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AGRONOMY

Effects of Weather on Cotton Responses to Harvest-Aid Chemicals

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INTERPRETIVE SUMMARY

Harvest-aid chemicals are a critical component in cotton production. They help prepare the crop for harvest by opening bolls, dropping leaves, and controlling regrowth. However, their performance is often inconsistent, making results unpredictable. A uniform cotton harvest-aid study conducted for 5 yr at 16 locations across the U.S. Cotton Belt provided an opportunity to evaluate the effects of varying weather conditions before, during, and following treatment. Previous literature contained some specific effects of weather, such as temperature or wind, but only for defined regions and for a limited number of products. It would be useful to understand the effects over a much wider area and a broader range of harvest aids. This understanding could help improve the choice of harvest-aid materials to apply under different weather conditions and climatic regimes.

In this study, we evaluated average daily maximum and minimum temperatures and precipitation prior to and following treatment, as well as cloud cover, air temperature, relative humidity, and wind speed at time of treatment. In most cases, weather data were collected from a National Weather Service Cooperative Station near each test site. At several locations, the researchers used automated weather stations. Although none of the treatments was applied in distinctly unfavorable conditions (such as very rainy or windy weather), the range in weather conditions was broad enough to provide some insights into the effects of weather on harvest-aid performance.

Harvest aids tested in this study were tribufos, dimethipin with a crop oil concentrate, and thidiazuron, each applied with and without ethephon, for a total of six treatments, plus an untreated check. Harvest-aid response data collected in the field were defoliation, desiccation, boll opening, and regrowth. Harvest-aid responses were calculated relative to performance of the untreated check in each test to normalize the response data across locations and years.

The weather environments in this study were characterized by cluster analysis, and individual weather variables were examined by univariate analyses. Most of the weather variables were not normally distributed. Weather variables were also multicollinear, so principal component analysis was used to group the major weather variables together and determine their influence.

We used simple linear correlation analysis to determine which weather factors had the most influence on treatment response. For each significant correlation, we compared the responses at two thresholds of each weather variable: the first quartile (Q1), or lowest quarter of the values for any given weather variable, and the fourth quartile (Q4), or the highest quarter of the values. This analysis determined the direction and magnitude of treatment response near the extremes of the range of each weather variable.

Results of this study support the broad concept that weather conditions before, during, and after application of harvest-aid chemicals influence the chemicals' effects. The proportional influence of these weather factors on different crop responses is noteworthy. For defoliation, seasonal daily minimum temperatures were the dominant weather factor influencing response to all of the harvest aids in this study. The results underscore the role of high night temperatures during the growing season in promoting crop maturity and susceptibility to defoliation. Weather conditions during and after application mainly influenced defoliation by the hormonal

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Abbreviations: DAT, days after treatment.

defoliant, thidiazuron, whereas the contact-type defoliants were generally less sensitive.

For boll opening, daily maximum temperatures before application and daily maximum and minimum temperatures after application dominated the weather factors influencing response to ethephon-based treatments. Although boll opening was promoted by warm conditions after treatment, ethephon had a proportionally greater boll opening response under cooler conditions in which boll opening of untreated cotton may have slowed with cooler temperatures. This result is noteworthy in that the lowest quartile of average daily minimum temperatures during 14 d after treatment was about 52 °F, considerably cooler than the reference minimum temperature threshold for ethephon activity (60 °F).

Terminal regrowth responses were most evident with relatively moist conditions before treatment and mild daily maximum temperatures (78 °F) after treatment. Under these conditions, the greatest reduction in terminal regrowth occurred when thidiazuron was applied with ethephon. These conditions evidently promoted vegetative regrowth in untreated cotton and thus increased the differential response to treatments in this study. By contrast, basal regrowth response to the tribufos and ethephon mixture was aggravated by relatively dry weather and warm daytime temperatures after treatment.

Overall, these results highlight some of the reasons why reliable performance from harvest aids may be difficult to reproduce from year to year and from place to place. A producer can adjust to some extent for weather prevailing at the time of application in the selection of harvest-aid materials and application rates, or perhaps by waiting for better weather. But the majority of weather factors influencing harvest-aid responses in this study were either from the period between planting and treatment or in the 14 d after treatment. Seasonal weather patterns bear upon crop condition and susceptibility to defoliation, boll opening, and regrowth. These effects are more complex and add to the challenge of preparing a cotton crop for a timely and efficient harvest.

ABSTRACT

Successful cotton harvest depends on the use of harvest-aid chemicals, but their performance is often inconsistent because of weather conditions. Our objective was to determine weather factors that most influence responses to various harvest aids. A 5-yr study was conducted at 16 locations across the United States. Responses to three defoliants, applied with and without ethephon, were compared with an untreated check. Response data included defoliation, desiccation, boll opening, and regrowth. Weather data collected prior to and following treatment were precipitation and average daily maximum and minimum temperatures. Data taken at time of treatment included cloud cover, air temperature, relative humidity, and wind speed. Correlation and quartile analyses showed that daily minimum temperatures from planting to treatment dominated the weather factors influencing the defoliation response to all harvest aids. High seasonal night temperatures apparently promoted crop maturity and susceptibility to defoliation. Weather had little influence on desiccation. Daily maximum temperatures from planting to treatment, and daily maximum and minimum temperatures after application were the main weather factors influencing the boll opening response to ethephon-based treatments. Although boll opening was promoted by warm weather after treatment, ethephon had a proportionally greater boll opening response under cooler conditions in which boll opening of untreated cotton apparently slowed. Terminal regrowth responses were most evident with relatively moist conditions before treatment and mild temperatures after treatment, which apparently promoted vegetative regrowth in untreated relative to treated cotton. These findings may help improve selection of harvest aids for different weather conditions and climatic regimes.

Timely cotton (*Gossypium hirsutum* L.) harvesting depends on the use of harvest-aid chemicals. However, performance of harvest aids is often inconsistent. Weather conditions are perhaps the most important factor affecting efficiency of defoliation (McCarty, 1995).

Environmental conditions during the growing season determine crop condition at time of harvest-aid application. These include temperature and moisture effects on the leaf cuticle, vegetative growth, fruit set, and maturation. More mature and senescent plants are usually more responsive to harvest aids (Hake et al., 1996). In humid cotton-growing environments, the cuticle is thinner than in arid environments, so it is more easily penetrated by harvest aids (Roberts et al., 1996). High temperatures during the growing season are often accompanied by low humidity, resulting in the development of thick and brittle leaf cuticles, even under well-irrigated conditions. In non-irrigated conditions, leaves become toughened under prolonged drought (Cathey, 1986).

Prevailing weather at time of application is a major factor influencing defoliation efficiency (Cathey, 1986). Weather factors that most influence harvest-aid performance are temperature, relative humidity, seasonal rainfall, and the occurrence of precipitation shortly following application. High temperatures and sunlight intensity at the time of application make the waxy layer of the leaf more pliable and speed movement of harvest-aid chemicals through the cuticle (Roberts et al., 1996). Crop water stress at the time of application tends to reduce the response to defoliants because leaves have a lower activity (Cathey, 1986). Drought stress reduces the defoliation effect of dimethipin (2,3-dihydro-5,6-dimethyl-1,4-dithiin 1,1,4,4-tetraoxide) (Uniroyal Chemical, 2000). Conditions that cause cotton leaves to be wilted, tough, or leathery tend to delay absorption of harvest-aid materials and reduce activity (Cathey, 1986).

The objective of using a chemical defoliant is to induce a change in the hormonal balance of a leaf that favors defoliation. The goal is to injure the leaf so that it forms an abscission layer. Under unfavorable conditions (cold temperatures or a thick waxy layer), defoliants may be unable to create sufficient leaf wounding to cause defoliation. Under cool conditions, there may be insufficient wounding by contact materials to cause defoliation (Roberts et al., 1996).

High atmospheric humidity at application time is desirable because harvest-aid chemicals remain solvent for a longer period on the leaf surface, facilitating uptake (Cathey, 1986). High humidity contributes to maintenance of water content in the leaf, aiding chemical movement into and within the plant (McCarty, 1995). Low humidity during application decreases uptake because of the rapid drying of materials on the surface (Hake et al., 1990).

Cloudy weather reduced response to some defoliants (Cathey, 1986). Precipitation shortly following application may wash harvest-aid materials from the foliage, reducing efficiency (Elsner and Taylor, 1978). If rain occurs as ethephon [(2- chloroethyl)phosphonic acid]-treated bolls are beginning to open, “hard locking” can occur and cause significant yield losses (Supak, 1991).

Responses to harvest-aid chemicals are frequently limited by temperatures following application that govern the rates of chemical and physiological activity. In general, contact-type defoliants such as tribufos (*S,S,S*,-tributyl phosphorotrithioate) have lower minimum temperatures (12.7-15.6°C) than materials with hormonal activity (15.6-18.3°C) such as ethephon and thidiazuron (*N*-phenyl-*N*'-1,2,3-thiadiazol-5-ylurea) (Hake et al., 1996). Above these minimums, the rate of activity doubles with a 10°C rise in temperature, such that defoliation proceeds two times faster at 35°C than at 25°C (Hake et al., 1990).

Minimum temperatures above 15.6°C are particularly important for boll opening (Cathey, 1986). The progress of boll opening is correlated with degree-day accumulation following treatment. Above the base temperature of 15.6°C, relatively cool temperatures following application (18.3-23.9°C) require higher rates of ethephon to achieve equivalent boll opening as lower rates under warmer conditions (29.4-35°C) (Gwathmey and Hayes, 1996). Gwathmey and Hayes (1997) reported inhibition of boll opening response to ethephon with the addition of tribufos under warm conditions.

A uniform harvest-aid performance and fiber-quality evaluation was conducted across the U.S. Cotton Belt from 1992 through 1996 (Snipes, 1996). Overall harvest-aid performance of core treatments in that study was reported by Snipes and Valco (1999), but specific weather effects were not evaluated across environments. Our objective was to determine the weather factors that most influence responses to harvest aids (tribufos, dimethipin, and thidiazuron, each applied with and without ethephon) across the U.S. Cotton Belt.

MATERIALS AND METHODS

A 5-yr (1992-1996) cotton harvest-aid study was conducted at 16 locations (4 in Texas, 1 each in Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, Tennessee, and South Carolina) throughout the U.S. Cotton Belt, representing a wide range in climatic conditions. A uniform experimental protocol was followed at all locations (Snipes, 1996). A locally adapted commercial cultivar of cotton was grown using recommended practices for each state, including irrigation at five locations (College Station, Lubbock, and Weslaco, TX; Altus, OK; and Hanford, CA). Each planting was divided into four-row plots, each at least 9.1 m long, to which the different-aid treatments were applied with a high-clearance sprayer at 55% ± 5% open bolls, based on boll counts. The harvest aids were tribufos, dimethipin with a crop oil concentrate, and thidiazuron, applied with and without ethephon, for a total of six treatments, plus an untreated check. Rates of application were described by Snipes (1996). All experiments were arranged in a randomized complete block design with four replications.

Harvest-aid response data collected from each plot included defoliation of the leaves present at the time of application (the percentage removed by treatment, taken at 7 and 14 d after treatment); desiccation (a percentage of the total leaf number remaining on the plant in a desiccated state as a result of treatment, taken at 7 and 14 d after treatment); percent open bolls (calculated from counts of open and closed bolls in a 1-m row segment of each plot, taken at 7 and 14 d after treatment); and terminal and basal regrowth (along a 1-m row section, the number of plants with terminal or basal regrowth larger than 10 mm divided by the total number of plants, taken at 21 d following treatment).

Weather data obtained from either the nearest National Weather Service Cooperative Station or from a nearby automated weather station were average daily maximum and minimum temperatures and total precipitation from planting to treatment and from treatment to 14 d after treatment. At the time of treatment, cloud cover (on a scale of 0 to 100, where 0 equals completely clear skies and 100 equals completely overcast), air temperature, relative humidity, and wind speed were collected. Precipitation was collected for 7 d prior to and 7 d following treatment. Five environments (yr × location) were not included in the study because of missing data, leaving a total of 75 environments (5 yr × 11 locations, 4 yr × 5 locations) in this study.

The weather environments in this study were characterized by cluster analysis (PROC CLUSTER, SAS Institute, 2001). Orthogonal contrasts were used to compare treatment responses between contrasting environments. Individual weather variables were examined by descriptive statistics (PROC UNIVARIATE, SAS Institute, 2001). Most of the weather variables were not normally distributed, but they were not standardized for this study. Weather variables were also multicollinear, so principal component analysis (PROC PRINCOMP, SAS Institute, 2001) was used to group the major weather variables together and determine their influence on harvest-aid responses (PROC GLM, SAS Institute, 2001).

For this analysis, responses to harvest aids were evaluated as differences from the untreated check plots in each location and year. Simple linear correlation analysis (in PROC REG, SAS Institute, 2001) was used to determine which weather factors had the most influence (at $p < 0.01$) on treatment response. Data used were the weather variables collected from planting to treatment, at the time of application, and from treatment to 14 d after treatment, for each year at 16 locations (five yr-locations were omitted because of missing data). For each significant correlation, we compared the responses at two thresholds of each weather variable: the first quartile (Q1), or lowest quarter of the values for any given weather variable, and the fourth quartile (Q4), or the highest quarter of the values. This analysis determined the direction and magnitude of treatment response near the extremes of the range of each significant weather variable.

RESULTS AND DISCUSSION

Overall harvest-aid performance in terms of defoliation, desiccation, boll opening, and regrowth responses across environments in this study was reported by Snipes and Valco (1999).

Weather Environments in the Study

Cluster analysis of weather (average of 5 yr) from planting to application of the 16 locations in

Table 1. Results of cluster analysis of average (1992-1996) weather from planting to application at 16 locations in the cotton harvest-aid study.

Location	Avg. max. temp	Avg. min. temp	Total precipitation
	°C	°C	mm
Warm, low precipitation			
Lubbock, TX	31.8	16.8	275†
Weslaco, TX	31.2	19.5	235†
Rohwer, AR	31.8	19.9	306
Hot, moderate precipitation			
College Station, TX	32.1	20.0	402†
Stoneville, MS	31.7	20.5	424
Tifton, GA	30.6	19.7	434
Altus, OK	32.4	18.8	395†
Hot, moist			
Prosper, TX	31.9	21.3	479
St. Joseph, LA	32.0	20.3	493
Florence, SC	31.6	19.6	553
Moderate temperatures, moist			
Portageville, MO	29.3	18.7	413
Belle Mina, AL	29.4	16.8	448
Jackson, TN	29.3	18.3	506
Lewiston, NC	29.9	18.6	513
Subtropical			
Milton, FL	31.8	20.1	850
Mediterranean			
Hanford, CA	31.0	13.4	24†

† Not including irrigation.

this study produced six distinct clusters of environments based on temperature and rainfall, as shown in Table 1. Average maximum temperatures during the season exceeded 30°C in most environments. Average minimum temperatures ranged from 16.8-21.3°C, except in the California location where night temperatures were cooler during the season. Average annual precipitation ranged from 235 to 553 mm, except in the subtropical and Mediterranean climates of the Florida and California locations, respectively. Five locations were irrigated as indicated in Table 1. The cluster analysis indicates that the major production environments for U.S. upland cotton were represented in this study.

Cluster analysis of weather from application to 14 d after treatment showed seven distinct clusters of environments, as shown in Table 2. Average maximum temperatures after application exceeded 30°C in only three clusters comprising four locations. Average minimum temperatures were below 16°C in four clusters comprising 10 locations in this study. Precipitation was moderate to excessive in four clusters (12 locations) during this time.

Table 2. Results of cluster analysis of average weather (1992-1996) from application to 14 d after treatment at 16 locations in the cotton harvest-aid study.

Location	Avg. max. temp	Avg. min. temp	Total precipitation
	°C	°C	mm
Hot, moderate precipitation			
College Station, TX	34.0	21.5	27
St. Joseph, LA	32.3	19.2	35
Hot, dry			
Weslaco, TX	36.7	23.9	12
Warm, moderate precipitation			
Prosper, TX	29.5	16.3	51
Rohwer, AR	29.8	16.3	20
Stoneville, MS	29.4	15.5	26
Moderate temperature, moist			
Jackson, TN	25.5	12.4	35
Belle Mina, AL	27.2	12.8	53
Tifton, GA	26.4	13.6	71
Milton, FL	26.8	13.2	110
Lewiston, NC	25.3	14.3	66
Florence, SC	27.6	14.8	100
Cool, dry			
Lubbock, TX	28.2	9.0	1
Atlus, OK	26.8	10.6	9
Very cool, moist			
Portageville, MO	23.5	10.3	49
Mediterranean			
Hanford, CA	31.3	12.5	0

Descriptive statistics of weather for all 75 environments (yr × location) showed wide ranges in most variables (Table 3), but their distributions were not normal in most instances. Weather at the time of treatment was favorable for harvest-aid application in most environments, relative to conditions described by Cathey (1986). With few exceptions, the weather at application was warm, clear to partly cloudy, with moderate humidity, low wind speed, and little rainfall in the week prior to or after application.

For weather at time of application, principal component analysis showed two components accounted for 60% of the variation in weather factors (Table 4). The first component was a cloudiness and humidity factor. The second

Table 3. Descriptive statistics for weather variables across 16 locations and 5 yr (1992-1996) of the cotton harvest-aid study.

Weather variable	Min.	Q1†	Median	Q4‡	Max.
Precipitation (mm) from planting to treatment	12	291	391	520	1144
Precipitation (mm) 7 d prior to treatment	0	0	3	13.5	65
Avg. max. temp (°C) from planting to treatment	27.9	30.0	31.3	32.2	33.8
Avg. min. temp (°C) from planting to treatment	13.1	18.1	19.2	20.2	22.1
Cloudiness (%) at time of treatment	0	0	10	37.5	100
Temperature (°C) at time of treatment	13.3	24.7	28.3	30.6	36.7
Relative humidity (%) at time of treatment	15	44	55	70	92
Wind speed (m s^{-1}) at time of treatment	0	1.3	1.8	3	4.5
Precipitation (mm) 7 d after treatment	0	0	3	20.3	215.9
Precipitation (mm) 14 d after treatment	0	1	18	63	394
Avg. max. temp (°C) 14 d after treatment	22.3	25.6	28.4	31.4	37.3
Avg. min. temp (°C) 14 d after treatment	5.8	11.3	13.8	17.7	24.6

† Upper threshold for first quartile.

‡ Lower threshold for fourth quartile.

component was more of a humidity, temperature, and wind factor. For weather before and after application, principal component analysis showed that two components accounted for 58% of the variation in weather factors. The first component weighed more on average maximum temperature from treatment to 14 d after treatment; the second component weighed more on average minimum temperature from planting to treatment, average maximum temperature from treatment to 14 dafter treatment, and precipitation from treatment to 14 d after treatment.

Harvest-Aid Responses to Weather

Significant ($p < 0.01$) linear correlation coefficients (r) and means of harvest-aid responses for the lowest (Q1) and highest (Q4) quartiles of weather variables are presented in Tables 5 through 7. Weather had no significant influence on desiccation at 7 or 14 d after treatment.

Defoliation

There was a positive effect of the "cloud and humidity" principal component of the weather at time of application on defoliation at 7 d after treatment for the two dimethipin treatments (Table 4). There was also a positive effect of the "humidity, temperature, and wind" principal component of the weather at time of application on defoliation at 7 d after treatment for the thidiazuron treatment. For weather before and after treatment, there was a positive influence of the "temperature" principal component on defoliation at 14 d after treatment for thidiazuron. The "temperature and precipitation" component had a positive influence on 14 d-after-treatment defoliation responses to all the non-tribufos treatments. Contact activity by tribufos appears to be less dependent on the moisture status of the plant than does activity of defoliants with hormonal activity, such as thidiazuron or dimethipin.

Defoliation responses at 7 d after treatment were not significantly affected by temperature or precipitation after treatment in this study. However, average minimum temperatures from planting to treatment were positively correlated with 7 d after treatment defoliation responses for all six treatments (Table 5). Correlation coefficients ranged from 0.41 (tribufos) to 0.49 (dimethipin + ethephon) for seasonal minimum temperature effects. Correlation coefficients were slightly higher for treatments with ethephon than for defoliants applied without ethephon. At the lowest quartile (Q1) level for average minimum temperature from planting to treatment (18.1°C), improvement in defoliation over the check plot ranged from 11% better (thidiazuron) to 36% (tribufos + ethephon). At the highest quartile Q4 temperature (20.2°C), improvement in defoliation over the check plot ranged from 38% better (thidiazuron) to 57% (tribufos + ethephon). The greatest relative improvement in defoliation response with higher seasonal minimum temperature occurred with thidiazuron, with or without ethephon.

Cloud cover and relative humidity at the time of application were also positively correlated with several 7 d-after-treatment defoliation responses (Table 5). Cloud cover increased the defoliation

Table 4. Effects of weather-related principal components on cotton responses to harvest-aids in a 5-yr (1992-1996) cotton harvest-aid study at 16 locations.

Treatment	Response	Weather at time of application†	
		Principal component‡	
		CLOUD/RH	RH/TEMP/WIND
		Direction of effect (prob < 0.05)	
Tribufos + ethephon	boll opening 7 DAT		–
Dimethipin	defoliation 7 DAT	+	
	boll opening 7 DAT		–
Dimethipin + ethephon	defoliation 7 DAT	+	
Thidiazuron	defoliation 7 DAT		+
	basal regrowth 21 DAT	–	+
Thidiazuron + ethephon	boll opening 7 DAT	+	–
	basal regrowth 21 DAT		+
		Weather before and after treatment	
		Principal component§	
		TMAX2	TMIN1/TMAX2/PPT2
Tribufos	terminal regrowth 21 DAT	+	–
	basal regrowth 21 DAT		–
Tribufos + ethephon	boll opening 14 DAT	–	
	terminal regrowth 21 DAT	+	–
	basal regrowth 21 DAT	+	
Dimethipin	defoliation 14 DAT		+
	boll opening 14 DAT	–	
	terminal regrowth 21 DAT	+	
	basal regrowth 21 DAT	+	
Dimethipin + ethephon	defoliation 14 DAT		+
	boll opening 14 DAT	–	
	terminal regrowth 21 DAT	+	–
	basal regrowth 21 DAT	+	
Thidiazuron	defoliation 14 DAT	+	+
	boll opening 14 DAT	–	
	terminal regrowth 21 DAT	+	–
	basal regrowth 21 DAT	+	
Thidiazuron + ethephon	defoliation 14 DAT		+
	boll opening 14 DAT	–	
	terminal regrowth 21 DAT	+	
	basal regrowth 21 DAT	+	

† Abbreviations for weather variables: CLOUD = cloud cover on a scale of 0 to 100, where 0 = completely clear skies and 100 = completely overcast; RH = relative humidity; TEMP = air temperature; WIND = wind speed; TMIN1 = average daily minimum temperature from planting to treatment; TMAX2 = average daily maximum during 14 d after treatment (DAT); PPT2 = precipitation during 14 DAT.

‡ Eigenvectors of principal component CLOUD/RH (CLOUD = 0.735, RH = 0.545); eigenvectors of principal component RH/TEMP/WIND (RH = 0.529, TEMP = 0.570, WIND = -0.624).

§ Eigenvector of principal component TMAX2 = 0.566; eigenvectors of principal component TMIN1/TMAX2/PPT2 (TMIN1 = 0.517, TMAX2 = 0.512, PPT2 = 0.504).

response of dimethipin, and higher humidity improved the defoliation response of thidiazuron, with or without ethephon. Principal component analysis showed that cloud and humidity conditions at time of application positively affected the 7 d-after-treatment defoliation response from the dimethipin treatments, with or without ethephon (Table 4). The principal component of wind, temperature, and humidity conditions at time of application had a positive influence on the 7 d-after-treatment defoliation response from the thidiazuron treatment (Table 4). The humidity findings are consistent with product information that satisfactory defoliation with thidiazuron depends on

Table 5. Effects of all weather variables (at time of treatment, and before and after treatment) on defoliation responses to harvest-aid treatments at 7 and 14 d after treatment in a 5-yr (1992-1996) cotton harvest-aid study at 16 locations: results of correlation analysis and means of first and fourth quartile response differences from untreated check.

Weather X	Treatment	*r*†	Q1‡	Q4§
	7 d after treatment		%	%
TMIN1¶	Tribufos	0.41	29	53
	Tribufos + ethephon	0.45	36	57
	Dimethipin	0.45	20	40
	Dimethipin + ethephon	0.49	26	48
	Thidiazuron	0.42	11	38
	Thidiazuron + ethephon	0.48	26	51
CLOUD	Dimethipin	0.32	29	42
RH	Thidiazuron	0.42	15	42
	Thidiazuron + ethephon	0.36	27	52
	14 d after treatment			
TMIN1	Tribufos + ethephon	0.32	34	54
	Dimethipin	0.32	20	38
	Dimethipin + ethephon	0.36	25	42
	Thidiazuron	0.38	16	41
	Thidiazuron + ethephon	0.41	27	51
RH	Thidiazuron	0.35	24	43
TMAX2	Thidiazuron	0.35	23	43
TMIN2	Thidiazuron	0.52	17	50

† Linear correlation coefficient ($p < 0.01$). Data not reported for cases in which $p \geq 0.01$.

‡ Mean first quartile response difference from untreated check.

§ Mean fourth quartile response difference from untreated check.

¶ Abbreviations for weather variables: TMIN1 = average daily minimum temperature from planting to treatment; CLOUD = percent cloudiness at time of treatment; RH = relative humidity at time of treatment; TMAX2 = average daily maximum temperature during 14 d after treatment; TMIN2 = average daily minimum temperature during 14 d after treatment.

high humidity and high moisture content in cotton leaves (AgrEvo USA, 2000). The positive response to cloud cover by dimethipin is contrary to the general statement by Cathey (1986) that cloudy weather may reduce defoliation response, but it is consistent with dimethipin research by Keng and Metzger (1987).

The influence of average minimum temperature from planting to treatment on defoliation was still evident 14 d after treatment in all treatments except tribufos alone (Table 5). The greatest relative improvement in the 14 d-after-treatment defoliation response with higher seasonal minimum temperature occurred with thidiazuron, with or without ethephon. The addition of ethephon increased the influence of minimum seasonal temperatures on activity of all defoliants. High night temperatures during the season, and especially after flowering, tend to promote crop maturity by advancing boll maturation (Gipson, 1986). Increased crop maturity at the time of harvest-aid application will probably favor defoliation response to hormonal-type materials such as thidiazuron and ethephon by promoting hormonal activation of the leaf abscission layer (Cathey, 1986).

The only weather variable measured at the time of application affecting the 14 d-after-treatment defoliation response was that of relative humidity effect on thidiazuron response (Table 5). Principal component analysis showed that by 14 d after treatment, influence on defoliation of the first two components of weather at time of application was negligible (data not shown).

The 14 d-after-treatment defoliation response with thidiazuron also improved with higher daily maximum and minimum temperatures after application (Table 5). The positive response to high night temperature $r = 0.52$) is consistent with product information indicating that night temperatures below 15.6°C after application may result in incomplete defoliation with thidiazuron (AgrEvo USA, 2000). Hake et al. (1996) cited 18.3°C as the minimum average temperature for optimal defoliation with thidiazuron. In this study, the median night temperature for 14 d after treatment was 13.8°C, implying that night temperatures were suboptimal for defoliation with thidiazuron in more than half of the test environments. As night temperatures after treatment dropped from 17.7°C to 11.3°C, the 14 d-after-treatment defoliation response to thidiazuron declined from 50% better (Q4) to just 17% better (Q1) than untreated cotton. These results emphasize the greater sensitivity of hormonal-type harvest aids (such as thidiazuron) to temperature, relative to contact types (Hake et al., 1990; Hake et al., 1996).

There were no significant post-treatment temperature correlations with 14 d-after-treatment defoliation responses to ethephon combinations. This result suggests that the addition of ethephon to these defoliants did not increase their temperature sensitivity after treatment. Gwathmey and Hayes (1997) found that defoliant activity was enhanced by adding ethephon, but the response was inconsistent across defoliants and temperature regimes.

Boll Opening

There was a positive effect of the cloud and humidity principal component of the weather at time of application on boll opening at 7 d after treatment for only the thidiazuron + ethephon treatment (Table 4). The humidity, temperature, and wind component of weather at time of application had a negative effect on boll opening in the tribufos + ethephon, dimethipin, and thidiazuron + ethephon treatments. For weather before and after treatment, the principal component of temperature had a negative influence on the 14 d-after-treatment boll opening response to all treatments except tribufos alone.

Table 6. Effects of weather variables (at time of treatment, and before and after treatment) on boll opening responses to harvest-aid treatments at 14 d after treatment in a 5-yr (1992-1996) cotton harvest-aid study at 16 locations: results of correlation analysis and means of first and fourth quartile response differences from untreated check.

Weather X	Treatment	*r*†	Q1‡	Q4§
			%	%
PPT1¶	Dimethipin + ethephon	0.33	4	11
TMAX1	Tribufos + ethephon	-0.39	12	6
	Dimethipin + ethephon	-0.45	12	4
	Thidiazuron + ethephon	-0.47	14	4
TMAX2	Tribufos + ethephon	-0.42	12	4
	Dimethipin + ethephon	-0.43	13	5
	Thidiazuron + ethephon	-0.42	13	5
TMIN2	Tribufos + ethephon	-0.33	11	5
	Dimethipin + ethephon	-0.31	11	3
	Thidiazuron + ethephon	-0.32	12	5

† Linear correlation coefficient ($p < 0.01$). Data not reported for cases in which $p \geq 0.01$.

‡ Mean first quartile response difference from untreated check.

§ Mean fourth quartile response difference from untreated check.

¶ Abbreviations for weather variables: PPT1 = precipitation from planting to treatment; TMAX1 = average daily maximum temperature from planting to treatment; TMAX2 = average daily maximum temperature during 14 d after treatment; TMIN2 = average daily minimum temperature during 14 d after treatment.

Results of correlation analyses and mean comparisons of upper and lower quartiles indicate that there were fewer weather effects on boll opening than on defoliation. There were no significant weather correlations with 7 d-after-treatment boll opening responses to treatments applied in this study (days after treatment not shown). Earlier research indicated that the boll opener, ethephon, required more than 7 d to significantly increase boll opening under relatively cool conditions (Gwathmey and Hayes, 1997). Across environments and defoliants in this study, the addition of ethephon increased boll opening only a few percentage points (from 71.3 to 75.6% open bolls) by 7 d after treatment (Snipes and Valco, 1999).

By 14 d after treatment, several weather effects on boll opening appeared, but only in response to treatments with ethephon (Table 6). The average maximum temperature from planting to treatment and average maximum and minimum temperatures in the 14 d after treatment were negatively associated with boll opening response to all three ethephon treatments. More boll opening occurred in cotton treated with ethephon combinations than in the check when the temperatures were cooler (lowest quartile). This result indicates that ethephon had relatively more influence on boll opening under cooler conditions, whereas warmer temperatures (highest quartile) tended to equalize boll opening between the ethephon treatment and the check. This result is noteworthy in that the lowest quartile value of average daily minimum temperature from treatment to 14 d after treatment was 11.3°C (Table 3), considerably cooler than the minimum temperature threshold (15.6°C) for ethephon activity (Hake et al., 1996).

Seasonal precipitation from planting to treatment was positively associated with boll opening response to dimethipin + ethephon (Table 6). This result suggests that crop condition in moist environments was perhaps more conducive to uptake and/or response to this harvest-aid combination. Cotton grown in moist environments tends to have thinner, more permeable leaf cuticles than drought-stressed cotton, in which cuticle thicknesss can impede dimethipin uptake (Oosterhuis et al., 1991).

A comparison of boll opening responses was made between the hot, moist environments (Prosper, TX; Louisiana; and South Carolina) and the moist environments with moderate seasonal temperatures (Missouri, Alabama, Tennessee, and North Carolina) (data not shown). Two of the ethephon-enhanced treatments (with dimethipin and thidiazuron) had greater boll opening effects in cotton grown in the hot environments, suggesting that higher seasonal temperatures and moisture produced crop conditions favorable to ethephon-induced boll opening. Another comparison was made between the hot, drier environments after treatment (College Station and Weslaco, TX; Louisiana) and the cooler, moister environments (Alabama, Tennessee, Georgia, South Carolina, North Carolina, and Florida) (data not shown). The 14 d-after-treatment boll opening response was greater in the hot, dry climates than in the cooler, moister environments, as expected.

Terminal Regrowth

The principal components of weather at time of application had no effect on terminal regrowth. However, principal component analysis of weather before and after treatment showed a positive response of terminal regrowth to the "temperature" component for all treatments (Table 4). The "temperature and moisture" component had a negative effect on terminal regrowth by all treatments except dimethipin and thidiazuron + ethephon treatments. This finding suggests that regrowth suppression may be less effective with these products in moist environments than in drier conditions.

None of the weather variables measured at the time of treatment significantly influenced terminal regrowth responses to harvest aids in this study. Seasonal precipitation from planting to treatment was negatively associated with terminal regrowth response to tribufos, tribufos + ethephon, and dimethipin + ethephon (Table 7). In the moist (Q4) environments, these treatments reduced regrowth by 20 to 27% relative to the check. In drier (Q1) environments, however, regrowth was similar in these treatments and the check. Similar effects were found for precipitation in the 7 d immediately prior to treatment for terminal regrowth responses to tribufos + ethephon and dimethipin + ethephon.

Table 7. Effects of weather variables (at time of treatment, and before and after treatment) on terminal and basal regrowth responses to harvest-aid treatments at 21 d after treatment in a 5-yr (1992-1996) cotton harvest-aid study at 16 locations: results of correlation analysis and means of first and fourth quartile response differences from untreated check.

Weather X	Treatment	*r*†	Q1‡	Q4§
	Terminal regrowth		%	%
PPT1¶	Tribufos	-0.37	4	-20
	Tribufos + ethephon	-0.36	4	-24
	Dimethipin + ethephon	-0.35	-2	-27
PPT7P	Tribufos + ethephon	-0.47	-1	-46
	Dimethipin + ethephon	-0.40	-6	-38
	Thidiazuron	-0.46	-16	-48
PPT2	Dimethipin + ethephon	-0.35	-9	-36
TMAX2	Tribufos	0.39	-25	-1
	Tribufos + ethephon	0.50	-45	0
	Dimethipin	0.46	-35	-1
	Dimethipin + ethephon	0.41	-38	-5
	Thidiazuron + ethephon	0.34	-46	-21
	Basal regrowth			
TMIN1	Tribufos	-0.37	23	1
PPT7P	Tribufos + ethephon	-0.34	27	5
	Thidiazuron + ethephon	-0.36	19	-11
TEMP	Thidiazuron + ethephon	0.37	-10	22
PPT7A	Dimethipin + ethephon	-0.34	18	-3
TMAX2	Tribufos + ethephon	0.35	4	30
	Dimethipin	0.41	-14	13
	Thidiazuron	0.34	-18	5
	Thidiazuron + ethephon	0.42	-14	24

† Linear correlation coefficient ($p < 0.01$). Data not reported for cases in which $p \geq 0.01$.

‡ Mean first quartile response difference from untreated check.

§ Mean fourth quartile response difference from untreated check.

¶ Abbreviations for weather variables: PPT1 = precipitation from planting to treatment; PPT7P = precipitation during 7 d prior to treatment; PPT2 = precipitation during 14 d after treatment; TMAX2 = average daily maximum temperature during 14 d after treatment; TMIN1 = average daily minimum temperature from planting to treatment; TEMP = air temperature at time of treatment; PPT7A = precipitation during 7 d after treatment.

Additionally, regrowth response to thidiazuron (with or without ethephon) was negatively associated with precipitation in the 7 d prior to treatment. The thidiazuron treatments reduced regrowth by 16% in drier (Q1) environments, and 48 to 58% in environments with abundant late-season moisture

(Q4), relative to the check. These differences indicate the role of late-season moisture in supporting terminal growth and regrowth in untreated cotton.

Relatively cool (Q1) daytime temperatures in the 14 d after treatment reduced terminal regrowth in all treatments except thidiazuron alone, relative to the check (Table 7). The reduction in terminal regrowth under mild daytime temperatures (25.6°C) ranged from 25% with tribufos alone, to 46% with thidiazuron + ethephon. Under warmer (Q4 = 31.4°C) daytime weather, regrowth was similar in the tribufos and dimethipin treatments (with or without ethephon), relative to the check. By contrast, thidiazuron + ethephon reduced terminal regrowth by 21% under these conditions. These results suggest that terminal regrowth control with thidiazuron + ethephon is most evident under the relatively mild but moist conditions that tend to promote regrowth.

Basal Regrowth

Principal component analysis showed that cloud and humidity conditions at time of treatment had a negative influence on basal regrowth response to thidiazuron (Table 4). The principal component of wind, temperature, and humidity conditions at time of treatment had a positive effect on basal regrowth in the thidiazuron treatments (with or without ethephon). The principal component of temperature before and after treatment had a positive influence on basal regrowth response to all treatments except tribufos alone. The principal component of temperature and precipitation conditions before and after treatment had a negative effect on basal regrowth response to tribufos.These findings suggest that basal regrowth was more readily controlled by thidiazuron in clear, dry weather at the time of application than under moist, cloudy conditions.

Weather effects on basal regrowth were more complex than those on terminal regrowth. Seasonal precipitation from planting to treatment did not significantly influence basal regrowth responses (Table 7). Precipitation during the 7 d prior to treatment was negatively associated with regrowth response to tribufos + ethephon and thidiazuron + ethephon. Correlation coefficients were lower (in absolute value) for basal regrowth than for terminal regrowth responses to these two treatments, and Q1-Q4 differences were lower, suggesting a weaker sensitivity of basal regrowth to late-season precipitation. Basal regrowth response to dimethipin + ethephon was negatively associated with precipitation in the 7 d after treatment. For all three defoliants, the addition of ethephon tended to increase basal regrowth relative to the check in drier (Q1) late-season environments, in contrast to the terminal regrowth responses to late-season moisture.

Air temperature at the time of application was positively correlated with basal regrowth response to thidiazuron + ethephon. Maximum air temperatures during the 14 d after treatment were also positively correlated with basal regrowth responses to thidiazuron (with or without ethephon), dimethipin, and tribufos + ethephon. Except for tribufos + ethephon, basal regrowth was reduced slightly by these treatments relative to the check when daytime air temperatures were mild (Q1 = 25.6°C). Under warmer conditions (Q4 = 31.4°C), basal regrowth was more prevalent in cotton treated with tribufos + ethephon or thidiazuron + ethephon than in the check. This finding is consistent with ethephon effects reported by Snipes and Valco (1999).

CONCLUSIONS

Results of this study support the broad concept that weather conditions before, during, and after application of harvest-aid chemicals influence the chemicals' effects. The proportional influence of these weather factors on different crop responses is noteworthy. For defoliation, seasonal daily minimum temperatures were the dominant weather factor influencing response to all of the harvest aids in this study. This result underscores the role of high night temperatures during the growing season in promoting crop maturity and susceptibility to defoliation. Weather conditions during and after application mainly influenced defoliation by the hormonal defoliant, thidiazuron, whereas the contact-type defoliants were generally less sensitive. For boll opening, daily maximum temperatures before application, and daily maximum and minimum temperatures after application dominated the weather factors influencing response to ethephon-based treatments. Although boll opening was promoted by warm conditions after treatment, ethephon had a proportionally greater boll opening response under cooler conditions in which boll opening of untreated cotton may have been more temperature-limited. Terminal regrowth responses were most evident with relatively moist conditions before treatment and mild daily maximum temperatures after treatment. These conditions may have promoted regrowth in untreated cotton and thus increased the differential response to treatments in this study. Basal regrowth response to most ethephon combinations, however, was aggravated by relatively dry weather and warm daytime temperatures after treatment. Results from this study may help improve choice of harvest-aid materials to prepare cotton for harvest under different weather conditions.

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