23.3	23.1	**27.0**	37.0	30.9	33.8	**33.9**
2, 4 D (0.5 %)	41.3	21.8	38.6	**33.9**	58.1	64.6	64.1	**62.3**	66.5	73.9	73.4	**71.3**	81.6	77.3	79.1	**79.3**
Ethephon (0.5 %)	32.9	27.9	34.8	**31.9**	53.2	47.3	51.1	**50.6**	68.5	60.5	65.5	**64.8**	74.6	68.1	66.4	**69.7**
Ethephon (0.5 %)+ TIBA (450 ppm)	43.2	22.2	41.0	**35.5**	52.6	40.2	54.2	**49.3**	69.2	50.4	63.6	**61.1**	73.2	61.6	68.8	**67.9**
Sodium chlorate (0.9 %)	15.4	23.3	55.4	**31.3**	62.7	54.3	74.1	**63.7**	77.8	79.1	86.2	**81.1**	91.9	94.6	94.3	**93.6**
6-BAP (0.1 %)	24.3	27.6	34.2	**28.7**	47.4	37.4	49.2	**44.6**	63.1	58.5	62.1	**61.2**	76.9	74.0	87.0	**79.3**
Thidiazuron + Diuron (0.03 %)	66.8	33.0	61.9	**53.9**	83.7	61.3	85.7	**76.9**	95.9	85.8	93.6	**91.8**	99.3	98.1	96.8	**98.1**
				63.2												
Mean	**32.7**	**23.17**	**38.86**		**55.40**	**46.12**	**56.69**		**67.93**	**61.66**	**66.79**		**76.36**	**72.09**	**75.20**	**67.93**
Factors	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	M
SEd	3.488*	6.403**	10.844	11.091**	0.0357**	0.573**	0.987**	0.994**	0.201**	0.797**	1.294**	1.381**	0.173**	0.976**	1.575**	0.201**
CD. (p = 0.05)	9.684	12.99	22.83	22.49	0.992	1.163	2.098	2.015	0.559	1.616	2.648	2.800	0.481	1.980	3.209	0.559

*Denotes significant at the 0.05 level of probability ** Denotes significant at the 0.01 level of probability M1 -120 Days After Sowing M2 -127 Days After Sowing M3 -137 Days After Sowing

Table 2. Effect of defoliants on leaf growth parameters of cotton variety CO 17

Treatments	5 days after defoliants spray											
	Leaf area (cm)				Leaf area ratio (cm g)				Specific leaf weight (mg dry weight cm)			
	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**
Control	1159	1223	1278	**1220**	16.6	8.7	11.2	**12.2**	30.4	33.2	41.9	**35.2**
2, 4 D (0.5 %)	1733	1813	1862	**1803**	26.3	25.2	29.1	**26.8**	18.8	35.2	24.8	**26.3**
Ethephon (0.5 %)	2051	1781	1832	**1888**	15.5	23.4	22.3	**20.4**	29.5	38.5	29.3	**32.4**
Ethephon (0.5 %)+ TIBA (450 ppm)	1086	1230	1273	**1196**	14.3	14.3	9.4	**12.7**	38.5	58.1	47.5	**48.0**
Sodium chlorate (0.9 %)	1756	1815	1796	**1789**	13.7	15.9	23.6	**17.8**	33.4	20.1	27.1	**26.9**
6-BAP (0.1 %)	641	1125	896	**887**	8.9	13.7	10.2	**10.9**	43.3	62.9	71.8	**59.3**
Thidiazuron + Diuron (0.03 %)	1645	1513	1685	**1614**	14.7	17.8	26.3	**19.6**	33.3	30.7	23.0	**29.0**
Mean	**1439**	**1500**	**1517**		**15.7**	**17.0**	**18.9**		**32.4**	**39.8**	**37.9**	
Factors	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M
SEd	10.59**	20.95**	35.22**	36.28**	0.112**	0.252**	0.419**	0.436**	0.534**	0.501**	0.965**	0.868**
CD (p = 0.05)	29.40	42.49	73.83	73.60	0.0310	0.511	0.872	0.884	1.484	1.017	2.180	1.762

*Denotes significant at the 0.05 level of probability ** Denotes significant at the 0.01 level of probability M_1 -120 Days After Sowing M_2 -127 Days After Sowing M_3 -137 Days After Sowing

Table 3. Effect of defoliants on Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) of cotton variety CO 17

Treatments	Photosynthetic rate															
	4 days after defoliants spray				8 days after defoliants spray				12days after defoliants spray				15 days after defoliants spray			
	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**
Control	17.1	18.2	21.4	**18.9**	15.3	16.1	18.2	**16.5**	14.2	13.5	18.0	**15.3**	14.0	10.4	18.0	**14.1**
2, 4 D (0.5 %)	6.4	5.7	7.1	**6.4**	6.0	5.6	5.2	**5.6**	6.0	5.5	4.7	**5.4**	5.3	5.1	4.5	**5.0**
Ethephon (0.5 %)	24.9	21.7	14.7	**20.4**	16.8	17.8	13.4	**16.0**	15.8	16.4	13.0	**15.1**	14.5	15.6	12.5	**14.2**
Ethephon (0.5 %)+ TIBA (450 ppm)	21.9	24.3	15.5	**20.6**	12.3	15.6	15.1	**14.4**	11.6	15.6	14.9	**14.0**	10.03	14.9	13.2	**12.8**
Sodium chlorate (0.9 %)	6.1	10.1	6.1	**7.4**	6.3	6.0	4.6	**5.6**	5.9	5.7	4.3	**5.3**	5.7	5.4	4.1	**5.1**
6-BAP (0.1 %)	26.9	25.8	15.3	**22.7**	14.7	20.7	9.8	**15.1**	14.1	13.3	8.6	**12.0**	13.5	7.7	7.5	**9.6**
Thidiazuron + Diuron (0.03 %)	9.5	11.2	4.9	**8.5**	8.6	9.3	4.8	**7.6**	8.4	8.7	4.6	**7.2**	8.0	8.2	4.5	**6.9**
Mean	**16.1**	**16.7**	**12.2**		**11.4**	**13.0**	**10.1**	**16.5**	**10.8**	**11.2**	**9.7**		**10.2**	**9.6**	**9.2**	
Factors	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M
SEd	0.124	0.247	0.415	0.428	0.132	0.154	0.280	0.266	0.080	0.137	0.234	0.237	0.041	0.140	0.229	0.243
CD (0.05)	0.0340 **	0.501**	0.870**	0.861**	0.0360**	0.0312**	0.610**	0.540**	0.223**	0.278**	0.495**	0.481**	0.114**	0.282**	0.469**	0.493**

*Denotes significant at the 0.05 level of probability ** Denotes significant at the 0.01 level of probability M_1 -120 Days After Sowing M_2 -127 Days After Sowing M_3 -137 Days After Sowing

Table 4. Effect of defoliants on Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) of cotton variety CO 17

Treatments	Stomata conductance															
	4 days after defoliants spray				8 days after defoliants spray				12days after defoliants spray				15 days after defoliants spray			
	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**	M_1	M_2	M_3	**Mean**
Control	0.22	0.039	0.43	**0.035**	0.25	0.031	0.28	**0.28**	0.24	0.29	0.21	**0.25**	0.17	0.25	0.17	**0.20**
2, 4 D (0.5 %)	0.02	0.03	0.05	**0.03**	0.02	0.08	0.09	**0.06**	0.04	0.07	0.07	**0.06**	0.04	0.05	0.02	**0.04**
Ethephon (0.5 %)	0.25	0.27	0.031	**0.27**	0.031	0.21	0.19	**0.24**	0.21	0.18	0.13	**0.17**	0.14	0.14	0.04	**0.11**
Ethephon (0.5 %)+ TIBA (450 ppm)	0.27	0.19	0.030	**0.25**	0.031	0.20	0.038	**0.030**	0.27	0.21	0.031	**0.26**	0.12	0.25	0.23	**0.20**
Sodium chlorate (0.9 %)	0.05	0.15	0.11	**0.10**	0.11	0.02	0.03	**0.05**	0.10	0.08	0.04	**0.06**	0.07	0.08	0.06	**0.07**
6-BAP (0.1 %)	0.16	0.19	0.21	**0.19**	0.24	0.23	0.26	**0.24**	0.19	0.16	0.19	**0.18**	0.18	0.12	0.16	**0.15**
Thidiazuron + Diuron (0.03 %)	0.030	0.12	0.02	**0.15**	0.20	0.13	0.02	**0.12**	0.15	0.10	0.05	**0.10**	0.12	0.06	0.06	**0.08**
Mean	**0.18**	**0.19**	**0.20**		**0.20**	**0.17**	**0.18**		**0.17**	**0.15**	**0.14**		**0.12**	**0.14**	**0.11**	
Factors	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M
SEd	0.0007	0.0029	0.0048	0.0051	0.0021	0.0032	0.0055	0.0055	0.0009	0.0021	0.0035	0.0037	0.0055	0.0007	0.0007	0.0019
CD (0.05)	0.0019**	0.0059**	0.0097**	0.0103**	0.0059**	0.0064**	0.0117**	0.0111**	0.0024**	0.0043**	0.0073**	0.0075**	0.0111**	0.0016**	0.0014**	0.0039**

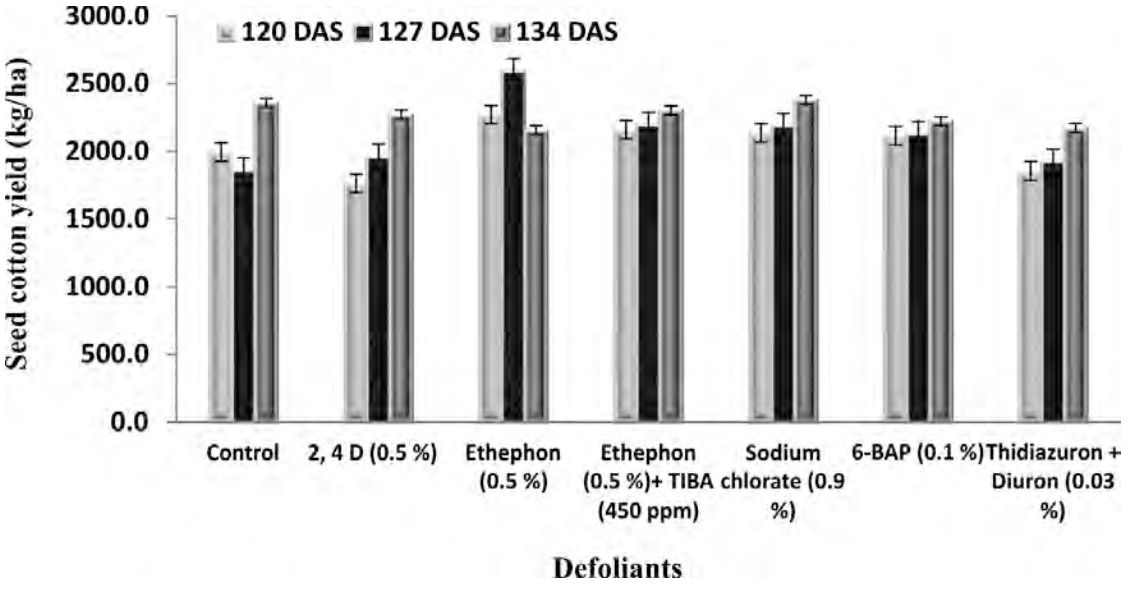

Fig. 1. Effect of defoliants on Seed cotton yield (kg/ha) of Cotton variety CO 17

exacerbate the adverse effects on leaf photosynthesis (Xu and Rothstein, 2018).

Seed cotton yield: The treatments, time of application and their interaction effects had a significant relationship with seed cotton yield (Fig. 1). 137 DAS solely recorded the superior seed cotton yield (2380 kg/ha). Ethephon (0.5 %) had higher seed cotton yield of 2272 kg/ha. Ethephon (0.5 %) spayed at 127 DAS registered more seed cotton yield (2592 kg/ha) compared to other combinations. Chemical defoliants stimulate defoliation process which leads to transport of nutrients and metabolites in leaves to developing bolls and increase the boll opening rate and seed cotton yield (Mrunalini *et al.,* 2018). Similar result were also found by Haliloglu *et al.,* (2020) and Kulvir Singh *et al.*, (2015). This may be due to the defoliant application would positively influenced the, number of opened bolls, boll weight, boll seed cotton weight and seed cotton yield.

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