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RESEARCH ARTICLE

Application of defoliants alters leaf growth and gas exchange parameters for cotton defoliation

Chandrasekaran, P[1]*, S. Ashok[2], R. Ajaykumar[3], N. Ashokkumar[4], R. Sathya[5], S. Karpagavalli[4]. A. Rajeshkumar[1] & S. Ramadass[1]

[1]Department of Crop Management, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, 603 201, India
[2] Department of Crop Physiology, Adhiparasakthi Agricultural College, Ranipet, 632 506, India
[3]Depatment of Crop Management, Vanavarayar Institute of Agriculture, Pollachi, 642 103, India
[4]Department of Crop Protection, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, 603 201, India
[5]Department of Crop Improvement, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, 603 201, India

*Email: chandrumano11@gmail.com

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Abstract

The goal of the current study was to determine how different chemical defoliants and application timing affected defoliation in cotton variety CO 17. The studies were conducted using a split-plot design with three applications at three different times as the main plot and seven defoliants as the subplot. Thidiazuron + Diuron (0.03%) defoliant reduced the gas exchange parameters, photosynthetic rate, transpiration rate and stomatal conductance by reducing plant growth parameters, leaf area, leaf area index, specific leaf weight which significantly increased the defoliation percentage. The negative correlation of cotton growth and gas exchange parameters with defoliation percentage was observed in correlation studies. In conclusion, Thidiazuron + Diuron (0.03%) defoliant was found to be superior in action for improving leaf defoliation and its associated parameters. And also it may be a cost-effective cotton defoliant for aiding the mechanical picking of cotton bolls.

Keywords

Cotton defoliation; thidiazuron; leaf characters; photosynthesis; transpiration; stomatal conductance

Introduction

Cotton is the third-largest economical crop in the world, after wheat and rice. The Global Cotton Market was worth US$ 38.54 billion in 2022 and is anticipated to reach a valuation of US$ 46.56 billion by 2027. India has grown into a major player in the global cotton markets because of recent technological improvements and trade liberalisation. From 33.4 million hectares, 121.7 million bales of cotton were produced globally in 2021-2022. India is the major contributor in world cotton production and produce 36.0 million cotton bales in 2021-2022, leading the world in both production and cotton cultivated area (12.58 million hectares, 486 kg/ha) (1). The majority of cotton cultivars produce dense foliage even when the crop is mature, which causes asynchronized boll opening. Asynchronous boll opening results in several pickings, which are labour-intensive and time-consuming. Currently, there are significant issues with labour availability and picking costs. The introduction of mechanised picking into the cotton cropping system can address these issues. Defoliants must be applied to artificially shed the leaves, which will synchronise the opening of the bolls, in preparation for mechanical picking (2). It assists in the timely clearing of the field for the upcoming crops, and it also stimulates ethylene production in plants by encouraging synchronous and early boll opening, and leaf drop. Nevertheless, it makes cotton ready for machine single-picking (3).

The defoliation, too late or early can negatively affect the yield due to the presence of a higher number of late-season immature bolls (4). The efficacy of defoliants depends on the crop maturity, uniformity of plant growth, environmental conditions, coverage of sprays, absorption and translocation. Defoliation enables farmers to harvest their crops before they are fully grown, but if defoliants are applied too early, the yield and fibre quality may be negatively impacted. The producers attempt to optimize the timing of defoliant applications by optimizing the number of young bolls that are mature and harvestable without compromising the yield and quality of older bolls (5). For the mechanical harvest, cotton variety needs to develop with high-density planting coupled with short sympodial and zero monopodial structure through a complete transformation in agronomic and breeding practices. The proper mechanism of morphological and physiological changes during defoliation is not still clear. Hence, this study was conducted to evaluate and identify the suitable defoliant and the time of application in cotton by assessing morpho-physiological parameters.

Materials and Methods

In this two years study, the changes in growth and gas exchange parameters during the defoliation by various defoliants were investigated using a cotton variety called "CO 17" with a special nature of medium duration (130-140 days) and erect and compact plant traits. The experiment was conducted during the years 2018 to 2019 and 2019 to 2020. Six defoliants with one control viz., S0 (Control), S1 (2, 4-D, 0.5% spray), S2 (Ethephon, 0.5% spray), S3 (Ethephon, 0.5% + TIBA, 0.05% spray), S4 (Sodium chlorate, 0.9% spray), S5 (6-BAP, 0.1 % spray), and S6 (Thidiazuron + Diuron, 0.03% spray) were considered as subplot, and three-time of application viz., M1 (spray at 120 DAS; Days After Sowing), M2 (spray at 127 DAS), M3 (spray at 134 DAS) were considered as main plot both the two years of studies.

Soil properties

The soil of the experimental field was clay loamy in texture, slightly alkaline(pH 8.38), low in organic carbon (0.52%) and available nitrogen (202 kg/ha), medium in phosphorus (14.0 kg/ha) and high in available potassium (878 kg/ha) during the 2019-20 year of study. In 2020-21, the soil was alkaline in nature (pH 8.1), medium in organic carbon (0.65 %), available nitrogen (232 kg/ha) and phosphorus (19.0 kg/ha) and high in available potassium (759 kg/ha).

Growth parameters

Growth parameters were recorded at random at four locations in each treatment plot 4 days after the defoliants application. Plant height was measured from the ground level to the tip of the plant and expressed in cm plant^{-1}. The total number of green leaves was counted from bottom to top of the randomly selected plants in each treatment and expressed in numbers plant^{-1}. Leaf area was measured with the Leaf Area Meter (LICOR, Model LI 3000) and expressed in cm^2 plant^{-1}. Leaf area index, specific leaf weight (mg cm^{-2}) and leaf area ratio (cm^2 g^{-1}) were calculated by following formulas,

$$\text{LAI} = \frac{\text{Leaf area of plant}}{\text{Ground area occupied by plant}} \quad \text{........(6)}$$

$$\text{SLW} = \frac{\text{Leaf dry weight per plant}^{-1}}{\text{Leaf area plant}^{-1}} \quad \text{.......(7)}$$

$$\text{LAR} = \frac{\text{Leaf area plant}^{-1}}{\text{Leaf dry weight per plant}^{-1}} \quad \text{.......(8)}$$

Total Dry Matter Production (TDMP) was calculated 15 days after defoliants spray. The whole plant was uprooted from the field; shade dried for 2 days and kept under the hot air oven at about 60°C for 48 hours. After that, the TDMP was recorded in each treatment and replications and expressed in g plant^{-1}. Leaf gas exchange parameters, photosynthetic rate (μmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}) and transpiration rate (mmol H_2O m^{-2} s^{-1}) were recorded by Portable photosynthesis system (Model LI-6400 of LICOR inc., Lincoln, Nebraska, USA, equipped with a halogen lamp (6400-02B LED) positioned on the cuvette. Leaves were inserted in a 3 cm^2 leaf chamber and photosynthetic photon flux density (PPFD) at 1200 μmol photons m^{-2}s^{-1} and relative humidity (50-55%) were set. The readings were taken between 9 am and 12.30 am at the remaining leaves after defoliation.

Statistical analysis

The data on various parameters were analyzed statistically as per the procedure suggested by (9). Wherever the treatment differences are found significant, critical differences were worked out at a five per cent probability level and the values were furnished. The mean values with Standard error are given in all figures. The correlation coefficient (‘r’) was worked out for several growth and gas exchange parameters against the defoliation percentage in cotton.

Results and discussion

In this study, we have focused on estimating the growth and gas exchange parameters involved in the process of leaf defoliation in cotton. Plant height has a direct impact on the growth and development of healthy plants (10). Taller plants have a greater number of fruiting branches and fruit sites, which is beneficial for vegetative development and helps to postpone senescence. However, cotton's dense foliage causes a delay in the maturation of the bolls as well as asynchronized boll opening. In this context, applying defoliants to cotton negatively affects plant height and vegetative development. Additionally, shorter plant heights are required for cotton harvesting by machine in order to increase picking efficiency. The total loss of leaves, which inhibited photosynthetic assimilation, may be responsible for the decrease in plant height. Due to the use of defoliants, plant height dropped in a number of ways that are related to yield potential (5). Defoliants like Thidiazuron and Sodium chlorate are classified as harvest aid chemicals because they are generally used to smooth the progress of mechanical harvesting of crops by reducing the number of leaves in cotton plants. It is important to remove cotton foliage before harvest to enhance the quality of cotton fibre with less debris during machine-picking practice.

In the first year of the experiment, Ethephon (0.5%) + TIBA (0.05%) and Thidiazuron + Diuron (0.03%) application significantly reduced the plant height to 9.5% and 5.6%, respectively, at 120 DAS. Similarly, in the second year of the study, the interaction effect of Ethephon (0.5%) + TIBA (0.05%) sprayed at 134 DAS reduced the plant height to 26.4% (Fig. 1). (11) suggested that the plant height was decreased by the application of defoliants such as Sodium chlorate and 2, 4- D, which reduces the plant growth by creating osmotic stress that leads to injury or specific ion toxicity in leaf tissues. Cessation of the leaf surface expansion is another immediate response to osmotic stress which affects plant growth. A decrease in plant height due to 2,3,5 Triiodobenzoic acid (TIBA) can be attributed to its growth retard action which can be attributed to decreased apical dominance, native auxin transport and breaking lateral bud dormancy (12).

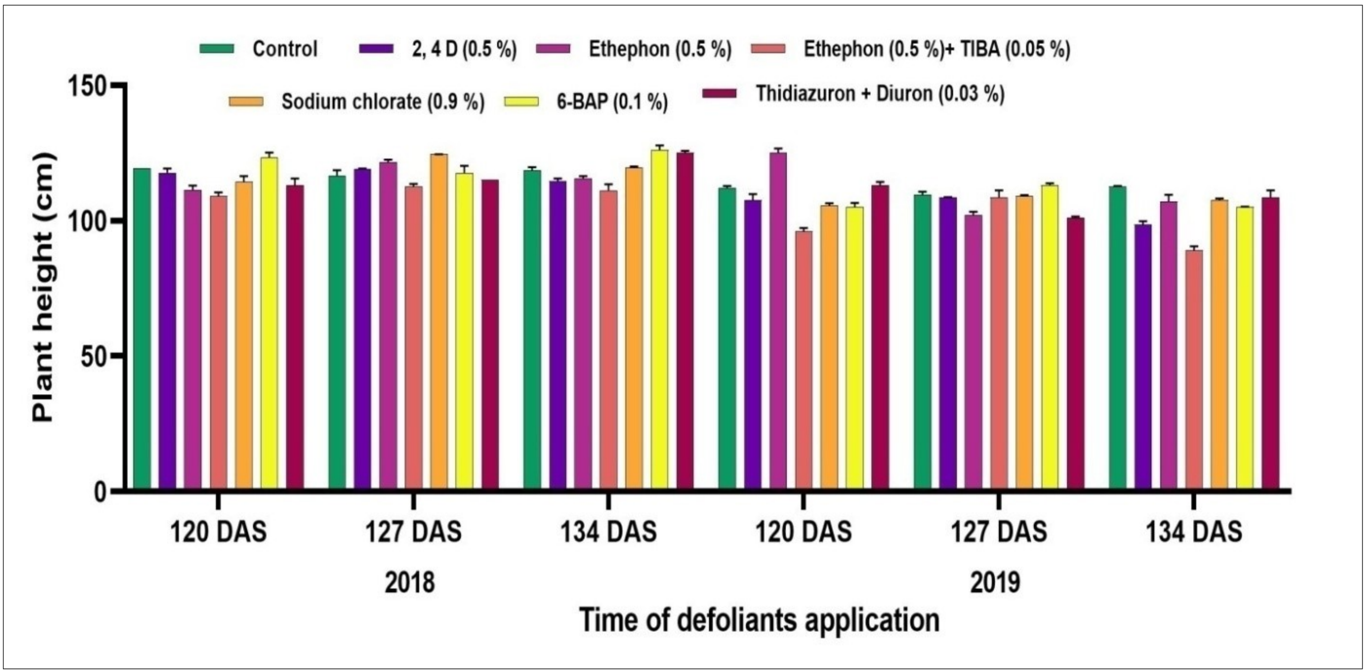

Fig. 1: Influence of defoliants and time of application on Plant height (cm) of Cotton variety (CO 17)

Number of leaves

The amount of leaves in the plant after defoliant application is crucial to the defoliation process. Maintaining less leaves implies that there is less debris in the machine-harvested cotton, which is important in increasing the cotton's quality (13). The major sources of trash content in lint are non-defoliated and desiccated leaves in the plant. Thidiazuron + Diuron (0.3%) sprayed plants at 120 and 134 DAS were shown to have lowered overall leaf numbers by 116.0% and 83.3%, respectively, in 2019-20 (Table 1). In a second-year trial, plants sprayed with sodium chlorate (0.9%) at 127 DAS and 134 DAS experienced a 4.4- and 5.1-fold reduction in leaf number, respectively. However, with the Thidiazuron + Diuron (0.03%) defoliant sprayed at three different times of application, 3.5-, 3.9-, and 4.5-fold reductions in leaf counts were noted (Fig. 2) (14). According to reports, compared to the early application of defoliants, the later stage of defoliant application decreases the number of intact leaves in the plant. The degree of crop boll retention, the vigour of foliage growth, and the maturity of the leaves are potential causes of leaf drop in the later stages of defoliant application. The effectiveness of defoliant sprays increased in plants with low to moderate foliage (15). These outcomes are consistent with the findings of (16).

Leaf area (cm^2 plant^{-1})

In order to understand how chemical defoliants affect plant performance, leaf area must be considered (17). Thinner plant leaves have more surface area per unit mass than thicker plant leaves. Increased leaf area has the ability to increase light interception, however, thicker leaves often have better photosynthetic performance (18). Defoliants Thidiazuron + Diuron (0.03%) applied at 127 DAS and 134 DAS reduced leaf area by 34.0% and 44.4%, respectively, and Sodium chlorate (0.9%) treated plants at 134 DAS reduced leaf area by 42.6% in the 2019-2020 year of study. However, in 2020-21, Thidiazuron + Diuron (0.03%) treatment recorded 97.5% of leaf area reduction at 120 DAS (Table 2). Leaf area reduction was reported in chemical defoliant-treated plants due to chlorophyll degradation and increased osmotic stress, which impairs cell turgor and cotton leaf expansion (19).

Table 1. Influence of defoliants and time of application on leaf numbers of Cotton variety (CO 17)

Treatments	Number of leaves							
	2018				2019			
	120 DAS	127 DAS	134 DAS	Mean	120 DAS	127 DAS	134 DAS	Mean
Control	54	50	44	49	54	59	61	58
2, 4 D (0.5%)	35	59	27	40	52	40	48	47
Ethephon (0.5%)	33	52	34	40	48	41	43	44
Ethephon (0.5%) + TIBA (0.05%)	36	35	34	35	50	54	51	52
Sodium Chlorate (0.9%)	42	50	28	40	15	11	10	12
6-BAP (0.1%)	41	45	33	40	55	48	53	52
Thidiazuron + Diuron (0.03%)	25	36	24	28	12	12	11	12
Mean	38	46	32		41	38	40	
Factors	M	S	M at S	S at M	M	S	M at S	S at M
SEd	0.35	0.66	1.11	1.14	0.26	0.64	1.06	1.11
CD (0.05)	0.97**	1.34**	2.34**	2.31**	0.73**	1.30**	2.20**	2.25**

** Denotes significant at the 0.01 level of probability

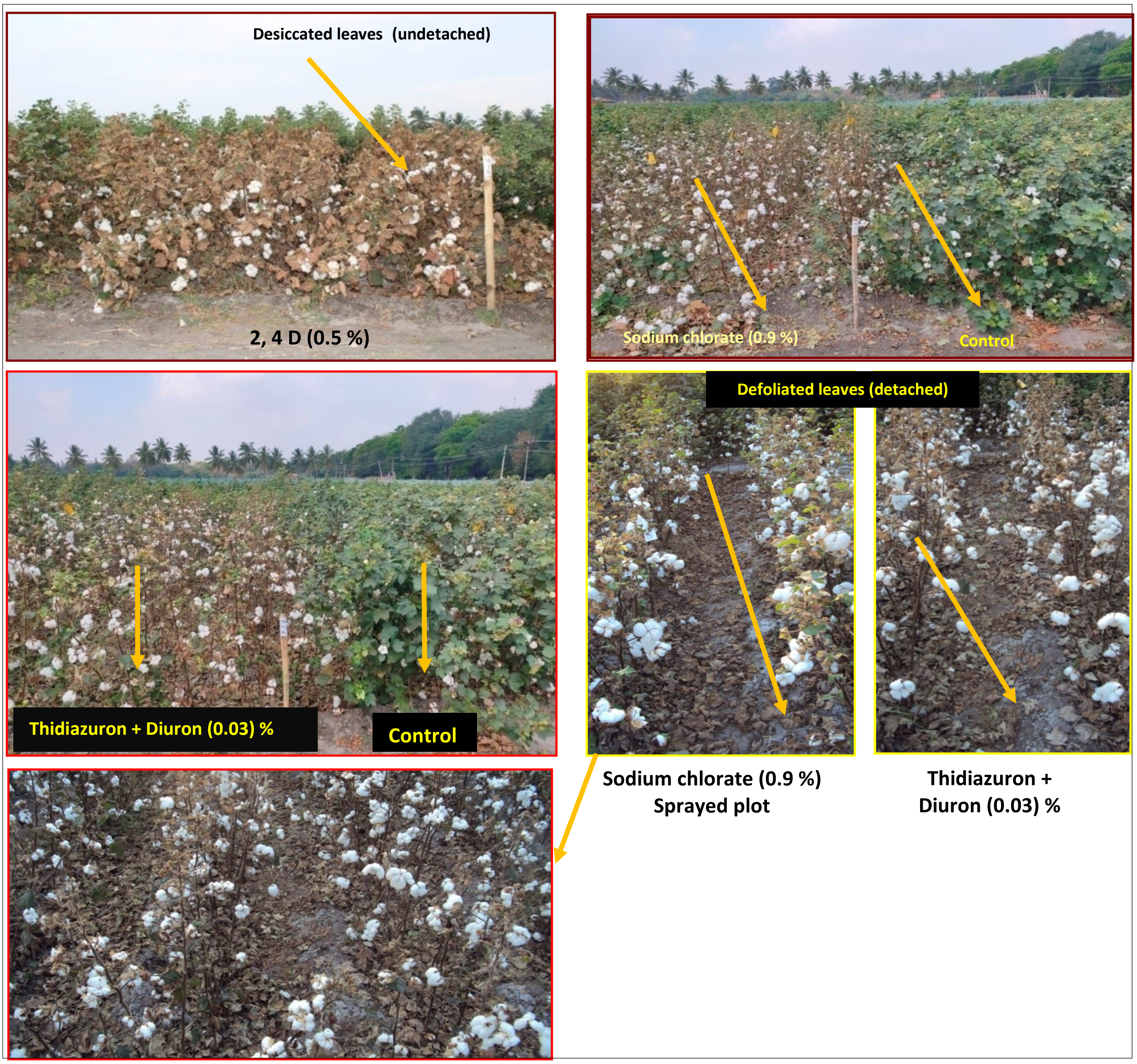

Fig 2. Field view of defoliants on leaf defoliation and boll opening percentage of Cotton

Table 2. Influence of defoliants and time of application on Leaf area (cm plant^{-1}) of Cotton variety (CO 17)

Treatments	Leaf area (cm plant^{-1})							
	2018				2019			
	120 DAS	127 DAS	134 DAS	Mean	120 DAS	127 DAS	134 DAS	Mean
Control	1159	1223	1278	1220	1511	1415	1278	1401
2, 4 D (0.5%)	1133	1013	1062	1069	1446	1313	1163	1307
Ethephon (0.5%)	1051	1081	1032	1055	1485	1430	1122	1346
Ethephon (0.5%) + TIBA (0.05%)	1086	1130	1173	1130	1172	1130	1162	1155
Sodium chlorate (0.9 %)	956	1015	896	956	1096	1015	983	1031
6-BAP (0.1%)	1041	1125	1096	1087	1286	1220	1396	1301
Thidiazuron + Diuron (0.03%)	945	913	885	914	765	816	784	788
Mean	1053	1071	1060		1252	1191	1127	
Factors	M	S	M at S	S at M	M	S	M at S	S at M
SEd	7.81	12.95	22.19	22.43	9.51	16.37	27.91	28.35
CD (0.05)	NS	2.27**	47.06**	45.50**	26.4**	33.1**	59.04**	57.50**

** Denotes significant at the 0.01 level of probability

Although defoliants cause leaf distortion, malformation, and tearing, this results in a loss in leaf area, photosynthesis, and lint yield (20).

Leaf area index (LAI)

The leaf area index (LAI) is an important measure for photosynthetic assimilation, transpiration, crop growth and development. The less amount of leaf area and plant density contributes to increased defoliation (21). Thidiazuron + Diuron (0.03%) sprayed at 134 DAS exhibited a larger reduction in leaf area index to 43.8%, while Sodium chlorate (0.9%) treatment lowered leaf area index to 42.2% during 2019-20. However, in the 2020-21 study year, Thidiazuron + Diuron (0.03%) treated plants at 120 DAS had a greater reduction of leaf area index (LAI) of up to 96.1% (Fig. 3). These results are consistent with the previous studies (3, 22).

rather complicated due to variations in the volume of water content and gas-filled space in mesophyll cells. SLW is directly proportional to concentrations of chlorophyll and total nitrogen content in the leaf (23). In our first year of the experiment, among the different treatments with the time of application, 2, 4- D (0.5%) sprayed at 120 DAS reduced specific leaf weight to 50.1% (Fig. 4). In the second year of the study, sodium chlorate (0.9%) sprayed at 134 DAS showed a larger reduction of SLW of 175.8% among the different treatments and time of defoliants application. Because SLW was tightly related to gas exchange parameters, the decline in SLW is mostly attributable to the reduced level of photosynthetic rate (24).

Leaf area ratio (LAR; cm^2 g^{-1})

The leaf area ratio (LAR) is the photosynthetic surface area per unit dry weight of a plant. It is a measure of how

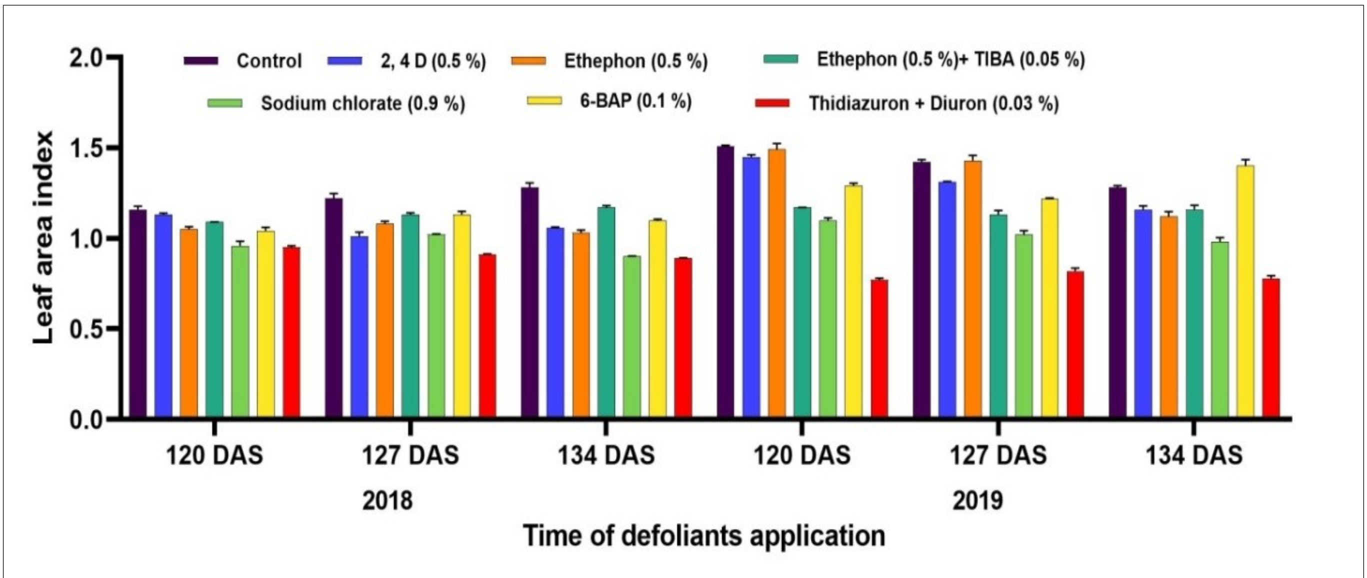

Fig 3. Influence of defoliants and time of application on leaf area index (cm^2 g^{-1}) of Cotton variety (CO 17)

Specific leaf weight (SLW)

Specific leaf weight (SLW) is the ratio of leaf area to leaf dry weight. The relationship between leaf thickness and SLW is

efficiently a plant uses its photosynthetic resources. Foliar applied 6-BAP (0.1 %) at 134 DAS reduced leaf area ratio to 1.3 per cent in 2019-20 year of the experiment. However, in 2020-21, the highest reduction of leaf area ratio was

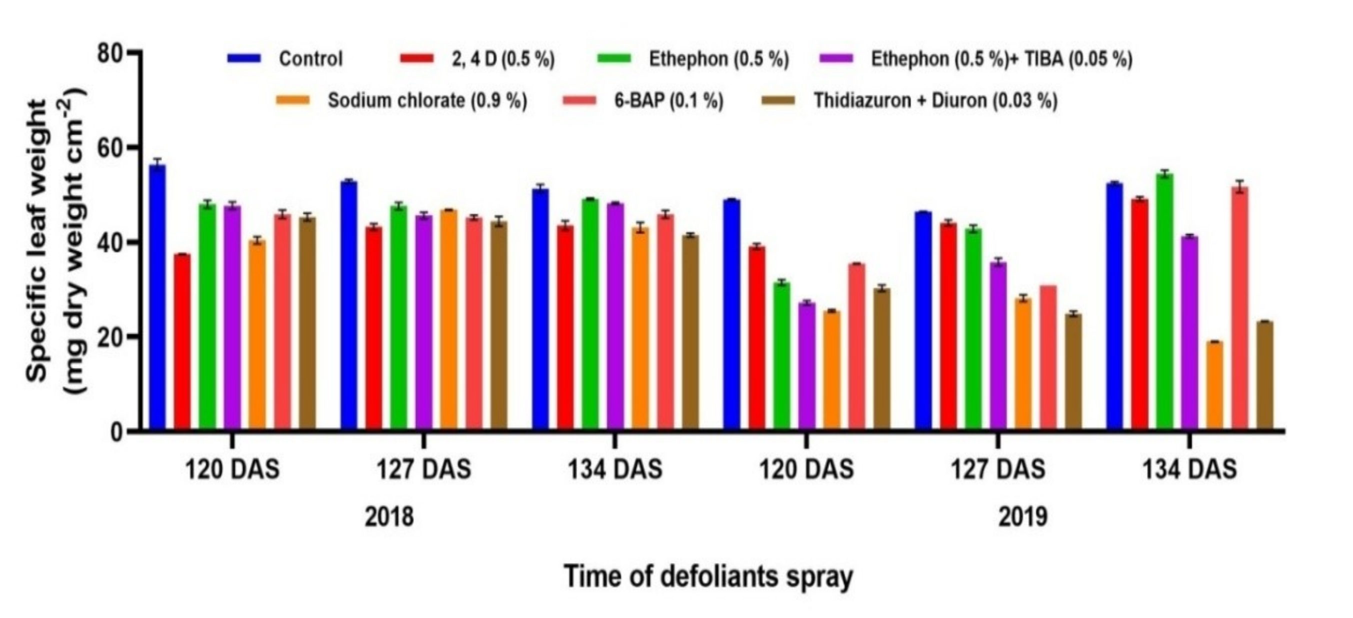

Fig 4. Influence of defoliants and time of application on Specific leaf weight (mg dry weight cm^{-2}) of Cotton variety (CO 17)

observed in Thidiazuron + Diuron (0.03 %) treatment at all three stages of application (11.1, 11.5 and 13.3%). The reduced LAR might be attributed to decreased leaf area and dry matter production (Table 3). Similarly, leaf area and leaf area ratio reduction was observed by (25) due to thiazuron + diuron and ethrel defoliants. It could be owing to the complete leaf shedding of cotton plants.

(55.2% and 62.5%, respectively). However, Sodium chlorate (0.9%) sprayed at 134 DAS showed lesser TDMP in the second year of the study (Fig. 5). The possible reason for this reduction of TDMP is correlated to the greater defoliation and boll opening percentage. This could be due to the nature of action of Thidiazuron and Diuron, which boosts ethylene production while decreasing auxin levels in the leaf abscission layer. These findings are supported by (25).

Table 3. Influence of defoliants and time of application on Leaf area ratio (cm^2 g^{-1}) of Cotton variety (CO 17)

Treatments	Leaf area ratio (cm^2 g^{-1})							
	2018				2019			
	120 DAS	127 DAS	134 DAS	Mean	120 DAS	127 DAS	134 DAS	Mean
Control	11.95	11.65	12.29	11.96	17.63	17.49	18.26	17.79
2, 4 D (0.5%)	17.17	14.07	16.59	15.94	23.74	20.17	17.62	20.51
Ethephon (0.5%)	12.51	14.22	12.59	13.11	24.26	22.63	18.07	21.65
Ethephon (0.5%) + TIBA (0.05%)	14.29	13.14	13.18	13.54	19.40	18.05	17.61	18.35
Sodium chlorate (0.9%)	13.10	14.50	13.37	13.66	26.35	25.06	25.87	25.76
6-BAP (0.1%)	14.46	13.72	12.45	13.54	26.94	27.12	26.85	26.97
Thidiazuron + Diuron (0.03%)	13.50	13.43	13.83	13.58	17.27	17.62	18.67	17.85
Mean	13.85	13.53	13.47		22.23	21.16	20.42	
Factors	M	S	M at S	S at M	M	S	M at S	S at M
SEd	0.12	0.16	0.28	0.29	0.21	0.25	0.45	0.43
CD (0.05)	NS	0.33**	0.62**	0.76**	0.58**	0.50**	0.98**	0.83**

** Denotes significant at the 0.01 level of probability

Total dry matter production (TDMP)

Dry matter partitioning analysis is an important tool for determining the allocation of current and reserve assimilates among plant parts. The reduction in dry matter production beyond maturity is associated with leaf senescence and the ageing process of plants (26). TDMP was found to decrease in defoliants applied plots. Defoliant, 2, 4- D (0.5%) sprayed at 120 DAS was found to have a greater reduction in the total dry matter by 62.5% at 134 DAS. Similarly, TDMP levels were lower in the first year of the study when sodium chlorate (0.9%) and Thidiazuron + Diuron (0.03%) were sprayed at 134 DAS

Gas exchange parameters

Photosynthesis is a biochemical process used by plants to convert light energy into chemical energy by using carbon dioxide and water that can be stored in carbohydrate molecules and it is important for maintaining plant growth and development. In this investigation, photosynthesis was severely impaired after four days of defoliant treatment. The reduction could be attributed to increased reactive oxygen species (ROS) formation and leaf membrane degradation, both of which have an impact on photosynthesis. Table 4 shows the influence of defoliants on gas exchange characteristics such as photosynthetic rate.

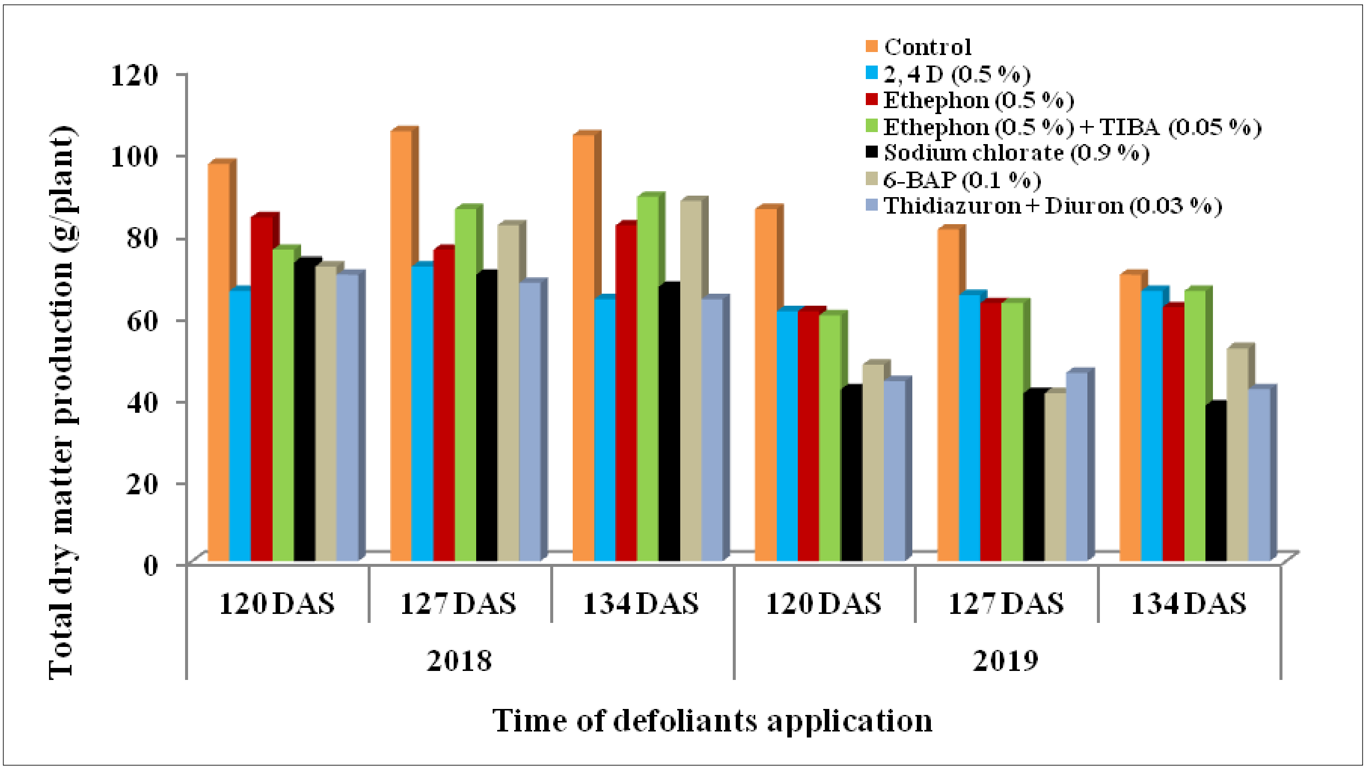

Fig 5. Influence of defoliants and time of application on Total Dry Matter Production (TDMP) (g/ plant) of Cotton variety (CO 17)

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

Treatments	Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})							
	2018				2019			
	120 DAS	127 DAS	134 DAS	Mean	120 DAS	127 DAS	134 DAS	Mean
Control	18.5	17.4	18.0	18.0	25.9	23.4	21.9	23.8
2, 4 D (0.5%)	5.3	5.1	4.5	5.0	9.6	7.8	8.4	8.6
Ethephon (0.5 %)	14.5	13.6	12.5	13.5	13.0	16.3	13.0	14.1
Ethephon (0.5 %) + TIBA (0.05%)	10.0	14.9	13.2	12.7	10.2	11.3	12.1	11.2
Sodium chlorate (0.9%)	5.7	5.4	4.1	5.1	6.3	4.0	7.3	5.9
6-BAP (0.1%)	13.5	7.7	7.5	9.6	23.0	21.0	22.2	22.1
Thidiazuron + Diuron (0.03%)	8.0	8.2	4.5	6.9	3.8	6.6	5.5	5.3
Mean	10.8	10.3	9.2		13.1	12.9	12.9	
Factors	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	0.104	0.198	0.334	0.343
CD (0.05)	0.340**	0.501**	0.870**	0.861**	0.288**	0.402**	0.702**	0.696**

** Denotes significant at the 0.01 level of probability

The drastic reduction of photosynthesis was observed in Sodium chlorate (0.9%) treatment (3.39-fold reduction) and Thidiazuron + Diuron (0.03%) treatment (3-fold) at 134 DAS in the 2019-20 year of study. Nevertheless, in the 2020-21 year of the experiment, Thidiazuron + Diuron (0.03%) sprayed at 120 DAS showed a 5.81-fold decrease in photosynthesis. This is consistent with the previous study, which discovered that ROS may exacerbate the detrimental effects on leaves (2, 27) and cause photo-oxidative stress in the plant. As a result of lower photosynthetic metabolism, yields may be reduced (28).

Thidiazuron has been shown to exhibit cytokine-like activity, increasing cell wall hydrolytic enzymes and hormone synthesis such as abscisic acid and ethylene (29). Diuron inhibits photosynthetic electron transport and acts at the quinone acceptor complex in the electron transport chain between the PS-I and PS-II photosystems. The diuron compounds bind to the secondary quinone (QB) binding site of the D1 and D2 proteins, which form the core of PS-II reaction centres. Due to the inability of the diuron to receive electrons, the electron cannot exit the initial quinone acceptor, quinine A (QA). As a result Diuron effectively blocks electron flow and reduces photosynthesis. A subsequent chain reaction of lipid peroxidation occurs in permeable membranes, causing cells to dry up quickly. The combined effect of these chemicals increases the possibility of defoliation. In plants, sodium chlorate is a powerful oxidising agent (30). (Table 5)

Table 5. Influence of defoliants and time of application on Transpiration rate (mmol H_2O m^{-2} s^{-1}) Cotton variety (CO 17)

Treatments	Transpiration rate (mmol H_2O m^{-2} s^{-1})							
	2018				2019			
	120 DAS	127 DAS	134 DAS	Mean	120 DAS	127 DAS	134 DAS	Mean
Control	3.3	4.4	2.8	3.5	10.6	8.5	5.5	8.2
2, 4 D (0.5%)	0.7	0.8	0.6	0.7	2.8	4.0	4.5	3.8
Ethephon (0.5 %)	2.3	3.0	2.9	2.7	1.5	7.4	4.9	4.6
Ethephon (0.5%) + TIBA (0.05%)	2.0	3.6	3.6	3.1	2.7	7.8	1.8	4.1
Sodium chlorate (0.9%)	1.2	0.8	0.9	1.0	4.9	5.9	7.9	6.2
6-BAP (0.1%)	3.4	2.6	2.6	2.9	5.0	12.1	8.9	8.7
Thidiazuron + Diuron (0.03%)	2.4	1.3	1.0	1.6	0.8	1.6	8.8	3.7
Mean	2.2	2.4	2.1		4.0	6.8	6.1	
Factors	M	S	M at S	S at M	M	S	M at S	S at M
SEd	0.018	0.029	0.050	0.050	0.021	0.066	0.107	0.114
CD (0.05)	0.051**	0.059**	0.107**	0.102**	0.058**	0.133**	0.220**	0.230**

** Denotes significant at the 0.01 level of probability

By reacting with nitrate reductase, sodium chlorate is converted to sodium chlorite. Sodium chlorite functions as both a cotton desiccant and a nonselective contact herbicide. One suggested explanation for this response is that high levels of reactive oxygen species (ROS) and leaf cell structural damage impair photosynthesis and stomatal conductance. This is consistent with our findings that ROS might exacerbate the negative effects on leaf photosynthesis (31). In both years of research, a significantly comparable trend in transpiration rate and stomatal conductance was detected. During 2019-20, the rate of transpiration was significantly lowered in the treatments with 2, 4- D (0.5%) and Sodium chlorate (0.9%) at 127 DAS. In 2020-21, however, a substantial amount of transpiration rate decrease was seen in Thidiazuron + Diuron (0.03%) sprayed plants at 120 DAS (Table 5). Stomata formed by a pair of guard cells are the channels through which plants exchange photosynthetic CO_2 and control transpiration (32). The stomatal conductance was reduced in the treatment of 2, 4- D (0.5%) sprayed plants at 134 and 127 DAS (7.5- and 4.0-fold reduction, respectively) (Table 6). The foliar-sprayed Thidiazuron (TDZ) significantly decreased the photosynthesis rate, stomatal conductance and transpiration rate of the cotton leaf. The possible reason could be the leaves' chlorophyll captures the energy from the sun to create sugary carbohydrates, which allows the plant to grow, but in the case of plants starting to senescence, the chlorophyll content of leaves decreases (33).

Cotton leaf stomata were damaged by defoliant treatment, indicating a significant negative association between leaf abscission and stomata damage. According to a few studies, ROS increase in stomatal guard cells may promote stomatal closure (34) and excessive ROS accumulation causes leaf cell death. The lack of stomatal control had an effect on protein synthesis, which was responsible in the early stages. It is related to leaf turgor loss and high rates of transpiration, resulting in desiccation and eventual abscission (35).

Correlation analysis

During 2020-21, a highly significant association between leaf growth parameters and defoliation percentage was

Table 6. Influence of defoliants and time of application on Stomatal conductance (mol H_2O m^{-2} s^{-1}) of Cotton variety (CO 17)

Treatments	Stomata conductance (mol H_2O m^{-2} s^{-1})							
	2018				2019			
	120 DAS	127 DAS	134 DAS	Mean	120 DAS	127 DAS	134 DAS	Mean
Control	0.17	0.25	0.17	0.20	0.48	0.30	0.18	0.32
2, 4 D (0.5%)	0.04	0.05	0.02	0.04	0.13	0.14	0.12	0.13
Ethephon (0.5%)	0.14	0.14	0.11	0.13	0.16	0.31	0.19	0.22
Ethephon (0.5%) + TIBA (0.05%)	0.12	0.25	0.23	0.20	0.12	0.24	0.12	0.16
Sodium chlorate (0.9%)	0.07	0.08	0.06	0.07	0.08	0.02	0.09	0.06
6-BAP (0.1%)	0.18	0.12	0.16	0.15	0.22	0.63	0.49	0.45
Thidiazuron + Diuron (0.03%)	0.12	0.06	0.06	0.08	0.03	0.05	0.24	0.11
Mean	0.12	0.14	0.12		0.17	0.24	0.20	
Factors	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	0.002	0.002	0.004	0.004
CD (0.05)	0.0019**	0.0059**	0.0097**	0.0103**	0.006**	0.005**	0.010**	0.008**

** Denotes significant at the 0.01 level of probability detected. Leaf area (LA), leaf area ratio (LAR), stomatal conductance (gs), and transpiration rate (E) were found to be non-significant (Table 7). However, other indicators such as the leaf area index (LAI), SLW, TDMP, and photosynthetic rate (Pn) were extremely significant and had a negative connection with the percentage of defoliation . However, in 2020-21, Leaf area ratio (LAR), stomatal conductance (gs) and transpiration rates (E) were determined to be non-significant with all other parameters. However, there was a substantial negative association between leaf area (LA), leaf area (LAI), SLW, photosynthetic rate (Pn) and defoliation percentage (Dp).

Authors contributions

PC planned and conducted the studies. SA, RA, NA, AR and SR participated in the data analysis and editing the manuscript. RS and SK involved in the writing of manuscript and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: : Authors do not have any conflict of interests

Ethical issues: None

Table 7. Correlation analysis of cotton defoliation against plant growth and gas exchange parameters during 2020-21

	LA	LAI	SLW	LAR	TDMP	Pn	E	gs	Dp
LA	1								
LAI	10.000**	1							
SLW	0.906**	0.908**	1						
LAR	0.141	0.141	-0.198	1					
TDMP	0.712	0.711	0.862*	-0.585	1				
Pn	0.745	0.742	0.733	0.149	0.535	1			
E	0.453	0.448	0.307	0.512	0.08	0.806*	1		
Gs	0.49	0.485	0.318	0.622	0.012	0.824*	0.964**	1	
DP	-0.839*	-0.837*	-0.896**	0.189	-0.844*	-0.903**	-0.564	-0.534	1

Leaf area (**LA**), Leaf area index (**LAI**), Leaf area ratio (**LAR**), Specific leaf weight (**SLW**), Total dry matter production (**TDMP**), Phostoynthetic rate (**Pn**), Transpiration rate (**E**), Stomatal conductance (**gs**), Defoliation percentage (**Dp**). *Denotes significant at the 0.05 level of probability, ** Denotes significant at the 0.01 level of probability

Conclusion

Labour shortage is a major problem in agriculture and allied activities in the world. Cotton cultivation is a labour-dependent activity during each field operation from sowing to harvest. Cotton picking by mechanical harvester is important for avoiding difficulties in manual picking, labour shortage and reduces the time of harvest. At the time of the mechanical harvesting of cotton, there is a problem with trash content, leaf and premature flowers which affected the lint quality of cotton. Hence, artificial detachment of leaves, flowers and other trash content is important for improving the mechanical picking as well as manual picking efficiency and lint quality in cotton. The study concluded that foliar-applied defoliants Thidiazuron and Diuron promote cotton defoliation up to 98% without increasing trash content in lint by lowering leaf growth and gas exchange characteristics in cotton. Further research was required to improve defoliant effects in poor environmental conditions, as well as to investigate the signal transduction pathways of ROS and other plant hormones.

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References

1. Mishra P, Vikas KT, Madhu KS, Babu KS, Kendappa G, Sudhakar S. Use of unmanned aerial vehicles in crop protection. J Adv Agric Technol. Vol. 2018;5(4). https://doi.org/10.18178/joaat.5.4.340-345
2. Wang H, Gao K, Fang S, Zhou Z. Cotton yield and defoliation efficiency in response to nitrogen and harvest aids. Agron J. 2019;111(1):250-56. https://doi.org/10.2134/agronj2018.01.0061
3. Feng A, Zhou J, Vories ED, Sudduth KA, Zhang M. Yield estimation in cotton using UAV-based multi-sensor imagery. Biosyst Engin. 20201;193:101-14. https://doi.org/10.1016/j.biosystemseng.2020.02.014
4. Hu W, Lv X, Yang J, Chen B, Zhao W, Meng Y, Wang Y, Zhou Z, Oosterhuis DM. Effects of potassium deficiency on antioxidant metabolism related to leaf senescence in cotton (*Gossypium hirsutum* L.). Field Crops Res. 2016;191:139-49. https://doi.org/10.1016/j.fcr.2016.02.025
5. Wright SD, Hutmacher RB, Shrestha A, Banuelos G, Rios S, Hutmacher K, Munk DS, Keeley MP. Impact of early defoliation on California pima cotton boll opening, lint yield and quality. J Crop Improv. 2015;29(5):528-41. https://doi.org/10.1080/15427528.2015.1056399
6. Williams SR. Methods of growth analysis. Plant photosynthetic production manual and methods, Drow, Jenk, NU Publishers, The Hague. 1946;348-91.
7. Pearce RB, Carlson GE, Barnes DK, Hart RH, Hanson CH. Specific leaf weight and photosynthesis in alfalfa 1. Crop Sci. 1969;9(4):423-26. https://doi.org/10.2135/cropsci1969.0011183X000900040010x
8. Radford PJ. Growth analysis formulae-their use and abuse 1. Crop Sci. 1967;7(3):171-75. https://doi.org/10.2135/cropsci1967.0011183X000700030001x

9. Gomez KA, Gomez AA. Statistical procedures for agricultural research. John wiley and sons. 1984.

10. Nagashima H, Hikosaka K. Not only light quality but also mechanical stimuli are involved in height convergence in crowded Chenopodium album stands. New Phytol. 2012;195(4):803-11. https://doi.org/10.1111/j.1469-8137.2012.04218.x

11. Meloni DA, Oliva MA, Martinez CA, Cambraia J. Photosynthesis and activity of superoxide dismutase, peroxidase and glutathione reductase in cotton under salt stress. Environ Experim Bot. 2003;49(1):69-76. https://doi.org/10.1016/S0098-8472(02)00058-8

12. Karademir E, Karademir Ç, Ekininci R, Gençer O. Relationship between yield, fiber length and other fiber-related traits in advanced cotton strains. Notul Botan Horti Agrobotan Cluj-Napoca. 2010;38(3):111-16. https://doi.org/10.15835/nbha3834889

13. Zhang T, Qian N, Zhu X, Chen H, Wang S, Mei H, Zhang Y. Variations and transmission of QTL alleles for yield and fiber qualities in upland cotton cultivars developed in China. PloS one. 2013;8(2):e57220. https://doi.org/10.1371/journal.pone.0057220

14. Kumari SR, George M. Effect of early ethrel application in enhancing cotton production in vertisols of Andhra Pradesh, India. Agric Sci Digest-A Res J. 2013;33(3):193-97. http://dx.doi.org/10.5958/j.0976-0547.33.3.006

15. Supak JR, Snipes CE, editors. Cotton Harvest Management: Use and influence of harvest aids. Cotton Foundation; 2001.

16. Xin F, Zhao J, Zhou Y, Wang G, Han X, Fu W, Deng J, Lan Y. Effects of dosage and spraying volume on cotton defoliants efficacy: a case study based on application of unmanned aerial vehicles. Agronomy. 2018;8(6):85. https://doi.org/10.3390/agronomy8060085

17. O'Neal ME, Landis DA, Isaacs R. An inexpensive, accurate method for measuring leaf area and defoliation through digital image analysis. J Econ Entomol. 2002;95(6):1190-94. https://doi.org/10.1603/0022-0493-95.6.1190

18. Pettigrew WT, Heitholt JJ, Vaughn KC. Gas exchange differences and comparative anatomy among cotton leaf-type isolines. Crop Sci. 1993;33(6):1295-99. https://doi.org/10.2135/cropsci1993.0011183X003300060035x

19. Zhang L, Ma H, Chen T, Pen J, Yu S, Zhao X. Morphological and physiological responses of cotton (*Gossypium hirsutum* L.) plants to salinity. PLoS One. 2014;9(11):e112807. https://doi.org/10.1371/journal.pone.0112807

20. Tung SA, Huang Y, Ali S, Hafeez A, Shah AN, Song X, Ma X, Luo D, Yang G. Mepiquat chloride application does not favor leaf photosynthesis and carbohydrate metabolism as well as lint yield in late-planted cotton at high plant density. Field Crops Res. 2018;221:108-18. https://doi.org/10.1016/j.fcr.2018.02.027

21. Hutmacher RB, Wright SD, Keeley MP, Marsh BH, Delgado R, Banuelos G, Shafter CA. Planting date, plant density and irrigation management: Responses of recent Upland varieties in the San Joaquin Valley of alley of California.

22. Liao J, Zang Y, Luo X, Zhou Z, Zang Y, Wang P, Hewitt AJ. The relations of leaf area index with the spray quality and efficacy of cotton defoliant spraying using unmanned aerial systems (UASs). Comput and Electron Agric. 2020;169:105228. https://doi.org/10.1016/j.compag.2020.105228

23. White JW, Montes RC. Variation in parameters related to leaf thickness in common bean (*Phaseolus vulgaris* L.). Field Crops Res. 2005;91(1):7-21. https://doi.org/10.1016/j.fcr.2004.05.001

24. Bondada BR, Oosterhuis DM. Canopy photosynthesis, specific leaf weight and yield components of cotton under varying nitrogen supply. J Plant Nutrit. 2001;24(3):469-77. https://doi.org/10.1081/PLN-100104973

25. Mrunalini K, Rekha MS, Murthy VR, Jayalalitha K. Impact of harvest-aid defoliants on yield and economics of high density cotton. Indian J Agric Res. 2019;53(1):116-19. http://dx.doi.org/10.18805/IJARe.A-4888

26. Afzal MN, Tariq M, Ahmad M, Mubeen K, Khan MA, Afzal MU, Ahmad S. Dry matter, lint mass and fiber properties of cotton in response to nitrogen application and planting densities. Pakistan J Agric Res. 2019;32(2):229. http://dx.doi.org/10.17582/journal.pjar/2019/32.2.229.240

27. Xu P, Chen H, Cai W. Transcription factor CDF4 promotes leaf senescence and floral organ abscission by regulating abscisic acid and reactive oxygen species pathways in Arabidopsis. EMBO reports. 2020;21(7):e48967. https://doi.org/10.15252/embr.201948967

28. Gong Z, Xiong L, Shi H, Yang S, Herrera-Estrella LR, Xu G, Chao DY, Li J, Wang PY, Qin F, Li J. Plant abiotic stress response and nutrient use efficiency. Sci China Life Sci. 2020;63:635-74. https://doi.org/10.1007/s11427-020-1683-x

29. Mutui T, Mibus H, Serek M. Effects of thidiazuron, ethylene, abscisic acid and dark storage on leaf yellowing and rooting of Pelargonium cuttings. J Hortic Sci Biotechnol. 2005;80(5):543-50. https://doi.org/10.1080/14620316.2005.11511975

30. Bohlke JK, Hatzinger PB, Sturchio NC, Gu B, Abbene I, Mroczkowski SJ. Atacama perchlorate as an agricultural contaminant in groundwater: isotopic and chronologic evidence from Long Island, New York. Environ Sci Technol. 2009;43(15):5619-25. https://doi.org/10.1021/es9006433

31. Xu J, Wang X, Li Y, Zeng J, Wang G, Deng C, Guo W. Host-induced gene silencing of a regulator of G protein signalling gene (Vd RGS 1) confers resistance to Verticillium wilt in cotton. Plant Biotechnol J. 2018;16(9):1629-43. https://doi.org/10.1111/pbi.12900

32. Agurla S, Gahir S, Munemasa S, Murata Y, Raghavendra AS. Mechanism of stomatal closure in plants exposed to drought and cold stress. Survival Strategies in Extreme Cold and Desiccation: Adaptation Mechanisms and Their Applications. 2018:215-32. https://doi.org/10.1007/978-981-13-1244-1_12

33. Khan MI, Khan NA. Ethylene reverses photosynthetic inhibition by nickel and zinc in mustard through changes in PS II activity, photosynthetic nitrogen use efficiency and antioxidant metabolism. Protoplasma. 2014;251:1007-19. https://doi.org/10.1007/s00709-014-0610-7

34. Liu J, Zhang C, Wei C, Liu X, Wang M, Yu F, Xie Q, Tu J. The RING finger ubiquitin E3 ligase OsHTAS enhances heat tolerance by promoting H2O2-induced stomatal closure in rice. Plant Physiol. 2016;170(1):429-43. https://doi.org/10.1104/pp.15.00879

35. Fang G, Yang S, Ruan B, Liu C, Zhang A, Jiang H, Ding S, Tian B, Zhang Y, Jahan N, Zhu L. Isolation of TSCD11 gene for early chloroplast development under high temperature in rice. Rice. 2020;13:1-3. https://doi.org/10.1186/s12284-020-00411-6