COTTON HARVEST PREPARATION USING THERMAL ENERGY

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ABSTRACT. *Cotton is prepared for mechanical harvest using desiccant and defoliant chemicals. Conventional chemical defoliation is not effective immediately, it requires a period of good weather, and it is restricted in organic production. Thermal defoliation may be an alternative to chemical defoliation if it does not harm the crop. This study was conducted to determine what impact thermal defoliation has on fiber value, yield, and gross returns. A thermal defoliation machine that used propane to heat treatment air was tested on several varieties at various locations in three states over two years. A mixed statistical model was used to compare thermal defoliation to conventional chemical defoliation and harvesting two or three days after treatment to harvesting two or three weeks after treatment. There were no statistically significant differences in yield or value between treatments or harvest dates. Thermal defoliation does not negatively impact fiber value or yield, and thermally defoliated cotton may be harvested early without reducing gross returns.*

Keywords. *Cotton, Defoliation, Fiber quality, Harvest timing, Lint value, Thermal defoliation.*

Crop preparation that desiccates and removes leaves facilitates mechanical cotton harvesting and reduces extraneous matter. In the case of picker harvesting, leaf removal also reduces gumming of spindles due to plant sap and reduces interference with the spindles' access into open bolls. Crop preparation is typically performed two to three weeks in advance of harvest to allow for an earlier start and quicker drying of dew, which increases harvester operating hours. An earlier harvest that avoids wet weather helps preserve fiber value. Crop termination also makes possible a one-pass harvest operation, eliminating a second trip through the field (Funk, 2004).

Leaf desiccation and removal can be accomplished by frost or by applications of chemicals (or thermal energy). Since not all cotton production regions have consistent autumn weather, chemical desiccants, defoliants, and boll openers have come into wide use. They are typically mixed together and applied by air or ground rig. However, costly additional applications may be required when nighttime temperatures fall below 15° to 18° C (60° to 65° F) (Hutmacher et al., 2001). Chemical defoliants are restricted in organic production and near sensitive crops such as citrus. High winds, rain, and urban encroachment can further limit crop preparation options.

An additional concern late in the growing season is the presence of sucking insects that mine plant sap for amino acids (protein). In the process, they excrete large quantities of sugars (honeydew) that can fall on open bolls, causing lint stickiness. Honeydew-contaminated lint can have disastrous consequences at a spinning mill, in some cases requiring the mill to cease operation for an extended period while sugar residues are removed from equipment (Hequet and Abidi, 2002). In addition, cotton from a region perceived to have a stickiness problem may have less market value for several years (Ellsworth et al., 1999). Proper crop termination reduces the risk of insect exposure by reducing the time to harvest; however, harvest preparation chemicals cause stress in cotton plants that may increase free amino acid levels, making defoliated cotton attractive to silverleaf whitefly, *Bemisia argentifolii* (Bellows and Perring), and cotton aphid, *Aphis gossypii* (Glover), during the interval between treatment and harvest (Showler, 2002).

The two-row prototype thermal defoliator constructed for this research improved on a one-row experimental thermal defoliator previously constructed. Field trials conducted with the experimental defoliator in 2002 (Funk et al., 2004) showed that this new method of crop preparation was feasible. However, a more practical apparatus was needed for the extensive tests and demonstrations planned at diverse locations across the cotton belt in 2003 and 2004. Because cotton production covers a broad spectrum of varieties, climate zones, and growing practices, quantifying the impact of thermal defoliation on fiber value and yield across a representative group of locations and determining the optimum delay between treatment and harvest was deemed necessary to win acceptance for this novel technology.

The objective of these trials was to compare the fiber value, yield, and gross return per hectare of chemically defoliated cotton to thermally defoliated cotton. Additionally, the fiber value, yield, and gross return per hectare of thermally defoliated cotton harvested normally (14 to 20 days after treatment) was compared to that of thermally

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defoliated cotton harvested earlier (two or three days after treatment).

Materials and Methods

Apparatus

The platform acquired to support the prototype thermal defoliator was a used corn detasseler (PDF 420 G, Production Design and Fabrication, Inc., Cedar Rapids, Iowa, ca. 1986). It had an open cab, two-wheel steering, four-wheel hydrostatic drive, auxiliary hydraulic power, and a six-cylinder 4.9 L (300 in.^{3}) gasoline engine that was converted to burn propane fuel. The platform had 1.75 m (69 in.) of ground clearance. The wheel center width was set to 2.00 m (80 in.) so that the machine could straddle two rows at a row spacing common to the irrigated Southwest.

The following items were added to the platform: a 50 kW (67 hp) generator, two electric propane vaporizers, two propane fuel tanks with a combined capacity of 606 L (160 gal), and a gas train (gas meter, pressure regulator, two pilot valves, two safety solenoid valves, and one control valve). The defoliation apparatus was suspended beneath the platform. It was composed of: a framework of rectangular steel tubing, crop dividers, treatment tunnels, fans, a burner, and distribution and return air duct work. Hydraulic cylinders raised the defoliation apparatus to facilitate maneuvering in the field and self-loading for transporting by flatbed trailer truck.

The auxiliary hydraulic pump powered a 22.4 kW (30 hp) motor turning two centripetal fans. The fans supplied 9,970 L s^{-1} (21,130 ft^3 min^{-1}) of air to a 732 kW (2,500,000 BTU h^{-1}) propane burner. Air was heated to 193°C (380°F), just below the scorching point of cotton. The hot air was forced through cotton plants as they passed through a pair of 4.57 m (180 in.) long treatment tunnels. To attain a heat exposure time of 10 s, the machine traveled 1.6 km h^{-1} (1 mph). This combination of time and temperature was found to be effective during 2002 trials with the experimental defoliator (Funk, 2004). Approximately two-thirds of the treatment air was recirculated to conserve energy. Figure 1 shows the prototype unit working at the University of California West Side Research and Extension Center near Five Points, California, in 2004. Figure 2 shows the crop dividers and some of the hot air nozzle openings that lined the treatment tunnel.

Field Trials

In both 2003 and 2004, fields at New Mexico State University Leyendecker Plant Science Research Center near Las Cruces, New Mexico, were planted in two varieties following a completely randomized design (CRD). For the statistical analysis, the fields were blocked by variety (Acala 1517-99 and Delta Pine 565) and year. In 2003, a separate Leyendecker field (Acala 1517-91) was treated with thermal defoliation only and harvested either 3 or 14 days after treatment, for a fifth CRD analysis block. In 2003, the USDA-ARS Cotton Production and Processing Research Unit (CPPRU) field near Lubbock, Texas, was stripper harvested with and without field cleaning following a randomized complete block design (RCBD). The two harvester settings (field cleaner on or off) were analyzed as separate blocks. In 2004, the CPPRU field also followed a RCBD, with all plots harvested with the field cleaner on. In 2004, RCBDs were applied to two fields 120 km (75 mi) apart

Figure 1. Prototype thermal defoliator working at the University of California West Side Research and Extension Center near Five Points, California, in September 2004.

Figure 2. Prototype thermal defoliator showing crop dividers and treatment tunnel. Hot air was forced through the crop from nozzles (pictured) lining the 4.57 m (15 ft) long tunnel.

Table 1. Analysis blocks with number of observations for each fixed effect and block mean value for each response variable. Conventional chemical and thermal defoliation treatment effects were compared by contrasting plots harvested two to three weeks after treatment (the "normal harvest" columns). Harvest timing effects were compared by contrasting plots harvested early (two or three days after treatment) with plots harvested after a normal delay of 14 to 20 days.

	Number of Observations				Response (Independent) Variables: Mean Values by Block		
	Treatment						
	Thermal		Chemical				
Block (Random Effects)	Early Harvest	Normal Harvest	Normal Harvest	Total	Fiber Value ($ kg^{-1})	Yield (kg ha^{-1})	Gross Return ($ ha^{-1})
2003 NMSU Acala 1517-99	7	7	2	16	$1.16	1248	$1,562
2003 NMSU Delta Pine 565	7	7	2	16	$1.15	1433	$1,770
2003 NMSU Acala 1517-91	12	12		24	$1.15	1327	$1,638
2003 CPPRU field cleaner on	3	3	3	9	$1.05	525	$591
2003 CPPRU field cleaner off	3	3	3	9	$1.04	553	$618
2004 ARS Shafter	4	3	3	10	$1.17	1277	$1,603
2004 UC-West Side	4	4	4	12	$1.16	1694	$2,121
2004 NMSU Acala 1517-99		3	3	6	$1.09	984	$1,150
2004 NMSU Delta Pine 565		3	3	6	$1.14	1048	$1,288
2004 CPPRU irrigated		3	3	6	$1.09	1025	$1,200
2004 KDLGSARC Panhandle		6	6	12	$0.96		
2004 KDLGSARC Ansul		6	6	12	$0.89		
Total number of plots analyzed			*n* =	138			

in California's San Joaquin Valley (at the USDA-ARS Shafter Research and Extension Center and at the University of California West Side Research and Extension Center) and to two fields 3 km (2 mi) apart at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center near Weslaco, Texas (fields Panhandle and Ansul). Each of these four fields was analyzed as a separate block. Overall, there were twelve analysis blocks. These are listed in table 1 with their respective mean values for fiber value, yield, and gross return.

Harvesting, Ginning, and Sampling

Each field plot was an individual replicate of a combination of defoliation treatment and harvest timing. Typical field plots were two, four, or eight rows approximately 180 m (600 feet) long, resulting in from 65 to 350 kg (145 to 770 lbs) of seed cotton. The seed cotton harvested from each field plot was emptied into a truck or a trailer and kept separate using plastic tarps. Each plot's seed cotton was ginned in a manner appropriate to the location (for example, more pre-cleaning for stripper-harvested cotton). From two to five lint subsamples from each plot were obtained sequentially during ginning and sent to the nearest USDA-ARS Cotton Program classing office for high-volume instrument (HVI) grading. The classing office grade was used to determine the USDA-FSA Commodity Credit Corporation (CCC) loan value for that crop year and location. Subsample values were averaged to obtain the fiber value for each plot. Lint weights and row lengths were used to estimate plot yields. The product of each plot's yield and fiber value was its gross return.

Analysis

Statistical analysis was performed using PC-SAS 9.1 (SAS Institute, Inc., Cary, N.C.), with the level of significance set at 5%. The mixed model procedure was used to calculate the statistical significance of differences in yield, fiber value, and gross return that could be ascribed to differences in treatment (thermal or chemical) and harvest timing (early or normal). Random effects were blocked by year, location, variety, control treatment chemicals, harvester setting, gin differences, and classing office. There were 138 observations (field plots) in twelve blocks. There were from two to twelve replicates of each treatment and harvest date within each block. There were noticeable differences in yield and value between locations (table 1).

Treatment Effect

Several hypotheses were tested in this analysis. The first three hypotheses were designed to determine if thermal defoliation had a negative impact on producer returns. They were constructed to compare cotton fiber value, yield, and gross return for thermal and conventional chemical defoliation. These three hypotheses were tested using three mixed effects models of the form:

$$y = \mu + \alpha + b + e \qquad (1)$$

where

y = fiber value (\$ kg^{-1}), yield (kg ha^{-1}), or gross return (\$ ha^{-1})
μ = intercept
α = fixed effect (thermal or chemical treatment)
b = random effect (block)
e = error.

In these models, the random variable "block" accounts for year and location and in some cases other differences such as variety or harvester setting. One block did not have both chemical and thermal defoliation treatments and was omitted from the analysis. Thermal treatment observations that were not harvested at the same time as the chemical treatment were also omitted. Actual desiccant and defoliant materials used at each location are listed in table 2.

Harvest Timing Effect

With chemical desiccants, leaves begin to die after five days and take seven days to reach the same levels of desiccation reached with thermal treatment in just one day (Showler et al., 2006). During the 2002 experimental defoliator research (Funk et al., 2004), near-immediate leaf desiccation was observed. Cooperators asked if their cotton could be picked earlier since their plants had the same appearance as that of plants after a hard frost. To find out, additional thermally defoliated plots were included in the 2003 and 2004 field trials. Cotton from these plots was

Table 2. Analysis block, field location, cultivar (variety), name of laboratory that conducted the ginning, classing office that quantified fiber properties, and materials used as a control treatment.

Block	Location	Variety[a]	Ginning[b]	Classing	Chemical Control[c]
2003 NMSU Acala 1517-99	Las Cruces, N.M.	Acala 1517-99	SWCGRL	ARS Clemson	6 oz GinStar[1], 1.5 pt Finish[2]
2003 NMSU Delta Pine 565	Las Cruces, N.M.	Delta Pine 565	SWCGRL	ARS Clemson	6 oz GinStar[1], 1.5 pt Finish[2]
2003 NMSU Acala 1517-91	Las Cruces, N.M.	Acala 1517-91	SWCGRL	ARS Clemson	
2003 CPPRU field cleaned	Lubbock, Texas	PayMaster 2260 BG/RR	CPPRU	AMS Lubbock	6 oz GinStar[1], 1.5 pt Cotton Quick[3]
2003 CPPRU no field clean	Lubbock, Texas	PayMaster 2260 BG/RR	CPPRU	AMS Lubbock	6 oz GinStar[1], 1.5 pt Cotton Quick[3]
2004 ARS Shafter	Shafter, Cal.	Sierra RR	SWCGRL	AMS Phoenix	6 oz GinStar[1]
2004 UC West Side	Five Points, Cal.	Sierra RR	SWCGRL	AMS Phoenix	6 oz GinStar[1], 2 pt Prep[4]; 6 oz GinStar[1], 1 pt Gramoxone[5]
2004 NMSU Acala 1517-99	Las Cruces, N.M.	Acala 1517-99	SWCGRL	ARS Clemson	2 pt Finish[6], 2 pt Folex[7]
2004 NMSU Delta Pine 565	Las Cruces, N.M.	Delta Pine 565	SWCGRL	ARS Clemson	2 pt Finish[6], 2 pt Folex[7]
2004 CPPRU (irrigated)	Lubbock, Texas	FiberMax 989 BG/RR	CPPRU	AMS Phoenix	8 oz GinStar[8]
2004 KDLGSARC Panhandle	Weslaco, Texas	Delta Pine 5415-RR	KDLGSARC	AMS Corpus Christi	1 pt Def[9]
2004 KDLGSARC Ansul	Weslaco, Texas	Delta Pine 5415-RR	KDLGSARC	AMS Corpus Christi	1 pt Def[9]

[a] BG signifies boll guard; RR signifies Roundup-ready transgenic varieties.
[b] SWCGRL = USDA-ARS Southwestern Cotton Ginning Research Laboratory, Las Cruces, N.M.
CPPRU = USDA-ARS Cotton Production and Processing Research Unit, Lubbock, Texas.
KDLGSARC = USDA-ARS Kika De La Garza Subtropical Agricultural Research Center, Weslaco, Texas.
[c] Chemical, trade name, manufacturer and application rate in SI units of control treatments:
[1] Thidiazuron, Diuron (Ginstar, Bayer CropScience, Research Triangle Park, N.C.), 0.44 L ha^{-1}.
[2] Ethephon, Cyclanilide (Finish, Bayer CropScience, Research Triangle Park, N.C.) 1.75 L ha^{-1}.
[3] Ethephon, Aminomethanamide dihydrogen tetraoxo-sulfate (CottonQuick, Entek Corp., Newark, Del.), 1.75 L ha^{-1}.
[4] Ethephon (Prep, Bayer CropScience, Research Triangle Park, N.C.), 2.34 L ha^{-1}.
[5] Paraquat (Gramoxone, Syngenta Crop Protection, Greensboro, N.C.), 1.17 L ha^{-1}.
[6] Ethephon, Cyclanilide (Finish, Bayer CropScience, Research Triangle Park, N.C.), 2.34 L ha^{-1}.
[7] Tributyl Phosphorotrihiolite (Folex, AMVAC Chemical Corp., Newport Beach, Cal.), 2.34 L ha^{-1}.
[8] Thidiazuron, Diuron (Ginstar, Bayer CropScience, Research Triangle Park, N.C.), 0.58 L ha^{-1}.
[9] S, SS (Tributyo) (Def, Bayer CropScience, Research Triangle Park, N.C.), 1.17 L ha^{-1}.

harvested earlier than possible with chemical defoliation (two or three days instead of two to three weeks after treatment). These experiments tested the impact of harvest timing. They were constructed to compare cotton fiber value, yield, and gross return for thermally defoliated cotton harvested early (two or three days after treatment) to either chemically defoliated or thermally defoliated plots harvested after the normal 14 to 20 day interval following treatment. These hypotheses were tested using the same mixed effects models (eq. 1), except that:

$$\alpha = \text{fixed effect (early or normal harvest).}$$

Again, the random variable "block" accounts for year and location and in some cases other differences like variety or harvester setting. Blocks that did not have multiple harvest dates were omitted from the analysis. Results from plots receiving the control treatment (standard chemical defoliation) were compared to results from plots receiving early thermal treatment. Additionally, results from plots harvested two or three days after thermal treatment were compared to results from plots harvested two to three weeks after thermal treatment. This second comparison was designed to eliminate possible differences due to the type of treatment, so that effects due to harvest timing alone might be compared.

Results and Discussion

Treatment Effect

The treatment effect mixed model (across all blocks having both thermal and chemical treatments) fiber value estimates were \$1.08 kg^{-1} for thermal and \$1.09 kg^{-1} for chemical defoliation (*n* = 86 observations). Yield estimates were 1106 kg ha^{-1} for thermal and 1092 kg ha^{-1} for chemical defoliation (*n* = 62). Gross return estimates were \$1,342.67 ha^{-1} for thermal and \$1,331.37 ha^{-1} for chemical defoliation (*n* = 62). Yield and gross return were based on a smaller data set because yield data were not available from the 2004 KDLGSARC Ansul and Panhandle sites.

Note that each gross return observation was the product of yield and fiber value for that individual observation in the original data set. However, in these mixed model results, the gross return estimate was not a product of the yield and fiber value estimates, but rather an independent estimate from the statistical model.

The least squares means difference Tukey-Kramer adjusted P values were 0.1518, 0.7593, and 0.8377 for value, yield, and gross return, respectively, indicating that there were no statistically significant differences between chemical and thermal defoliation treatments for any of the three response (dependent) variables. The gross return attained by thermal defoliation was not statistically different from the gross return attained by conventional chemical defoliation because their respective yields and fiber values were not statistically different.

Harvest Timing Effect: Early versus Chemical

Comparisons were made between thermally defoliated plots harvested early (where treatment and timing are both experimental) and chemically defoliated plots harvested after a normal delay (the control, or current practice). The harvest timing effect mixed model fiber value estimates were \$1.12 kg^{-1} for early thermal and \$1.12 kg^{-1} for chemical treatment normal harvest timing. Yield estimates were 1098 kg ha^{-1} for early thermal and 1097 kg ha^{-1} for chemical treatment normal harvest timing. Gross return estimates were \$1,349.49 ha^{-1} for early thermal and \$1,347.19 ha^{-1} for chemical treatment normal harvest timing. For each model, there were *n* = 45 observations.

The least squares means difference Tukey-Kramer adjusted P values were 0.5253, 0.9935, and 0.9746 for value, yield, and gross return, respectively, indicating that differences between early harvest and normal harvest were insignificant. The amounts were also insignificant for this subset of data (six blocks had both early thermal and normal chemical harvest timings and treatments). From this result, it would appear that harvesting cotton two or three days after thermal defoliation will not result in a decrease in price or yield. For producers, having their "harvest window" open several days earlier could mean better harvest equipment utilization and a reduction in risks associated with exposure to weather and insects.

Harvest Timing Effect: Early versus Thermal

To determine if fiber value or yield were significantly reduced by early harvest, comparisons were also made between thermally defoliated plots harvested early and after a normal delay (ruling out treatment differences). The harvest timing effect mixed model fiber value estimates were \$1.12 kg^{-1} for early and \$1.13 kg^{-1} for normal harvest timing. Yield estimates were 1134 kg ha^{-1} for early and 1177 kg ha^{-1} for normal harvest timing. The gross return estimates were \$1,390.83 ha^{-1} for early and \$1,450.72 ha^{-1} for normal harvest timing. For each model, there were *n* = 79 observations.

The least squares means difference Tukey-Kramer adjusted P values were 0.1215, 0.0905, and 0.0733 for value, yield, and gross return, respectively, indicating that the difference between early harvest and normal harvest was statistically insignificant at the 0.05 level. While there was a small chance that thermal defoliation gross returns might be less with early harvest compared to normal harvest, producers may be willing to accept a small loss from harvesting early if it means avoiding a potentially larger loss from insect-induced stickiness or a forecasted storm event.

Conclusion

Loan value, yield, and gross return were not significantly different for cotton prepared for harvest using thermal treatment compared to cotton prepared using conventional chemical defoliation. The heat required for thermal treatment did not damage the cotton fiber.

Loan value, yield, and gross return were not significantly different for cotton harvested two to three days after thermal treatment compared to cotton harvested two to three weeks after either thermal or chemical treatment. Thermal treatment makes it possible to harvest cotton early without negatively impacting fiber value or yield.

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