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Effect of Thermal Defoliation on Cotton Leaf Desiccation, Senescence, Post-harvest Regrowth, and Lint Quality

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ABSTRACT

Thermal defoliation is a potential alternative to chemical defoliation, particularly for organically grown cotton. A two-row prototype thermal defoliation vehicle that forces air at 193 °C through cotton was compared with the application of a chemical defoliant in three field experiments. The thermal and chemical treatments caused >80% leaf mortality within 24 h and 6 d, respectively. Leaf abscission with the chemical treatment was >80% after 6 d, but abscission in the thermal treatment did not exceed 65% even after 13 d. Fiber length uniformity, strength, micronaire, and value, and percentage trash were not affected by thermal defoliation. Staple length was 2.8% less (*P* < 0.05) in the thermal treatment than in the chemical treatment in one of the three field tests. Regrowth at the base of defoliated cotton plants occurred in both treatments, so total stalk destruction by cultivation or use of herbicides will have to occur as part of boll weevil management or eradication strategies.

Since the mid-1960s, cotton harvest has been predominantly mechanized, which involves use of defoliation methods to reduce chlorophyll-staining of cotton fiber, trash content of harvested seed cotton, and gumming of picker spindles (Funk, 2004). Harvest-aid chemicals, such as defoliants, desiccants, and boll openers, help to manage harvest timing and to reduce harvest costs. Chemical harvest-aids eliminate the need for a second harvest in 90% of cotton grown in the United States (Funk et al., 2003; Funk, 2004).

Label regulations restrict chemical usage when producing organic cotton, and the restriction must commence 3 yr before the production of any crop labeled "organic" (USDA-AMS, 2004). Although the first patent on thermal defoliation was obtained in 1954 (Nisbet and Nisbet, 1954) and subsequently put into practice (Kent and Porterfield, 1967), it was not widely adopted.

Thermal defoliation of crops has mostly been attempted with hot combustion gases, air, and steam (Funk, 2004). Defoliation was achieved using infra-red burners and reflectors as a source of heat, but the cost of the burners was prohibitive (Reifschneider et al., 1968). Superheated steam was an effective defoliant, but the mass of the boiler and feed-water tank and the need for deionized water limited its application (Funk et al., 2001).

Costs of thermal defoliation using hot air (Funk, 2004) are competitive with chemical defoliation, and the cotton fiber quality was either not damaged (Batchelder et al., 1971; Funk et al., 2004a; 2005) or improved (Batchelder et al., 1970; Funk et al., 2004b). Leaf kill was 80 to 90% (Funk et al., 2004a) and abscission was 80% (Porterfield and Batchelder, 1969) using thermal defoliation with hot air, but field comparisons of contemporary hot air and chemical defoliation methods are necessary to evaluate its performance with different cultivars, climates, and field conditions.

Boll weevil (*Anthonomus grandis grandis* Boheman) eradication has occurred throughout most of the temperate cotton growing areas in the United States (Barker et al., 2001), which relies on insecticide applications and a cotton-free period during the winter (Brazzel, 1959; Brazzel et al., 1961). Cotton regrowth after cotton harvest-related operations (Showler, 2003) can provide sources of food, shelter, and reproduction for boll weevils, which are active year-round from the Lower Rio Grande Valley of Texas (Guerra et al., 1982) to Argentina (Ramalho and Jesus, 1987; Cuadrado, 2002), particularly when large (5.5- to 8-mm-diameter) squares (buds) are available (Showler, 2004). Regrowth is currently destroyed by cultivation and use of herbicides, but thermal defoliation has been reported to be particularly effective when applied directly to young growth on cotton (Batchelder et al., 1971).

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The purpose of this study was to compare the effect of thermally induced defoliation with a commonly used chemical defoliant on lint properties, and the ability of each defoliation method to prevent regrowth.

MATERIALS AND METHODS

The research was conducted at the Kika de la Garza Subtropical Agricultural Research Center (KSARC) in Weslaco, TX, during 2004 and 2005, and at a USDA-ARS location 3 km south called the South Farm during 2004. Eighteen plots, each 0.019 ha in area were prepared. Plots were 12 rows wide and 15.2 m long with a 1 m bare ground buffer between plots. Row spacing was 1 m. Cotton (*Gossypium hirsutum* L.) cv. Deltapine 5415RR (Delta Pine and Land Co.; Scott, MS) was planted on 2 March 2004 and on 8 March 2005. Pendimethalin (Prowl 3.3 EC; American Cyanamid; Parsippany, NJ) at 924 g ai/ha was broadcast over the plots immediately after planting with a tractor-mounted boom-sprayer traveling 1.7 km/h. Spray pressure was 350 kPa. There were 16 Teejet 8003E nozzles (Spraying Systems; Wheaton, IL) aimed downward. Subsequent weed control was conducted with a rolling cultivator and by hand-pulling. Irrigation occurred at the start of bloom in mid-May.

Three treatments, thermal defoliation, a chemical defoliant, and a non-treated control, replicated six times each were arranged in a randomized complete block design in all tests. The thermal and chemical defoliant treatments were applied on 21 July 2004 and 27 July 2005.

The two-row thermal defoliator constructed for this research was based on field trial results obtained using a one-row experimental thermal defoliator prototype in 2002 (Funk, 2004). The platform used to support the two-row thermal defoliator prototype was initially a corn detasseling unit. It came equipped with an open tilt cab, two-wheel steering, four-wheel hydrostatic drive, auxiliary hydraulic power, and a six cylinder gasoline engine. The platform had nearly 2 m of ground clearance, which provided ample room for the defoliation apparatus. The thermal apparatus was suspended beneath the platform and could be raised with hydraulic cylinders to facilitate maneuvering in the field and loading for transport. A framework of rectangular steel tubing supported crop dividers, treatment tunnels, fans, a burner, and duct work for the distribution and return of air. Two propane fuel tanks, two electric vaporizers, the gas train with meter, regulator, pilot, safety and control valves, and a 50 kW generator were also added to the platform.

The thermal defoliator prototype auxiliary hydraulic pump powered a 22.4 kW motor that turned two centripetal fans. The fans supplied 9,970 liters/sec of air to a 732 kW propane burner where the air was heated to 193 °C. Hot air from the burner was directed at cotton plants passing through a 4.57-m long treatment tunnel. Two-thirds of the treatment air was recirculated to conserve energy. The thermal defoliator was driven at 0.45 m/sec.

Defoliant (Def 6, Bayer CropScience; Kansas City, MO) was applied at 1.6 kg ai/ha from a tractor-mounted boom-sprayer moving at 1.7 km/h. Spray pressure was 350 kPa. There were 16 Teejet 8003E nozzles (Spraying Systems), two angled toward each row and drop-lines between rows.

In all plots, numbers of cotton plants were counted from an arbitrarily selected meter of row at two locations from the middle two rows of each plot. The heights of 10 arbitrarily selected plants were recorded on 19 July 2004 and on 26 July 2005. Ten randomly selected cotton plants were marked with a paper tie-on tag marked with a different letter. Numbers of leaves per plant were recorded on the morning the treatments were applied, and number of dead leaves (includes all abscised leaves) and abscised leaves were counted on the same day, and on 1, 3, 5, 7, 9, 11, and 13 d after the treatments were applied. Leaves were considered dead when no green tissue was visible, or after abscission. Numbers of abscised leaves were determined by counting the numbers of leaves remaining on each plant and subtracting from the number counted prior to treatment for the same plant. On day 13, the number of plants with >5% of visually estimated green leaf surface area >5% per plant was visually estimated (excluding regrowth at the base of the plant) compared with the surface before treatment were counted. Twenty arbitrarily selected plants in each plot were examined 30 d after treatment for the presence of vegetative regrowth at the base of primary stem.

One kg of hand-harvested cotton lint was collected from the thermally defoliated plots on 22 July 2004 and 28 July 2005 and from the control and chemically defoliated plots on 29 July 2004 and 4 August 2005. The days for harvest were different so that harvest occurred reasonably quickly after an acceptable level of foliar desiccation was observed.

The lint was sent to the USDA-AMS cotton classing office in Corpus Christi for high volume instrument (HVI) quantification of fiber properties (USDA-AMS, 2005). Lint properties analyzed were fiber length uniformity, staple length, strength, micronaire, and value, and percentage trash.

Plant densities, heights, total number of leaves per plant, percentage of plots with >5% green leaf surface area per plant, percentage of plants with re-growth, and cotton lint properties were analyzed using ANOVA to detect treatment and block effects, and treatment by block interaction (Statistix for Windows; Analytical Software; Tallahassee, FL). Percentage of dead leaves and abscised leaves per plant were analyzed using repeated measures for treatment, block, and time effects, and treatment by time, and treatment by block interactions. Percentage data was arcsine-square transformed before analyses, but non-transformed data are presented.

RESULTS

Prior to treatment, plant densities, heights, or leaves per plant were not different among plots (Table 1). Repeated measures detected differences between treatments for percentage of dead leaves per plant, and percentage defoliation at KSARC in 2004 (F = 4857.89, df = 2, 105, $P < 0.0001$) and in 2005 (F = 4641.40, df = 2, 105, $P < 0.0001$) and at the South Farm in 2004 (F = 7556.47, df = 2, 105, $P < 0.0001$). Thermal treatment caused the death of 80 to 98% of the leaves after 1 d in all three field experiments. In the chemical treatment, 30 to 40% leaf mortality was not observed until day 5, and 84 to 87% were dead on day 7 (Fig. 1). Leaf mortality in the thermal treatment did not change significantly ($P \geq 0.05$) after the first day. The chemical defoliant resulted in gradual death of some remaining leaves after the day 7 until 91 to 98% leaf mortality was observed on day 13. On days 1 through 5, more leaves per plant were dead in the thermal treatment than in the chemical treatment, but statistical differences were not detected after day 7 when leaf mortality was >80%. Leaf mortality was greater in the thermal and chemical treatments from days 1 and 5, respectively, than in the control (Fig. 1).

Treatment effects on leaf abscission per plant were detected at KSARC in 2004 (F = 1549.29, df = 2, 105, $P < 0.0001$) and in 2005 (F = 4302.25, df = 2, 105, $P < 0.0001$) and at the South Farm in 2004 (F = 14794.81, df = 2, 105, $P < 0.0001$). The thermal treatment resulted in the loss of 2 to 4 leaves during the first 24 h and every 2 d thereafter until 60 to 65% of the leaves had abscised by day 13 (Fig. 2). In the chemical treatment, <5% defoliation was observed on the day 3 in all three field experiments,

Table 1. Cotton plant density, height, and leaves/plant before treatment and plants with green leaf area >5% and regrowth after treatment with chemical defoliant or hot air

Location	Year	Treatment[x]	Pre-treatment[y]			Post-treatment[z]	
			Plant density	Plant height (cm)	Leaves/ plant	Plants with >5% green leaf area (%)	Plants with regrowth (%)
KSARC	2004	Thermal	12.9 ± 0.5	75.3 ± 1.0	50.6 ± 0.8	0 b	100 a
		Chemical	13.1 ± 0.9	74.1 ± 1.6	49.8 ± 1.5	0 b	100 a
		Control	13.7 ± 1.2	74.8 ± 2.3	47.6 ± 1.4	100 a	0 b
South Farm	2004	Thermal	14.2 ± 1.1	77.2 ± 1.6	52.8 ± 1.1	0 b	100 a
		Chemical	13.8 ± 0.7	75.0 ± 1.9	46.2 ± 3.7	0 b	100 a
		Control	13.9 ± 0.9	74.2 ± 2.4	48.4 ± 1.6	100 a	0 b
KSARC	2005	Thermal	13.7 ± 1.0	75.6 ± 1.8	51.2 ± 1.8	0 b	100 a
		Chemical	13.5 ± 0.9	77.3 ± 1.9	49.7 ± 2.6	0 b	100 a
		Control	13.1 ± 1.1	75.2 ± 2.2	50.3 ± 1.8	100 a	0 b

[x] Chemical defoliant was Def 6. Thermal and chemical treatments were applied on 21 July 2004 and 27 July 2005.

[y] Plant density taken from two arbitrarily selected 1-m sections of row per plot. Plant height and leaves/plant taken from 10 plants. Mean (±SE) within a column for each location and year are not significantly different.

[z] Plants with >5% green tissue were determined by visual estimates 7 d after treatment. Plants with regrowth taken from 20 plants 30 d after treatment. Means within a column for each location and year followed by same letter are not significantly ($P \leq 0.05$) different. Values were arcsine-square transformed for analysis.

but by day 7 defoliation was 84 to 87%. From day 9 to 13, the level of defoliation in the chemical treatment remained constant at over 90%. More leaves per plant dropped in the chemical treatment than in the thermal treatment after day 5 (Fig. 2). Both treatments caused greater defoliation than in the control after day 3.

By day 13, all thermally or chemically treated plants had <5% green leaf tissue at both locations. During 2004, the remaining green tissue was on the top 3 or 4 leaves and limited to the junction with the petiole. In the control, 100% of the cotton plants had >5% of the leaves with green tissue (for all three field experiments, $F = 15419.17$, df = 2, 23, $P < 0.0001$) (Table 1).

By day 13, regrowth had occurred on all of the plants in the thermal and chemical treatments, but no regrowth was found in the control treatment at both locations (for all three field experiments, $F = 25441.00$, df = 2, 23, $P < 0.0001$). The regrowth

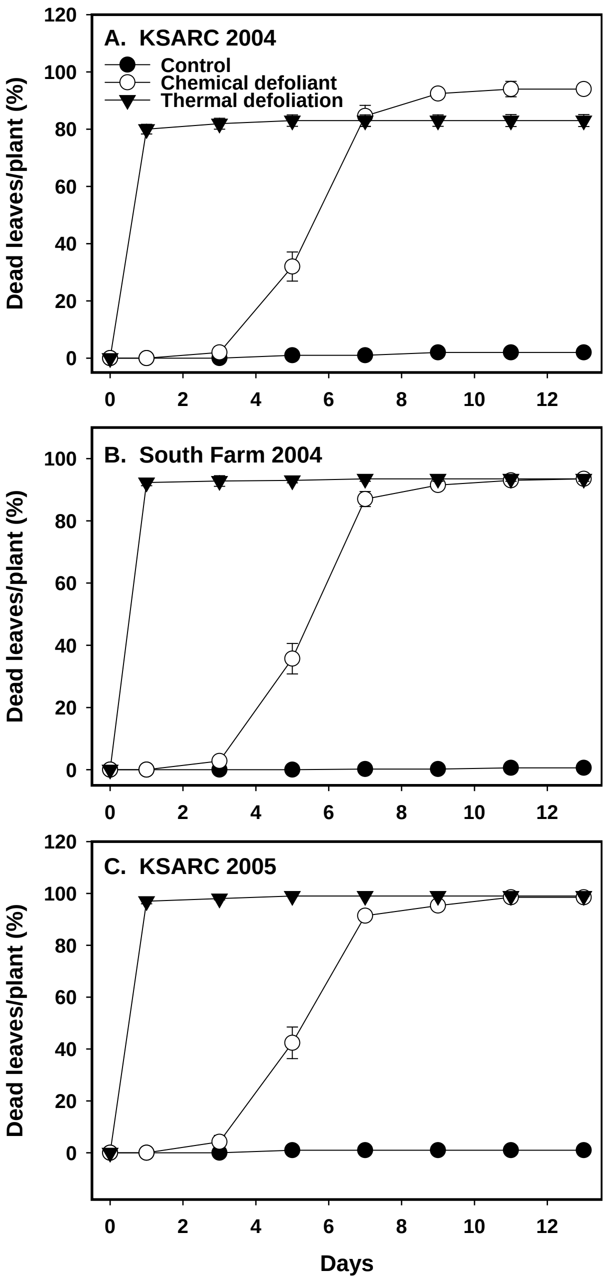

Figure 1. Mean percentages (±SE) of dead leaves per cotton plant after thermal or chemical defoliation at *A*, KSARC and *B*, South Farm 19 July –4 August 2004, and *C*, KSARC 26 July - 8 August 2005.

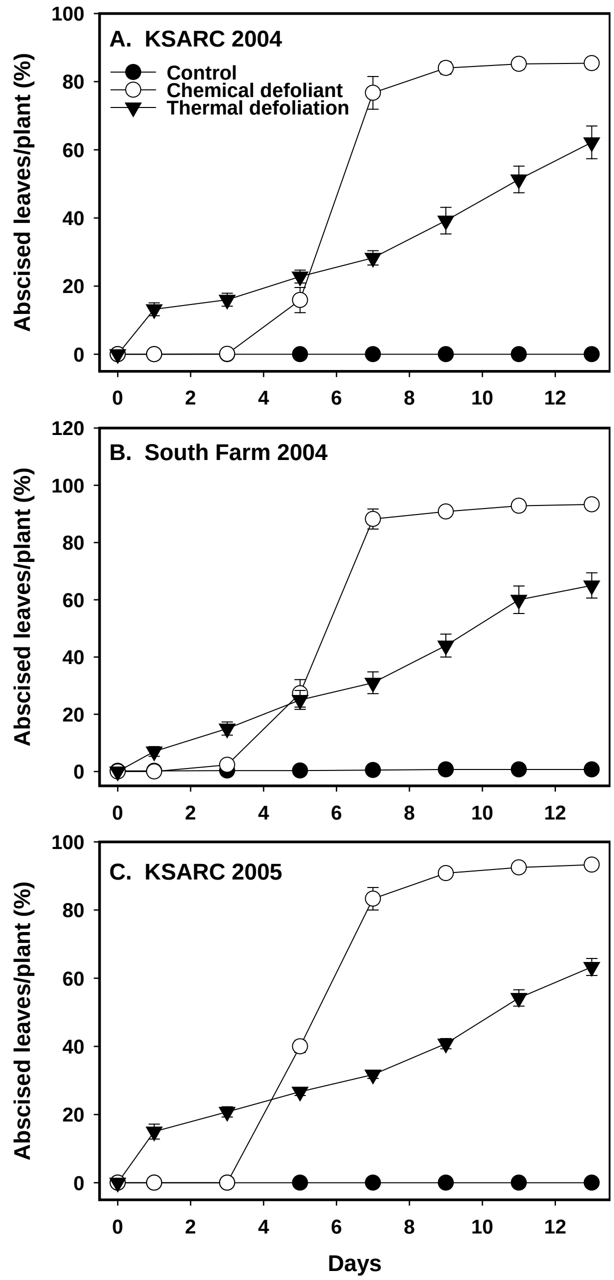

Figure 2. Mean percentages (±SE) of abscised leaves per cotton plant after thermal or chemical defoliation at *A*, KSARC and *B*, South Farm 19 July –4 August 2004, and *C*, KSARC 26 July - 8 August 2005.

developed to the four true-leaf stage before the field was treated with an herbicide.

Except for staple length at KSARC in 2004, treatment effects were not significant for cotton lint properties (Table 2). Fiber length at KSARC in 2004 for the thermal treatment was 4.2% and 2.8% less (F = 9.55, df = 2, 17, P = 0.0048) than for the control and chemical treatment, respectively (Table 2).

DISCUSSION

Since there were no differences in plant density, height, and total leaves per plant prior to treatment, differences observed after the treatments were attributable to the treatments. Leaf kill exceeded 80% following the application of chemical defoliant 5 d later than the thermal treatment at both locations. In the thermal plots, >80% of desiccation was observed within 24 h. Hot air at 149 °C for 8 sec has been reported to result in 89% desiccation and 60% defoliation after 2 wk (Funk et al., 2003), but this study demonstrates the rapidity of desiccation. Defoliation was >75% in the chemical treatment after 6 d, but further defoliation was negligible. Although leaves in the thermal treatment were killed quickly, they tended to stay attached to the plant longer, and defoliation did not exceed 65% after 13 d. It is possible that the sudden exposure to heat disrupted the physiological or chemical processes essential to leaf abscission.

The failure of the thermal treatment to completely kill all of the leaves during 2004 was likely the result of insufficient exposure to the hot air, which could be remedied by slowing the speed of the thermal defoliator. Although the shock of the thermal treatment caused sudden and substantial leaf mortality, regrowth at the base of the cotton plants was observed within 2 wk. The extensive regrowth observed in this study indicates that neither the chemical defoliation nor thermal defoliation will avert the need for stalk destruction. Regardless, the need for post-harvest herbicide application or cultivation will continue as long as cotton seeds mixed with debris left in the field germinate and grow.

Fiber value, seed quality, and operational costs are competitive between chemical and thermal defoliation (Batchelder et al., 1970; 1971; Funk et al., 2004b), but thermal defoliation eliminates the application of chemicals and associated drift-related problems. Thermal defoliation is also compatible with production of organic cotton.

Although leaf abscission was impaired by the rapid desiccation caused by thermal heating, fiber quality and value were not affected. The dry crumbly nature of leaves killed by thermal treatment facilitated cleaning by gin machinery (Funk et al., 2004b).

One possible advantage of thermal defoliation is rapid desiccation of leaves, which might enable harvest in advance of adverse weather. While yields

Table 2. Fiber properties, percentage trash, and fiber value for thermally and chemically defoliated cotton

Location	Year	Treatment[x]	Fiber property[y]						
			Uniformity (%)	Length (mm)	Staple length[z]	Strength (cN/tex)	Micronaire	Trash (%)	Value (cents/kg)
KSARC	2004	Chemical	82.0 ± 0.4	28.2 ± 0.1 a	35.5 ± 0.2 a	30.5 ± 0.2	4.9 ± 0.1	1.4 ± 0.2	94.6 ± 1.3
		Thermal	82.2 ± 0.3	27.4 ± 0.2 b	34.5 ± 0.3 b	30.0 ± 0.3	5.1 ± 0.8	2.0 ± 0.2	96.1 ± 1.3
		Control	83.2 ± 0.3	28.6 ± 0.3 a	36.0 ± 0.4 a	30.3 ± 0.3	4.9 ± 0.2	2.0 ± 0.1	97.2 ± 2.6
South Farm	2004	Chemical	82.2 ± 0.3	27.1 ± 0.2 a	34.2 ± 0.3 a	31.0 ± 0.3	5.6 ± 0.1	2.8 ± 0.3	107.1 ± 2.2
		Thermal	81.8 ± 0.3	27.1 ± 0.4 a	34.2 ± 0.5 a	31.4 ± 0.5	5.4 ± 0.1	2.5 ± 0.4	104.3 ± 3.3
		Control	82.5 ± 0.2	27.4 ± 0.4 a	34.5 ± 0.5 a	31.2 ± 0.6	5.5 ± 0.1	2.9 ± 0.5	99.7 ± 1.8
KSARC	2005	Chemical	83.0 ± 0.2	27.5 ± 0.3 a	34.6 ± 0.4 a	29.0 ± 0.5	4.2 ± 0.1	0.4 ± 0.1	111.3 ± 2.0
		Thermal	83.2 ± 0.2	27.9 ± 0.4 a	35.2 ± 0.5 a	27.5 ± 0.5	4.4 ± 0.1	0.4 ± 0.1	112.2 ± 2.0
		Control	82.6 ± 0.2	27.8 ± 0 a	35.0 ± 0 a	28.4 ± 0.5	4.2 ± 0.1	0.6 ± 0.1	111.1 ± 1.8

[x] Chemical defoliant was Def 6. Thermal and chemical treatments were applied on 21 July 2004 and 27 July 2005.

[y] Means (±SE) within a column for each location and year followed by same letter are not significantly ($P \leq 0.05$) different. Values without letters are not significantly different.

[z] Data presented in 32nds of an inch.

will not be as high in cotton picked immediately after thermal defoliation because of a lack of time for late bolls to mature and open, having some cotton delivered to the gin is preferable to having all of it damaged by a hurricane.

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DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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