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AGRONOMY AND SOILS

Effect of Carrier Volume and Nozzle Type on Cotton Harvest-aid Efficacy

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ABSTRACT

Chemical defoliation of cotton (*Gossypium hirsutum* L.) in preparation for mechanical harvest can be difficult because of inconsistent response of plants to harvest-aid applications. Unsatisfactory harvest-aid performance is often blamed on environmental conditions, but proper selection of carrier volume and nozzle type may help to improve harvest-aid efficacy. The objective of this study was to determine the optimum combination of carrier volume and nozzle type for maximizing harvest-aid efficacy. Desiccation, defoliation, and regrowth were evaluated on cotton treated with tribufos or thidiazuron alone at carrier volumes of 47, 94, and 140 L ha^{-1} with flat fan, hollow cone, or air induction nozzles. In Alexandria, carrier volume did not influence defoliation; however, defoliation with hollow cone and flat fan nozzles was at least 6% higher than defoliation with air induction nozzles at all evaluation dates regardless of carrier volume. In St. Joseph, percentage defoliation increased as carrier volume increased, and defoliation with flat fan and hollow cone nozzles was similar and superior to that of air induction nozzles. Carrier volumes ≥ 94 L ha^{-1} provided at least 10% more defoliation than 47 L ha^{-1} in Jackson, and performance of hollow cone nozzles was superior to both flat fan and air induction. A conclusion that can be drawn from these data are that harvest-aid applications should be made with flat fan or hollow cone nozzles at carrier volumes of at least 94 L ha^{-1} to maximize efficacy; however, the influence of carrier volume and nozzle type seem to be greater at more northern latitudes where environmental conditions often limit the performance of harvest-aids. Air induction nozzles should not be recommended for cotton defoliation due to inconsistent and inferior performance; however, they should still be considered in drift sensitive areas.

Chemical defoliation is one of the more unpredictable aspects of cotton production. A major limitation to effective defoliation in cotton is the inconsistent abscission of leaves (Oosterhuis et al., 1991). The efficacy of a harvest-aid is directly related to plant condition and weather at the time of application (Cathey, 1986). Other factors, including spray coverage, canopy penetration, volatilization, photodecomposition, absorption, and translocation, can also impact harvest-aid performance (Oosterhuis et al., 1991). Spray coverage and canopy penetration can be manipulated through carrier volume and nozzle selection; however, limited information is available on the effects of varying these factors on harvest-aid efficacy.

A carrier serves as a diluent for the harvest-aid chemical and enables a relatively small dosage of chemical to be distributed over a relatively large area. Changes in carrier volume can affect leaf run-off, canopy penetration, drift potential, and chemical concentration per unit leaf area (Monaco et al., 2002). In general, reducing droplet size and increasing carrier volume improves weed control, but results vary with species, herbicide rate, and mode of action (Buehring et al., 1973). Carrier volume effects on herbicide performance are inconsistent. For herbicides other than glyphosate (Knoche, 1994), efficacy generally decreases as carrier volume decreases, but there is no consistent difference on the effect of carrier volume with respect to herbicides with systemic or contact modes of action (Knoche, 1994, Edmund and York, 1987). Several references correlate increased weed control with increased carrier volume (Stougaard, 1999; Brewster and Appleby, 1990; Lee and Oliver, 1982).

Nozzles convert the spray mixture into spray droplets for even distribution on the soil or plant surface (Monaco et al., 2002). Several types of nozzles exist; however, flat fan and cone nozzles are most often used in agricultural applications. Flat fan nozzles with their small droplet size (median droplet diameter 330 - 640

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microns) provide excellent coverage and moderate canopy penetration, but are prone to drift (off-target movement) (Anonymous, 1996). Cone nozzles increase canopy penetration with equal coverage and greater drift potential than flat fan nozzles because of a median droplet diameter of 200 – 280 microns (droplets < 200 microns are considered potential drift contributors) (Anonymous, 1996). Increased use of non-selective herbicides on transgenic crops has created the need to reduce off-target movement when applying herbicides near sensitive crops. Primary contributors to drift are wind speed and spray nozzle height above the intended target (Ellis et al., 2002). Air induction or venturi type nozzles introduce air into the nozzle body prior to the nozzle orifice resulting in larger droplets and reduced drift potential (Griffin et al., 2003). Performance of systemic herbicides generally increase as droplet size decreases (Knoche, 1994); however, weed control with drift reduction (air induction) nozzles was equal to that of standard flat fan nozzles with carrier volumes ranging from 28 to 234 L ha^{-1} (Griffin et al., 2002).

Harvest-aids, much like herbicides, have several modes of action and coverage may be a crucial factor in their performance. The results from previous studies related to herbicide efficacy indicate that increased coverage can enhance the activity of contact harvest-aids because of limited translocation. Complete coverage may not be as important when using a systemic harvest-aid that is translocated throughout the plant. Herbicidal or contact harvest-aids physically injure the leaf, stimulating an ethylene response and subsequently causing abscission. Leaf drop with hormonal harvest-aids is mediated by enhanced ethylene evolution (Suttle, 1985). Hormonal harvest-aids, such as thidiazuron, have been shown to disrupt the polar auxin transport system and are excellent inhibitors of regrowth (Suttle, 1988); however, this product is not recommended when temperatures drop below 16 °C, which limits its use in late-fall applications (Snipes and Wells, 1994). Herbicidal harvest-aids provide little or no suppression of regrowth but are active at lower temperatures. Excessive rates can result in rapid leaf injury and death prior to the formation of the abscission zone (Snipes and Evans, 2001; Cothren, 1999).

The objective of this research was to determine the optimal combination of carrier volume and nozzle type to maximize efficacy of cotton harvest-aids with herbicidal and hormonal modes of action.

MATERIALS AND METHODS

Experiments were conducted on a Norwood silt loam soil (fine-silty, mixed, superactive, hyperthermic Fluventic Eutrudepts) at the Dean Lee Research Station near Alexandria, LA, in 2003, on a Commerce silt loam soil (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) near St. Joseph, LA, at the Northeast Research Station in 2003 and 2004, and on a Grenada silt loam soil (fine-silty, mixed, active, thermic Oxyaqyuic Fraglossudalts) at the West Tennessee Experiment Station near Jackson, TN, in 2004. All experimental areas were planted in cotton and maintained according each state's extension service recommendations (Table 1). Publications

Table 1. Cotton cultivar, planting date, nozzle, spray pressure, and ground speed used for applications at each location

	Alexandria, LA	St. Joseph, LA		Jackson, TN
	2003	2003	2004	2004
Cotton cultivar[y]	Stoneville 'ST 4892 BR'	Stoneville 'ST 4892 BR'	Fibermax 'FM 960 BR'	Deltapine 'DP 444 BG/RR'
Planting date	25 May	25 May	20 May	22 May
Nozzle type	Nozzle model [z]/spray pressure (kPa)			
Flat fan	TJ XR11001VS/144	TJ XR11002VS/207		TJ XR8003VS/276
Hollow cone	TJ TKVS3/243	TJ TKVS12/207		TJ TKVS12/276
Air induction	GL TDXL11001-V01/152	TJ AI11002VS/207		TJ AI110015VS/276
Carrier volume	Ground speed (km h^{-1})			
47 L ha^{-1}	6.4	17.6		12.9
94 L ha^{-1}	3.2	8.9		6.4
140 L ha^{-1}	2.1	5.9		4.0

[y] Stoneville, Emergent Genetics, Inc.; Memphis, TN; Fibermax, Bayer CropScience; Research Triangle Park, NC; Delta and Pine Land Company; Scott, MS.

[z] TJ = TeeJet Spraying Systems Company; Wheaton, IL; GL = Greenleaf Technologies; Covington, LA.

outlining LA and TN extension recommendations are available online at http://www.lsuagcenter.com/en/crops_livestock/crops/Cotton and http://www.utextension.utk.edu/publications/fieldCrops/default.asp. The experimental design was a randomized complete block with four replications and a three factor factorial arrangement of treatments. Factors were harvest-aid (hormonal or herbicidal mode of action), carrier volume (47, 94, or 140 L ha^{-1}), and nozzle type (flat fan, hollow cone, or air induction). Plot size was four rows on 97-cm (Alexandria) or 102-cm (St. Joseph and Jackson) centers and 12 m long.

Treatments were applied to the center two rows of each four-row plot when plants reached 70% open boll on 19 Sept. (Alexandria) and 3 Oct. 2003 (St. Joseph) and 28 Sept. (Jackson) and 20 Oct. 2004 (St. Joseph). Treatments were applied using a CO_2 – pressurized sprayer calibrated to deliver 94 L ha^{-1}. Carrier volumes of 47 and 140 L ha^{-1} were achieved by changing ground speed to maintain a constant spray pressure. Specific nozzles, spray pressure, and ground speeds used at each location are listed in Table 1. A four-nozzle boom was used to apply either hormonal (thidiazuron at 84.1 g ai ha^{-1}; Dropp SC; Bayer CropScience; Research Triangle Park, NC) or herbicidal (tribufos at 841.0 g ai ha^{-1}; DEF 6; Bayer CropScience) harvest-aids. Adjuvants were not added to the treatments.

Visual estimates of desiccation and defoliation were made 7 to 21 days after treatment (DAT) using a scale of 0 to 100%, where 0 = no defoliation or desiccated leaf material present, and 100 = complete desiccation of leaf material or no leaves remaining on the plants. Terminal and/or basal regrowth were visually evaluated 21 to 35 DAT. Vegetative regrowth ratings in Alexandria and Jackson were based on a 0 to 100% scale (percentage regrowth, percentage of new leaf material present), where 0 = no new juvenile vegetative growth and 100 = complete regrowth of all leaf material on plants. In St. Joseph regrowth control (rather than the percentage of vegetative leaf regrowth present) was rated using a 0 to 100% scale, where 0 = no regrowth control (harvest-aid provided no suppression of juvenile growth) and 100 =complete regrowth control (no juvenile leaves present).

Data were subjected to analysis of variance and interactions tested for significance (version 6; SAS Institute; Cary, NC). Tables were constructed based on significant treatment interactions and means were separated using Fisher's protected LSD at $P = 0.10$.

RESULTS AND DISCUSSION

Significant treatment by location interactions were observed for all variables measured, so data are presented by location. Interactions were attributed to differences in environmental conditions (heat unit accumulation) among locations and cotton cultivars planted, which influence harvest-aid activity.

Alexandria, LA (2003). A significant harvest-aid by nozzle type interaction was observed for leaf desiccation ratings at 7 DAT, but interactions between the main effects of carrier volume and harvest-aid, and nozzle type and carrier volume were not significant. Averaged across carrier volumes, thidiazuron applied with flat fan nozzles resulted in significantly more desiccated leaf material (12%) than application with air induction nozzles (6%), but was similar to desiccation observed with hollow cone nozzles (9%) (data not shown). Desiccated leaf material associated with tribufos applications was not significantly different among nozzle types.

There were no other significant interactions, but each main effect was significantly different. Averaged across carrier volumes and nozzle types, leaf desiccation at 7 DAT was significantly higher with thidiazuron than with tribufos (Table 2). Thidiazuron also provided greater defoliation at 14 and 21 DAT and was significantly better at controlling basal and terminal regrowth. Performance differences between these two harvest-aids are well documented (Valco and Snipes, 2001). The lack of harvest-aid by nozzle and carrier volume interactions for defoliation and regrowth measurements shows consistent responses to the main effects of carrier volume and nozzle type regardless of type of harvest-aid.

Desiccated leaf material at 7 DAT was equivalent for carrier volumes of 47 and 94 L ha^{-1} (6%), which was significantly less than desiccation associated with applications at 140 L ha^{-1} (9%). Carrier volume did not influence defoliation or regrowth, which may have been due to the rapid progression of natural senescence at the time of treatment application.

Leaf desiccation at 7 DAT (8%) was the same for applications with flat fan and hollow cone nozzles, but desiccation was higher than with air induction nozzles (5%) (Table 2). At 14 DAT, defoliation was 77% for both flat fan and hollow cone nozzles, which was slightly greater than the 71% with air induction nozzles. At 21 DAT, hollow cone nozzles (72%) still provided greater defoliation than air induction nozzles (63%). Terminal regrowth was less than or equal to 15% with hollow cone and flat fan nozzles and was significantly greater with air induction nozzles (20%). Basal regrowth was not influenced by nozzle type and exceeded 20% with all treatments.

Jackson, TN (2004). Because of low temperatures at and following application, treatments containing thidiazuron provided little defoliation activity and were eliminated from statistical analysis. All thidiazuron treatments provided less than 25% defoliation at 14 DAT. It is well documented that the performance of thidiazuron significantly declines with temperatures below 15.5 °C. Thidiazuron tank mixes are not practical from mid- to late fall when temperatures begin to decline and are not recommended by the Tennessee Cooperative Extension Service. The carrier volume by nozzle type interaction was not significant for treatments containing tribufos, but differences were associated with the main effects.

Desiccated leaf material at 7 DAT significantly increased as carrier volume increased from 47 to 140 L ha^{-1}, but was not greater than 3% (Table 3). Defoliation was at least 10% higher at 7 DAT with carrier volumes greater than or equal to 94 L ha^{-1}. At 14 DAT, differences in defoliation were small but increased with each increase in carrier volume. Terminal regrowth was similar for tribufos applied at 47 and 94 L ha^{-1} and was reduced by 5% with applications at 140 L ha^{-1} (Table 3).

Nozzle type did not influence leaf desiccation at 7 DAT (Table 3). Hollow cone nozzles resulted in 82% defoliation at 7 DAT, which was significantly greater than for air induction nozzles (75%). At 14 DAT, defoliation with hollow cone nozzles was 89% and was greater than both flat fan (85%) and air induction nozzles (84%) (Table 3). Terminal regrowth was at least 5 to 8% greater for applications made with flat fan nozzles compared with hollow cone and air induction nozzles.

Table 2. The effect of harvest-aid, carrier volume, and nozzle type on cotton defoliation and regrowth in Alexandria, LA (2003)

Factor[w]	Desiccation (%)[x]	Defoliation[y]		Regrowth (21 DAT)[z]	
	7 DAT	14 DAT	21 DAT	Terminal	Basal
Harvest-aid					
Thidiazuron	9	84	80	7	15
Tribufos	5	67	55	26	32
LSD (P = 0.10)	2	5	7	4	4
$P > F$	0.0008	0.0001	0.0001	0.0001	0.0001
Carrier volume (L ha^{-1})					
47	6	75	66	17	24
94	6	74	65	17	24
140	9	71	72	16	22
LSD (P = 0.10)	3	NS	NS	NS	NS
$P > F$	0.0439	0.6306	0.2387	0.8759	0.5372
Nozzle type					
Flat fan	8	77	68	14	20
Hollow cone	8	77	72	15	24
Air induction	5	71	63	20	26
LSD (P = 0.10)	3	6	8	5	NS
$P > F$	0.0466	0.0672	0.0961	0.0354	0.1147

[w] Thidiazuron and tribufos applied at 84.1 and 841.0 g ai ha^{-1}, respectively, at approximately 70% open bolls on 19 Sept. 2003. Harvest-aid data averaged across carrier volumes and nozzle types. Carrier volume data averaged across harvest-aids and nozzle types. Nozzle type data averaged across harvest-aids and carrier volumes.

[x] Desiccation ratings are visual evaluations based on a 0 to 100 scale. DAT = days after treatment.

[y] Defoliation ratings are visual evaluations based on a 0 to 100 scale.

[z] Regrowth ratings are the percentage of juvenile vegetative leaf material present.

St. Joseph, LA (2003 and 2004). There were no significant interactions for defoliation and regrowth measurements during 2003 and 2004; however, significant differences were detected for each main effect. Desiccated leaf material present in both 2003 and 2004 was too low to rate and did not differ among treatments. Averaged across carrier volumes and nozzle types, defoliation with tribufos was at least 22% greater than thidiazuron at 7 and 19 DAT in 2003 (Table 4). In 2004, tribufos provided 79% defoliation at 12 DAT compared with 77% obtained with thidiazuron. By 21 DAT, defoliation increased to 91% with thidiazuron and was significantly better than tribufos (88%). Regrowth control was much greater with thidiazuron in both years compared with tribufos, which never exceeded 30% (Table 4). The difference in activity of defoliants between years is due to temperature and heat unit accumulation following application. In 2003, the daily low temperature was below 10 °C for 2 d following application, and a total of nine heat units were accumulated during that period (Anonymous, 2005). These conditions favor herbicidal-type defoliants like tribufos (Anonymous, 2001). In 2004, night temperatures were above the 18.3 °C, which is the threshold required for adequate activity of thidiazuron (Snipes and Wells, 1994), for an entire week after defoliation and averaged 18.1 heat units per day. Similar to Alexandria during 2003, the lack of significant harvest-aid by carrier volume or nozzle type interaction supports the finding that harvest-aid mode of action is not an important factor when choosing carrier volumes or nozzle types.

In 2003 and 2004, defoliation generally increased as carrier volume increased. In 2003, 140 L ha^{-1} provided significantly greater defoliation than 47 L ha^{-1} at 7 and 19 DAT (Table 4). This trend was also evident in 2004 with defoliation levels significantly decreasing with each decrease in carrier volume from 140 to 47 L ha^{-1} at 12 DAT, but not at 21 DAT. Womac et al. (1992) documented a 4.8% increase in the coverage of water sensitive paper when carrier volume was increased from 47 to 94 L ha^{-1} using flat fan nozzles. In the same study, defoliation ratings increased from 58.8 to 74.1% with an increase in carrier volume from 47 to 187 L ha^{-1}, respectively. Terminal regrowth control was not influenced by carrier volume or nozzle type in either year (Table 4).

Defoliation with flat fan and hollow cone nozzles was not significantly different at all rating dates in both years (Table 4). In 2003, flat fan and hollow cone nozzles provided 42 and 43% defoliation at 7 DAT, respectively, and 62 and 60% defoliation at 19 DAT, respectively. Defoliation with flat fan and hollow cone nozzles was always at least 16% greater

Table 3. The effect of carrier volume and nozzle type on cotton defoliation and regrowth in Jackson, TN (2004)

Factor[w]	Desiccation (%)[x]	Defoliation (%)[y]		Regrowth (26 DAT)[z]
	7 DAT	7 DAT	14 DAT	Terminal
Carrier volume (ha^{-1} L)				
47	1	71	82	19
94	2	81	87	19
140	3	83	90	14
LSD (P = 0.10)	1	6	3	4
$P > F$	0.0098	0.0005	0.0001	0.0184
Nozzle type				
Flat fan	2	78	85	22
Hollow cone	2	82	89	17
Air induction	2	75	84	14
LSD (P = 0.10)	NS	6	3	4
$P > F$	0.6330	0.0465	0.0011	0.0031

[w] Tribufos was applied at 841.0 g ai ha^{-1} at approximately 70% open bolls on 28 Sept. 2004. Carrier volume data averaged across harvest-aids and nozzle types. Nozzle type data averaged across harvest-aids and carrier volumes.

[x] Desiccation ratings are visual evaluations based on a 0 to 100 scale. DAT = days after treatment.

[y] Defoliation ratings are visual evaluations based on a 0 to 100 scale.

[z] Regrowth ratings are the percentage of juvenile vegetative leaf material present.

than with air induction nozzles. Differences in defoliation were not as great in 2004; however, flat fan and hollow cone nozzles resulted in at least 9 and 4% greater defoliation than air induction nozzles at 12 and 21 DAT, respectively (Table 4).

CONCLUSION

Across the wide range of environmental conditions in which these studies were conducted some similar results were observed. Defoliation, when using either hormonal or herbicidal harvest-aids and averaged across nozzle types, was enhanced at Jackson (herbicidal harvest-aid only) and St. Joseph (2003 and 2004) with applications at higher carrier volumes. At all locations defoliation with hollow cone nozzles was superior to air induction nozzles regardless of carrier volume. Defoliation with flat fan nozzles was generally numerically, but not statistically superior to air induction nozzles. Increasing carrier volume helped to reduce vegetative regrowth in Jackson, but at all other locations the influence was minimal, and regrowth rarely exceeded 25% by 21 d after application.

Cooperative Extension service guidelines in all mid-South cotton producing states (Louisiana, Mississippi, Arkansas, and Tennessee), as well as the product labels of many currently registered cotton harvest-aids, recommend application at carrier volumes of no less than 94 L ha^{-1}. In these studies, a trend was observed that suggests carrier volume is a less influential factor in defoliant efficacy with earlier defoliation timings or defoliation at more southern latitudes. This was due to temperature and relative humidity at and following defoliant application. Producers should carefully examine the

Table 4. The effect of harvest-aid, carrier volume, and nozzle type on cotton defoliation and terminal regrowth in 2003 and 2004 at St. Joseph, LA

Factor[x]	Defoliation (%)[y]				Terminal regrowth (% control)[z]	
	2003		2004		2003	2004
	7 DAT	19 DAT	12 DAT	21 DAT	21 DAT	35 DAT
Harvest-aid						
Thidiazuron	19	44	77	91	83	51
Tribufos	56	66	79	88	30	25
LSD (P = 0.10)	2	4	2	2	6	7
$P > F$	0.0001	0.0001	0.0347	0.0040	0.0001	0.0001
Carrier volume (L ha^{-1})						
47	34	50	76	89	57	38
94	37	55	78	90	55	38
140	40	60	81	91	56	38
LSD (P = 0.10)	4	5	2	NS	NS	NS
$P > F$	0.0053	0.0026	0.0001	0.2142	0.8446	0.9762
Nozzle type						
Flat fan	43	62	81	91	55	36
Hollow cone	42	60	82	91	55	39
Air induction	26	43	72	87	59	39
LSD (P = 0.10)	4	5	2	2	NS	NS
$P > F$	0.0001	0.0001	0.0001	0.0008	0.4827	0.6422

[x] Thidiazuron and tribufos applied at 84.1 and 841.0 g ai ha^{-1}, respectively, at approximately 70% open bolls on 3 Oct. 2003 and 20 Oct. 2004. Harvest-aid data averaged across carrier volumes and nozzle types. Carrier volume data averaged across harvest-aids and nozzle types. Nozzle type data averaged across harvest-aids and carrier volumes.

[y] Defoliation ratings are visual evaluations based on a 0 to 100 scale. DAT = days after treatment.

[z] Regrowth control (treatment performance) rated using a 0 to 100% scale, where 0 = no regrowth control and 100 =complete regrowth control.

cost and benefits associated with increasing carrier volume for what may be small increases in defoliation. Before choosing to apply defoliants at carrier volumes less than recommended, a producer must be willing to accept the risk associated with this. Poor product performance resulting in a second defoliant application would result in additional cost that far out weight the initial cost of increased carrier volume on the first application.

Even though hollow cone nozzles are generally preferred, these data indicate the performance of flat fan nozzles was similar. In any case, air induction nozzles should not be recommended for cotton harvest-aid application due to inconsistent and generally inferior performance. It is important to recognize that air induction nozzles are excellent at accomplishing the function for which they were designed, reducing off-target movement of pesticides. Air induction nozzles should be considered for applications in or around sensitive urban areas, and these applications should be made with the highest practical and economical carrier volume possible to maximize harvest-aid efficacy.

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REFERENCES

Anonymous, 1996. TeeJet Agricultural Spray Products Catalog. Catalog 45A: 6-7. Spraying Systems Co., Wheaton, Il.

Anonymous. 2001. DEF 6 specimen label. Available online at http://www.greenbook.net/docs/Label/L3566.PDF (verified 6 June 2006).

Anonymous. 2005. Louisiana Agriclimatic Information. LSU AgCenter, Baton Rouge, LA. Available online at http://www2.lsuagcenter.com/weather/tabledata.asp (verified 28 July 2005).

Brewster, B. D., and A. P. Appleby. 1990. Effect of rate, carrier volume, and surfactant on imazamethabenz efficacy. Weed Technol. 4:291-293.

Buehring, N. W., L. O. Roth, and P. W. Santelmann. 1973. Plant response to herbicide spray drop size and carrier volume. Trans. ASAE 16:636-638.

Cathey, G. W. 1986. Physiology of defoliation in cotton production. p. 143-154. *In* J. R. Mauney, and J. McD. Stewart (ed.) Cotton physiology. The Cotton Foundation Reference Book Series, Cotton Foundation, Memphis, TN.

Cothren, J. T. 1999. Physiology of the cotton plant. p. 207-268. *In* C. W. Smith (ed.), Cotton: Origin, History, Technology, and Production. John Wiley & Sons, Inc., New York, NY.

Edmund, R. M., Jr., and A. C. York. 1987. Factors affecting postemergence control of sicklepod (*Cassia obtusifolia*) with imazaquin and dpx-f6025: spray volume, growth stage, and soil-applied alachlor and vernolate. Weed Sci. 35:216-223.

Ellis, J. M., J. L. Griffin, and C. A. Jones. 2002. Effect of carrier volume on corn (*Zea mays*) and soybean (*Glycine max*) response to simulated drift of glyphosate and glufosinate. Weed Technol. 16:587-592.

Griffin, J. L., J. M. Ellis, C. A. Jones, J. D. Siebert, E. P. Webster, and S. D. Linscombe. 2003. Reducing Roundup Drift. Louisiana Agric. 46(1):16-18.

Griffin, J. L., C. A. Jones, and J. D. Siebert. 2002. Weed science 2001 annual research report. LSU AgCenter, Baton Rouge, LA. Available online at http://www.lsuagcenter.com/weedscience/annualreport01.aspm (verified 7 July 2005).

Knoche, M. 1994. Effect of droplet size and carrier volume on foliage-applied herbicides. Crop Prot. 13(3):168-178.

Lee, S. D. and L. R. Oliver. 1982. Efficacy of acifluorfen on broadleaf weeds. Times and methods for application. Weed Sci. 30:520-526.

Monaco, T. J., S. C. Weller, and F. M. Ashton. 2002. p. 117-2-2. Weed Science: Principles and Practices. 4th ed. John Wiley & Sons, Inc., New York, NY.

Oosterhuis, D. M., R. E. Hampton, and S. D. Wullschlegar. 1991. Water deficit effects on the cotton leaf cuticle and the efficiency of defoliants. J. Prod. Agric. 4:260-265.

Snipes, C. E. and L. P. Evans. 2001. Influence of crop condition on harvest-aid activity. p. 119-142. *In* J. R. Supak and C. E. Snipes (ed.) Cotton Harvest Management: Use and Influence of Harvest Aids. The Cotton Foundation Book Series, Cotton Foundation, Memphis, TN.

Snipes, C. E. and G. D. Wells. 1994. Influence of temperature and adjuvants on thidiazuron activity in cotton leaves. Weed Sci. 42:13-17.

Stougaard, R. N. 1999. Carrier volume adjustments improve imazamethabenz efficacy. Weed Technol. 13:227-232.

Suttle, J. C. 1985. Involvement of ethylene in the action of the cotton defoliant thidaiazuron. Plant Physiol. 78:272-276.

Suttle, J. C. 1988. Disruption in the polar auxin transport system in cotton seedlings following the treatment with the defoliant thiadiazurin. Plant Physiol. 86:241-245.

Valco, T.D. and C.E. Snipes. 2001. Uniform harvest-aid performance and lint quality evaluation. p. 172-180. *In* J. R. Supak and C. E. Snipes (ed.) Cotton Harvest Management: Use and Influence of Harvest Aids. The Cotton Foundation Book Series, Cotton Foundation, Memphis, TN.

Womac, A.R., J.E. Mulrooney, and W.P. Scott. 1992. Characteristics of air-assisted and drop-nozzle sprays in cotton. Trans. ASAE 35:1369-1376.