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AGRONOMY AND SOILS

Water Volume and Deposition Effects on Harvest-Aid Efficacy

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ABSTRACT

Harvest aids provide cotton farmers with the ability to harvest in an efficient and timely manner. Harvest aids also assistant in preserving overall fiber quality by reducing fiber degradation and discoloration from exposure to weather and by the reduction of foreign matter. Many harvest-aid active ingredients do not translocate within the plant, thus adequate spray coverage is recommended to improve efficacy of these products. The widespread and rapid adoption of auxin-tolerant cotton varieties has increased the use of larger droplet size nozzles that are required for use with auxin herbicides. Subsequently, the use of larger droplet size nozzles for harvest-aid applications will likely increase. The objective of this study was to determine the impact of droplet size and carrier volume on defoliation, desiccation, boll opening, terminal and basal regrowth, and cotton leaf grade. Varying water volumes of 47, 93, 140, and 187 L ha^{-1}, and nozzles that produced fine, medium, and ultra-coarse droplets were evaluated at 14 site years across the Cotton Belt in 2016 and 2017. Numeric trends indicate higher carrier volumes are more successful at defoliating and opening bolls than lower carrier volumes. Water volumes of 47 L ha^{-1} should be avoided when making cotton harvest-aid applications, as all defoliation, open boll, and regrowth values were consistently reduced at the lowest carrier volume. Treatments of various nozzle types had less impact on harvest-aid efficacy than carrier volume. Site interactions with harvest aids had a greater effect than nozzle type or water volume.

Cotton (*Gossypium hirsutum* L.) is an indeterminate perennial shrub that is grown as an annual row crop. Producers rely on harvest aids to achieve optimal fiber quality and prepare plants for efficient and timely mechanical harvesting (Chen and Dong, 2016). Harvest aid is a broad term that includes products that serve as defoliants, desiccants, regrowth inhibitors, and boll openers, with some products having activity in more than one of these areas. The effectiveness of harvest aids is greatly influenced by weather conditions, plant condition, immature fruit load on the plant, plant size, residual soil nitrogen, and varietal differences (Gwathmey et al., 1986; Oosterhuis et al., 1991; Snipes and Evans, 2001; Supak and Snipes, 2001). Weather conditions at the time of application, but also before and after application, affect harvest-aid efficacy (Gwathmey et al., 2004).

Defoliants allow more efficient harvest as these products remove unwanted plant material such as leaves, petioles, and bracts and potentially reduce the amount of regrowth a plant will exhibit (Supak and Snipes, 2001). Plants that are naturally mature, nutrient limited, and have higher leaf-moisture content tend to defoliate more readily. Higher temperatures and humidity levels also increase the efficacy of some defoliant products (Cathey, 1986). The removal of vegetative plant material helps preserve fiber quality by reducing lint staining, moisture within modules, and leaf and petiole material that must be removed in the gin. The reduction of vegetative material in harvested cotton delivered to the gin reduces lint cleaning requirements and thereby reduces ginning costs (Bechere et al., 2011). Additionally, excessive cleaning at the gin increases fiber breakage,

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which decreases fiber length and increases short fiber content, which can lead to additional fiber quality discounts (Larson et al., 2002).

Defoliants are generally separated into two categories: hormonal and herbicidal. Hormonal defoliants (thidiazuron and ethephon) increase the ethylene concentration in the leaf, limiting auxin transport, which in turns initiates the abscission process at the base of the petiole and allows the leaf to separate from the stem or branch (Morgan and Durham, 1975). Herbicidal defoliants (e.g., carfentrazon-ethyl, fluthiacet-methyl, pyraflufen ethyl, saflufenacil, tribufos) injure the leaf, which stimulates ethylene production and leads to the initiation of the abscission process. If herbicidal defoliants rates are too high for the crop condition, the injury will increase leaf desiccation causing leaf tissue to die too rapidly and prevent the abscission layer from developing. This leads to desiccated leaves remaining attached to the plant and increases leaf material entering the harvester and module.

Harvest aids also include boll openers that promote mature bolls to open more rapidly by weakening the boll sutures. Boll openers are not systemic and are not translocated from the leaves to the bolls (Gwathmey and Hayes, 1997). As a result, coverage is crucial; boll openers must reach and adequately cover unopened bolls to obtain effective boll opening. Cooler temperatures (highs below 24° C) require rates twice has high compared to warmer temperatures (highs above 29° C) (Gwathmey et al., 1986). Properly timed boll openers expedite cotton harvest to avoid inclement weather and minimize cellular degradation, staining, rotting, and hard locking (Logan and Gwathmey, 2002).

Sprayer nozzles are designed to deliver various droplet sizes and volume output capabilities depending on the needed coverage, product (systemic or non-systemic), application speed, and chemical properties of the products being applied. The spray volume output is regulated by the exit orifice size and pressure with increasing orifice size and/or pressures delivering higher spray volume. Application speed impacts carrier volume with faster speeds lowering application rates and possibly detrimentally influencing deposition in other ways (Heidary et al., 2014).

There are numerous sprayer nozzles manufactured by various companies with various designs, but most are a variation of flat fan or hollow-cone nozzle (TeeJet Technologies, 2017). Nozzles are designed to create or change different spray droplet sizes and patterns based on desired applications. In 1985, extended-range nozzles that allow for greater variation with pressure were brought to the marketplace and allow producers more flexibility in spray droplet size without having to change nozzles frequently.

Due to the 2016 release of auxin-resistant traited cotton, applicators are required by federal law to apply auxin herbicides with extremely coarse to ultra-coarse nozzles to create large spray droplets and with minimal, driftable fine droplets (Monsanto Company, 2018). Larger droplet sizes reduce the potential for off-site movement by physical drift and/or temperature inversions. However, larger droplets decrease coverage: a 500-micron water droplet is equal to eight 250-micron (categorized as medium droplet size) water droplets in volume (Kruger et al., 2013). The reduction in coverage resulting from large droplet size can be partially compensated for by increasing the carrier volume. However, increasing carrier volume is not preferred by growers due to added expenses and time refilling nurse and spray tanks.

For maximum canopy penetration, 47 to 93 L ha^{-1} should be used for aerial application and 93 to 187 L ha^{-1} for ground applications to significantly increase defoliation (Siebert et al., 2006). Siebert et al. (2006), using three different nozzles, flat fan, hollow cone, and air induction, demonstrated that higher carrier volumes provided greater efficacy and were recommended to obtain adequate canopy coverage and penetration in cotton with rank or excessive growth (Snipes and Evans, 2001). Harvest-aid labels for products containing the active ingredients of tribufos (Amvac Chemical Corporation, 2019), thidiazuron (Loveland Products, 2019b), or ethephon (Loveland Products, 2019a) make the same general recommendations on their labels for high spray volumes, but with no mention of nozzle selection. The objective of this research study was to address which spray volumes are most suitable for proper defoliation, boll opening, and minimizing leaf grades.

MATERIAL AND METHODS

Research trials were conducted during the 2016 and 2017 growing seasons. In 2016, trials were conducted in six locations across the Cotton Belt, including Starkville, MS; Jackson, TN; Sikeston, MO; College Station and Lubbock, TX; and Solomon, AZ (Table 1). In 2017, the trials were repeated at the 2016 locations and two additional locations were added: Raleigh, NC and Brewton, AL. Weather data were compiled from the National Oceanic and Atmosphere Administration's (NOAA) Global Historical Climatology Network (GHCN) stations (NOAA, 2019). Average daily temperatures, DD15.5 accumulation, and rain amounts for the three difference rating periods are given for each location by year (Table 1). All locations were planted at the same seeding rate, 120,000 seeds ha^{-1}, with the same cultivar, Phytogen® 333 WRF (Corteva Agrisciences, Indianapolis, IN), which is a semi-smooth leaf cultivar. The trial design was a four replicate, two-way factorial design with plots consisting of four rows 9 m in length. Harvest-aid treatments were made to the center two rows and the center two rows were used for collecting visual ratings and harvested cotton for ginning. Applications in Solomon, AZ; Lubbock and College Station, TX; and Raleigh, NC were made with CO_2-pressurized backpack sprayers. Applications in Sikeston, MO; Brewton, AL; Starkville, MS; and Jackson, TN were made with self-propelled ground rigs.

Treatments consisted of applications of four carrier volumes (47, 93, 140, and 187 L ha^{-1}) and three nozzle types: TeeJet hollow cone XR80015 (fine droplets), TT11002 Turbo Teejet® (medium droplets), and TTI110002 Turbo Teejet Induction® (ultra-coarse droplets). A complete list of the 12 nozzle-type-by-carrier-volume treatments is presented in Table 2. An untreated check (UTC) was also included. Plots at all sites were treated with tribufos (Folex®, Amvac Chemical Corporation, Newport Beach, CA) at 0.42 kg a.i. ha^{-1}, ethephon (Superboll®, Nufarm Limited, Alsip, IL) at 1.2 kg a.i. ha^{-1}, and thidiazuron (Freefall®, Nufarm Limited) at 0.06 kg a.i. ha^{-1} (Table 1) when the majority of plants in all plots reached four nodes above uppermost, first-position cracked boll or 60% open bolls.

Visual ratings included defoliation (DEF), open boll (OB), desiccation (DES), terminal regrowth (TRG), and basal regrowth (BRG) percentages and were made 7, 14, and 21 days after application (DAA) of the harvest-aid treatments. Visual rating observations were made on a 0 to 100 scale with 0 indicating no effect and 100 indicating maximum effect. The three observation ratings were averaged for one value due to the ratings exhibiting a consistent positive linear relationship. The numerical observation rating held rank throughout the three observation timings.

Table 1. Weather data including date of harvest aid applications, average temperatures, accumulated DD15s, and rainfall for rating periods from all locations over the 2-year study

Location/Year		**0 to 7 DAA**			**7 to 14 DAA**			**14 to 21 DAA**		
2017	**Date of App.[z]**	**Avg Temps (°C)[y]**	**DD15s[v]**	**Rainfall (cm)[w]**	**Avg Temps (°C)**	**DD15s**	**Rainfall (cm)**	**Avg Temps (°C)**	**DD15s**	**Rainfall (cm)**
College Station, TX	**8/23**	**26.0**	**73.5**	**46.3**	**27.4**	**83.0**	**0.0**	**23.7**	**57.4**	**0.05**
Raleigh, NC	**9/5**	**19.1**	**25.3**	**1.5**	**22.9**	**51.6**	**1.6**	**23.8**	**58.7**	**0.0**
Brewton, AL	**9/19**	**25.9**	**72.7**	**0.6**	**25.0**	**66.3**	**0.05**	**25.1**	**66.9**	**7.3**
Jackson, TN	**9/23**	**23.9**	**59.1**	**0.0**	**21.0**	**38.3**	**0.0**	**21.1**	**39.1**	**3.6**
Sikeston, MO	**9/27**	**18.5**	**20.8**	**1.01**	**17.6**	**15.0**	**3.5**	**16.4**	**7.4**	**2.0**
Starkville, MS	**9/28**	**22.8**	**50.8**	**0.0**	**22.8**	**51**	**0.18**	**17.9**	**21.0**	**0.08**
Safford, AZ	**10/2**	**24.1**	**60.5**	**0.0**	**21.5**	**41.9**	**0.0**	**22.4**	**48.6**	**0.0**
Lubbock, TX	**10/11**	**17.9**	**22.4**	**0.0**	**17.0**	**16.9**	**0.03**	**11.1**	**3.4**	**0.18**
2016										
College Station, TX	**8/24**	**26.9**	**79.6**	**2.0**	**27.8**	**86.3**	**1.0**	**27.8**	**86.3**	**0.0**
Safford, AZ	**9/20**	**25.4**	**69.1**	**0.0**	**24.9**	**66.0**	**1.0**	**25.1**	**67.4**	**2.4**
Jackson, TN	**9/23**	**21.8**	**44.1**	**0.41**	**20.5**	**35.2**	**0.0**	**18.6**	**21.9**	**0.0**
Starkville, MS	**9/23**	**26.1**	**74.1**	**0.0**	**21.6**	**42.7**	**0.0**	**21.1**	**38.9**	**0.0**
Lubbock, TX	**9/27**	**18.7**	**22.2**	**0.0**	**19.6**	**35.5**	**0.0**	**20.3**	**35.4**	**0.0**
Sikeston, MO	**9/28**	**18.7**	**22.2**	**0.0**	**20.6**	**35.5**	**0**	**20.3**	**35.4**	**0.0**

[z] **Date of harvest aid application**

[y] **Average temperatures during a 7-d period (0 to 7 days, 7 to 14 days, 14 to 21 days after application)**

[x] **Degree days 15's accumulated in a 7-d period (0 to 7 days, 7 to 14 days, 14 to 21 days after application)**

[w] **Accumulated rainfall in a 7-d period (0 to 7 days, 7 to 14 days, 14 to 21 days after application)**

Table 2. List of treatments for nozzle type and carrier volume, application details, and spray droplet size category

Treatments	Nozzle Type	Carrier Volume ($L\ ha^{-1}$)	Pressure (kPa)	Speed ($km\ h^{-1}$)	Spray Droplet Size Category
UTC[z]			Untreated Control		
Fine:47	TXR80053VK	47	276	4.83	(Very Fine)
Med:47	TT11001	47	207	8.05	(Medium)
Coarse:47	TTI110015	47	103	8.05	(Ultra-Coarse)
Fine:93	TXR8001VK	93	276	4.83	(Fine)
Med:93	TT110015	93	310	8.05	(Medium)
Coarse:93	TTI110015	93	103	4.83	(Ultra-Coarse)
Fine:140	TXR80015VK	140	276	4.83	(Fine)
Med:140	TT110015	140	276	4.83	(Medium)
Coarse:140	TTI110015	140	276	4.83	(Ultra-Coarse)
Fine:187	TXR8002VK	187	276	4.83	(Fine)
Med:187	TT11002	187	276	4.83	(Medium)
Coarse:187	TTI11002	187	276	4.83	(Ultra-Coarse)

[z] **Untreated Control**

All plots were harvested and a minimum of 2 kg of raw cotton was sent to the University of Tennessee MicroGin to be ginned on a commercial scale gin, which was cut down to a 20-saw gin. The University of Tennessee MicroGin includes (in order): a Continental Model 511 six-drum inclined cleaner, a Model 601 Continental/Moss-Gordin stick machine, a Continental Model 511 six-drum inclined cleaner, a Model 550 Continental Master Double X feeder, a Model 521 Continental 20-saw 16-in gin, two Moss/Gordin Model 560 Cleanmaster 12-in lint cleaners, and one laboratory size condenser (Infante et al., 1971). After ginning, approximately 60 g samples were sent to the USDA Agricultural Marketing Service (AMS) Classing Office in Memphis, TN for fiber analysis by high volume instrumentation (HVI).

Individual locations were evaluated by the three timing observations (7, 14, and 21 DAA) averages first using ANOVA tables to identify studies with significance. Once significance was discovered, The SAS JMP Tukey-Kramer's honest significant difference (HSD) test was utilized at a 0.05 alpha value to compare treatment differences (individual location data not presented).

Prior to analysis of all locations, all data were normalized to each location's UTC as a preprocessing step aimed at accounting for maturity and environmental variability across locations. Normalized data were analyzed using the R statistical software program (R Core Team, Vienna, Austria) and the nlme package for linear and nonlinear mixed-effects models (Pinheiro et al., 2018). Statistical modeling and inference were conducted via linear mixed-effects models. For each defoliation, desiccation, boll opening, terminal and basal regrowth, and cotton leaf grade response variables, linear models were fit with independent variables for water volume, nozzle type, and their interactions, with random effects for location and year. The use of random effects enables all locations and both years to be combined and modeled together while observing differences in response values variances across the different location-year combinations.

Due to non-normality of the data, classical parametric mixed-effects models were not appropriate. For the purpose of estimating standard errors of model coefficients and computing confidence intervals for their values, bootstrap resampling techniques were employed (Efron and Tibshirani, 1998). The β estimates of each model coefficient were used as an empirical estimate of the coefficient estimate's sampling distribution. Model coefficients were interpreted as average differences between one level of a dependent variable to its respective carrier volume (47 L ha^{-1}), nozzle (Fine), and two-factor (Fine 47 L ha^{-1}) baseline, holding all other dependent variables constant. Similarly, larger absolute effect sizes along with smaller *p*-values for one dependent variable (or level within one dependent variable) with respect to another dependent variable (or another level of the same dependent variable) were used as indication of greater relative importance of the one dependent level. An example from Table 3, under the defoliation column, 93 L ha^{-1} shows a *p*-value of 0.03 compared to 47 L ha^{-1} displaying significance. Along with a positive β coefficient of 4.78, indicates a positive significant interaction.

Table 3. Treatment effect estimates utilizing a linear mixed model using sites and years as random effects. Beta coefficients (β), standard errors (se), *t*-values (*t*), and *p*-values (*p*) given for each factor

Factors	Defoliation		Desiccation		Open Bolls		Terminal Regrowth		Basal Regrowth	
Intercept[v]	**β[z] (SE[y])**	**T[v] (P[w])**	**β (SE)**	**T (P)**	**β (SE)**	**T (P)**	**β (SE)**	**T (P)**	**β (SE)**	**T (P)**
Medium	52.37 (5.66)	9.26 (<0.001)	8.73 (4.07)	2.14 (0.03)	3.14 (2.49)	1.26 (0.21)	4.69 (1.80)	2.60 (0.01)	8.48 (4.05)	2.09 (0.04)
Coarse	3.58 (2.19)	*1.64* *(0.10)*	1.10 (0.79)	1.40 (0.16)	1.35 (1.41)	0.96 (0.34)	-2.90 (0.97)	-2.99 (0.003)	-1.82 (1.69)	-1.08 (0.28)
LPH93	-2.57 (2.18)	-1.18 (0.24)	2.13 (0.79)	2.71 (0.007)	0.50 (1.40)	0.36 (0.7)	-0.32 (0.97)	-0.33 (0.74)	0.73 (1.68)	0.44 (0.66)
LPH140	4.78 (2.18)	2.20 (0.03)	2.01 (0.79)	2.55 (0.01)	0.72 (1.40)	0.51 (0.61)	-1.98 (0.97)	-2.05 (0.04)	-3.13 (1.68)	-1.86 (0.06)
LPH187	6.08 (2.18)	2.79 (0.01)	0.89 (0.79)	1.14 (0.26)	2.10 (1.40)	1.50 (0.13)	-1.24 (0.97)	-1.29 (0.20)	-1.28 (1.69)	-0.76 (0.45)
Medium: LPH93	8.67 (2.18)	3.98 (0.0001)	1.80 (0.79)	2.29 (0.02)	1.88 (1.40)	1.35 (0.18)	-1.98 (0.97)	-2.05 (0.04)	0.59 (1.68)	0.35 (0.73)
Coarse: LPH93	-7.92 (3.09)	-2.57 (0.01)	-1.64 (1.11)	-1.48 (0.14)	-1.19 (1.99)	-0.60 (0.55)	2.91 (1.37)	2.12 (0.03)	3.97 (2.38)	1.67 (0.10)
Medium: LPH140	0.20 (3.09)	.06 (0.95)	-2.39 (1.10)	-2.17 (0.03)	0.73 (1.98)	0.37 (0.71)	0.72 (1.37)	.053 (0.60)	-0.22 (2.37)	-0.09 (0.93)
Coarse: LPH140	-4.53 (3.09)	-1.47 (0.14)	-1.69 (1.11)	-1.53 (0.12)	-1.49 (1.99)	-0.75 (0.45)	2.37 (1.37)	1.73 (0.08)	1.20 (2.38)	0.50 (0.62)
Medium: LPH187	-1.59 (3.08)	-0.52 (0.61)	-2.17 (1.11)	-1.94 (0.05)	-0.73 (1.98)	-0.37 (0.71)	1.19 (1.37)	0.87 (0.39)	0.35 (2.38)	0.15 (0.88)
Coarse: LPH187	-5.43 (3.09)	-1.75 (0.08)	-1.77 (1.11)	-1.60 (0.11)	-0.83 (1.99)	-0.42 (0.68)	2.38 (1.37)	1.74 (0.08)	-1.15 (2.38)	-0.48 (0.63)

[Z] **β- Beta coefficients for each parameter**

[Y] **SE- Standard Error of Beta coefficients in parenthesis**

[x] ***T*-value of factor and intercept**

[w] ***P*-value of comparison of Factor and intercept in parenthesis**

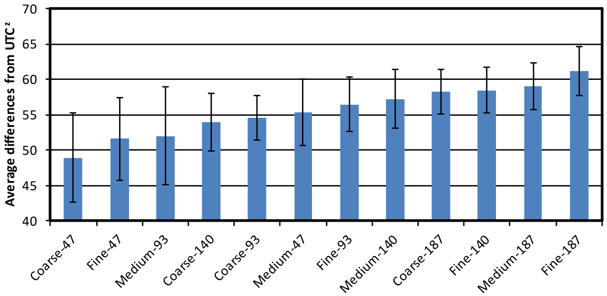
[v] **intercept is representation of Fine, LPH47, and Fine:LPH47 for each grouping**

RESULTS

Differences were observed in Alabama (2017) with coarse nozzles applying 47 L ha^{-1} (Coarse-47) resulting in the lowest averaged defoliation levels and significantly less than Medium-93, 140, 187, and Coarse-187 (data not shown). Coarse-47 had the highest defoliation levels in the Arizona 2016 study and significantly better than Medium-93, Fine-47, and Coarse-140. However, in 2017 in Arizona, the results were more comparable to previously reported research, where defoliation was significantly better for the highest carrier volume, Medium and Coarse-187, compared to Fine and Coarse nozzles at the lowest carrier volume (data not shown). At the 2016 Lubbock site, Fine-187 was numerically the best although only significantly greater than Coarse-93. At the same location in 2017, the only treatments that were significantly different were Coarse-187 being the most efficacious and Fine-47 being least effective by 63%. The only statistical differences in defoliation ratings were between the highest carrier volume, 187 L ha^{-1}, with fine nozzles being greater than lowest carrier volume, 47 L ha^{-1}, for both fine and coarse nozzles. The general numerical trends suggested increasing carrier volume resulted in increased defoliation ratings and mitigated the impact of the nozzle types. As indicated in the mixed model, all water volumes were significantly better than 47 L ha^{-1}, whereas nozzles did not vary from Fine (Table 3). Furthermore, as the water volumes increased in relation to 47 L ha^{-1}, *p*-values became highly significant, demonstrating increased treatment benefit from the higher carrier volumes. Medium and coarse nozzles were not found to be significant, although medium did have a *p*-value of 0.10. Coarse nozzles had a negative coefficient, indicating a negative effect on defoliation compared to fine nozzles.

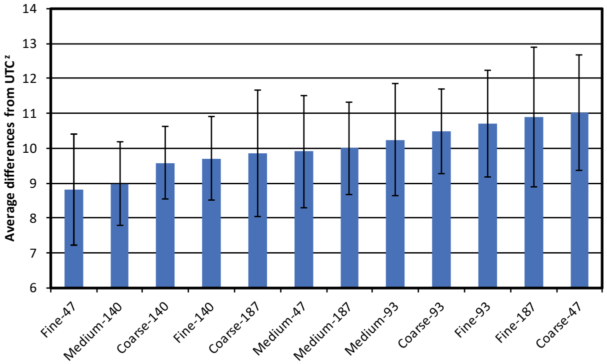
The 2017 Alabama location had higher desiccation levels from both Fine-93 and -187 compared to Fine-47. The Arizona 2016 study rated desiccation Medium-47 and Coarse-93 as the highest two treatments and Coarse-187 and Medium-140 as the lowest and were significantly different from other treatments. Desiccation levels for Lubbock (2017) were the highest for Fine-47, compared to other treatments. North Carolina (2017) study had only Fine-93 rated significantly higher than Fine-47.

When combined across all locations and years, no significant differences were observed for desiccation levels for the various treatments, due in part, to relatively low levels of desiccation observed from the chosen harvest-aid products. Additionally, desiccation was generally more variable across locations, nozzles, and carrier volume than defoliation (Fig. 1). Siebert et al. (2006) reported comparable findings, whereas defoliation ratings displayed higher significance by nozzle type and carrier volume than the desiccation ratings. Typically, more desiccation would be expected from greater coverage (Snipes and Evans, 2001); however, in this study lower water volumes lead to quicker and more obvious leaf tissue necrosis (Fig. 2). From the mixed model and combined across carrier volume, coarse nozzles showed more desiccation than fine nozzles, whereas medium nozzles were statistically similar to the fine and coarse nozzles. Carrier volumes of 93 L ha^{-1} were significantly better than 47 L ha^{-1} (Table 3). Coarse nozzles by all water volumes were shown to be significantly lower than Fine-47.



^{Z} **Untreated Control**

Figure 1. Average leaf defoliation percentages for 7, 14, and 21 DAA ratings across 13 locations in 2016 and 2017. Error bars representing 95% Confidence Intervals.

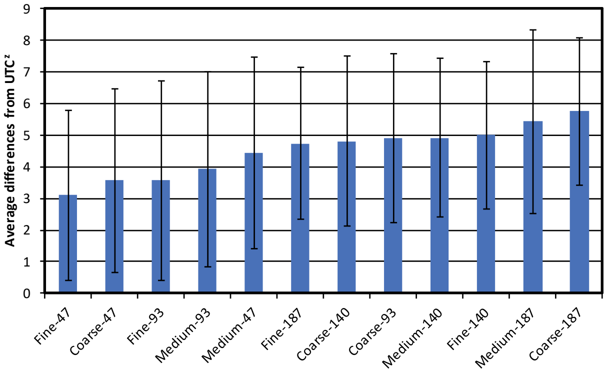


^{Z} **Untreated Control**

Figure 2. Average leaf desiccation percentages across 7, 14, and 21 DAA ratings across 14 locations in 2016 and 2017. Error bars representing 95% Confidence Intervals.

Arizona in 2017 had the greatest percentage of open bolls from the Fine-140 and Medium-187 and the lowest from Fine-47; however, little consistency existed across carrier volume or nozzles. Lubbock (2016) reported the lowest percent open bolls from Fine-47, but no other differences were significant. In 2017 in Lubbock, Coarse-187 had the highest percentage of open bolls of which Fine-47 was the lowest, but again, little consistency existed for nozzles or carrier volume. The Medium- and Coarse-187 numerically improved the percentage of open bolls in Tennessee (2017), but these treatments were not significantly different than the lowest performer, Fine-47.

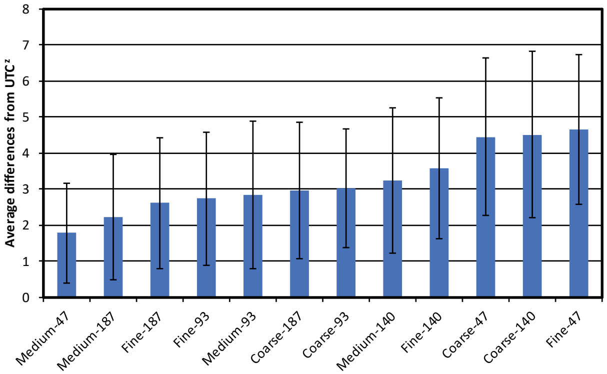
Some numerical trends were noted as more water volume produced better results from the control, where Coarse-187 L ha^{-1}and Medium-187 L ha^{-1} produced the best results. However, the aggregated difference in open boll ratings was only 2.65%. Even when compiling across site years, no significant differences were observed for the open boll ratings based on confidence interval comparisons (Fig. 3) or utilizing the mixed model approach (Table 3). Studies have shown boll opening is greatly affected by temperatures and coverage. Under cooler temperatures ethephon takes longer to open bolls (Gwathmey and Hayes, 1997).



^{Z} **Untreated Control**

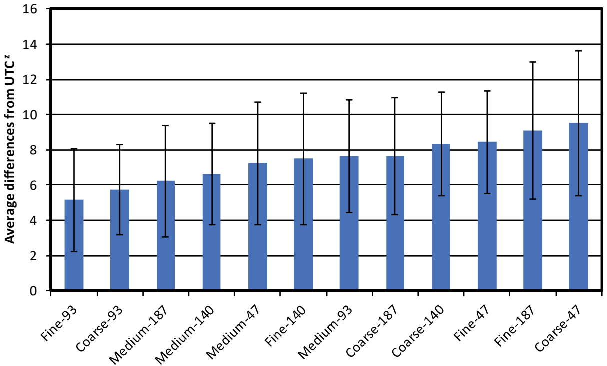
Figure 3. Average open boll percentages for 7, 14, and 21 DAA Ratings across 14 locations in 2016 and 2017. Error bars representing 95% Confidence Intervals.

Terminal regrowth across all locations was the lowest as a result of medium nozzles using 47 L ha^{-1} followed by medium nozzles applying 187 L ha^{-1} and Fine-187 L ha^{-1} of water volume; however, there was little consistency in carrier volume or nozzles regarding increased efficacy for terminal regrowth (Fig. 4). These results are consistent with Siebert et al. (2006) who reported only one of three locations where carrier volume or nozzle type had significant impact on terminal regrowth. From the mixed model analysis (Table 3) medium nozzles were significantly better than both coarse and fine nozzles. Medium nozzles offered the most consistent results compared to the other two nozzles used in these studies, but no treatments were significantly different (Table 3). The mixed model analysis (Table 3) showed LPH-187 produced significantly improved the reduction of terminal regrowth than LPH-93. Medium-93 was found to be more significant than Medium-187 and Coarse-187 at causing regrowth compared to the baseline of Fine-47. No numeric or statistical trends were observed for basal regrowth (Fig. 5).



^{Z} Untreated Control

Figure 4. Average terminal regrowth percentages for 7, 14, and 21 DAA ratings across 14 locations in 2016 and 2017. Error bars representing 95% Confidence Intervals. Lower numbers represent better efficacy with untreated checks (UTC) regrowth rated as zero for regrowth.



^{Z} Untreated Control

Figure 5. Average basal regrowth percentages for 7, 14, and 21 DAA ratings across 14 locations in 2016 and 2017. Error bars representing 95% Confidence Intervals. Lower numbers represent better efficacy with untreated checks (UTC) regrowth numbers rated as zero for regrowth.

In theory, the ultimate value of increased defoliation and lower desiccation is to decrease cotton leaf grades. However, leaf grade had the highest variance compared to all the other quantification methods for harvest-aid performance. With the categorical measurement of leaf grade from HVI, the measurement resolution is low and decreases the potential to identify harvest-aid treatment effects. A general trend was the medium nozzles provided a more consistent response than the other nozzles. These findings were similar to Byrd et al. (2016), Eder et al. (2018), and Gormus et al. (2017) in that defoliation levels did not consistently impact cotton leaf grades.

DISCUSSION

The average leaf defoliation within this trial coincide with findings by Knoche (1994), where efficacy of post-emergence contact herbicides is normally increased as droplets reduce in size with constant carrier volumes. Similarly, in this study the level of defoliation increased as carrier volume increased regardless nozzle treatment. Much like defoliation within a cotton canopy, the efficacy of boll opener harvest-aid products is highly dependent on coverage due to the lack of translocation to or within the boll. As a result, open boll ratings responded similarly to defoliation, where water volume had a greater influence than nozzle type. This research expanded on the carrier volume and droplet size nozzles evaluated by Siebert et al. (2006) to include ultra-coarse nozzles labeled for auxin herbicides in XtendFlex™ and Enlist™ cotton. However, the general conclusions were similar, where increased carrier volume can be used to compensate for ultra-coarse tips.

Regrowth control and desiccation were less consistent than in prior research. These inconsistencies are attributed to the many confounding physiological and environmental factors that influence both regrowth and leaf desiccation (Snipes and Evans, 2001). In this study, an inconsistent response was expected for these parameters and the response was highly variable and inconsistent for both carrier volume and nozzle type. Various State Extension publications (Dodds et al., 2018; Kelley et al., 2014) recommend adjusting harvest-aid rates depending on forecasted weather, and McCarty (1995) reported weather conditions as being the most critical factor facing efficacy of harvest aids. One major purpose of harvest-aid applications is to reduce the amount of plant material harvested to preserve fiber quality. Similar to previous research with a wide range of leaf defoliation levels within their trials (Byrd et al., 2016; Eder et al., 2018; Gormus et al., 2017) only low correlations were observed in the present study between defoliation levels and leaf grade values. Within this trial, insufficient differences in defoliation levels for the carrier volume and nozzles were obtained to expect to observe a significant leaf grade response even with a hairy leaf variety.

CONCLUSIONS

Our results suggest nozzle type likely will have less impact on harvest-aid efficacy than carrier volume. Higher carrier volumes typically resulted in greater levels of defoliation and boll opening than lower carrier volumes, whereas all defoliation, open boll, and regrowth values were consistently reduced at the lowest carrier volume. Subsequently, water volumes of 47 L ha^{-1} should be avoided when making cotton harvest-aid applications. Although additional research evaluating differences in nozzle types and carrier volume with desiccants is warranted, these studies suggest larger droplet size nozzles could be used for harvest-aid applications at carrier volumes in excess of 93 L ha^{-1}.

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DISCLAIMER

Reference to commercial products or trade names is made with the understanding that no discrimination or endorsement is intended.

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