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AMADS Increases the Efficacy of Glyphosate Formulations on Corn[1]

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Abstract: Greenhouse studies were conducted to determine the effect of 1-aminomethanamide dihydrogen tetraoxosulfate (AMADS) as a spray adjuvant on the efficacy of three different glyphosate formulations, the isopropylamine salt (glyphosate-IPA), potassium salt (glyphosate-K), and the acid of glyphosate dissolved in AMADS (glyphosate-A). All formulations were tested at multiple rates with and without AMADS (2% v/v) on greenhouse-grown corn, and growth inhibition was determined by measuring the elongation of the newest emerging leaf between 1 and 7 d after treatment. AMADS increased the efficacy of all three glyphosate formulations by threefold to fourfold. The IC_{50} values for glyphosate-IPA, glyphosate-K, and glyphosate-A without AMADS on corn were 77, 54, and 53 g ae/ha, respectively; and with AMADS the values were 20, 18, and 21 g/ha, respectively. AMADS was more effective than ammonium sulfate (2% w/v) in overcoming the antagonism of hard water (200 parts per million Ca^{+2}) on glyphosate-K efficacy on corn. The rainfastness of glyphosate-IPA, glyphosate-A, and glyphosate-K was improved with AMADS.

Nomenclature: Glyphosate; corn, *Zea mays* L. 'Triumph 1416'.

Additional index words: Ammonium sulfate, rainfastness, surfactant.

Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; glyphosate-TMS, formulated trimethylsulfonium salt of glyphosate; HAT, hours after treatment; IC_{50}, concentration that inhibits growth by 50%; NIS, nonionic surfactant.

INTRODUCTION

Glyphosate is a versatile herbicide that is being applied to an increasing number of hectares. In the United States, glyphosate use in cotton and soybeans increased from approximately 7.5 tons in 1997 to 35 tons in 2003 (U.S. Department of Agriculture–National Agricultural Statistics Service 1998, 2004). Much of this increase has been due to the widespread adoption of glyphosate-resistant crops.

Glyphosate is a foliar-applied, systemic herbicide, and its efficacy depends on retention, cuticular penetration, and subsequent translocation to plant meristems. Efforts to increase the foliar absorption of glyphosate have primarily involved adding different adjuvants to the spray solution. Leaper and Holloway (2000) suggested that an effective glyphosate adjuvant would (1) be hydrophilic, (2) improve spray retention, (3) prevent spreading of the spray droplet, (4) provide a concentrated deposit of glyphosate in a soluble form, and (5) be nonphytotoxic.

More than 30 different glyphosate formulations are available that contain different glyphosate salts either with or without surfactants (Martin and Green 2004). The trend has been to increase the concentration of active ingredient in the formulation. Two of the newest formulations of glyphosate, Roundup Weathermax[3] and Touchdown HiTech,[4] contain the potassium salt at a concentration of 49 and 52% w/w active ingredient, respectively.

Multiple studies that compared the efficacy of glyphosate-IPA with the diammonium salt or the trimethylsulfonium salt (glyphosate-TMS) found no significant differences in efficacy, absorption, or translocation among the formulations (Krausz and Young 2001; Norris et al. 2001; Richardson et al. 2003; Satchivi et al. 2000).

Feng et al. (2000) did find differences in the absorption, translocation, and rainfastness among three different glyphosate formulations. Two formulations, Roundup Original[3] and Roundup Ultra,[3] contained glyphosate-IPA but had different surfactants, and the third contained glyphosate-TMS. There were no differences in the retention of the different formulations, but the Roundup Ultra formulation was absorbed more rapidly compared to the other two formulations. The enhanced rate of absorption

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[3] Monsanto Company, 800 N. Lindbergh Boulevard, St. Louis, MO 63167.

[4] Syngenta Crop Protection Inc., Greensboro, NC 27409.

led to increased rainfastness and greater glyphosate translocation out of the treated leaf.

Feng et al. (1998) compared the absorption and translocation of different glyphosate formulations in velvetleaf (*Abutilon theophrasti* Medicus) and found that formulations containing a proprietary ethoxylated tallowamine surfactant were absorbed more rapidly and translocated to a greater extent than a formulation containing an alkyl polyglucoside. There was a positive correlation between leaf damage caused by the ethoxylated tallowamine surfactant and glyphosate absorption in velvetleaf (Feng et al. 1998; Ryerse et al. 2004), which suggests that the surfactant disrupts the cuticle and the epidermal cell membranes. This disruption may facilitate the absorption of glyphosate into the leaf tissue.

Engame[5] is a new formulation that contains glyphosate acid at 147.4 g ae/L dissolved in AMADS. AMADS, a patented mixture of urea and sulfuric acid, is a versatile compound that is used as a fertilizer,[6] a water conditioner[7] for golf courses, a blossom thinner[8] for peaches and apples, a herbicide/desiccant,[9] and a cotton harvest aid/desiccant.[10]

Molin and Hirase (2004) compared the efficacy of glyphosate formulated as Engame with Roundup Ultra and Touchdown on prickly sida (*Sida spinosa* L), morningglory (*Ipomoea* spp), sicklepod (*Cassia obtusifolia* L.), and purple nutsedge (*Cyperus rotundus* L.). The concentration that inhibits growth by 50% (IC_{50}) for Engame was two to three times lower on these species than the other glyphosate formulations. They suggested that the increased efficacy of Engame versus the other glyphosate formulations was due to disruption of the cuticle by AMADS.

Belles et al. (2004) found that the IC_{50} of glyphosate as Engame was about fourfold lower than Roundup Ultramax on greenhouse-grown velvetleaf. The initial absorption rate of radiolabeled glyphosate in Engame was approximately twice as rapid as Roundup Ultramax. This increased rate of initial absorption resulted in greater translocation of glyphosate to velvetleaf meristems.

Adjuvants are often added with glyphosate to increase efficacy (Leaper and Holloway 2000). For example, ammonium sulfate (AMS) is mixed with glyphosate to overcome divalent cation antagonism (Ramsdale et al. 2003). AMADS, which is a mixture of urea and sulfuric acid, might also be an effective adjuvant for glyphosate. The objectives of this study were to determine the effect of AMADS on the herbicidal efficacy of three different glyphosate formulations and to determine whether AMADS affects the rainfastness of these formulations or the antagonism of divalent cations on glyphosate efficacy.

[5] Engame™, Entek, 6835 Deerpath Road, Elkridge, MD 21075.
[6] N-pHuric®, Agrium Incorporated, 13131 Lake Fraser Drive SE, Calgary, AB T2Y 7E8 Canada.
[7] pHairway®, Agrium Incorporated, 13131 Lake Fraser Drive SE, Calgary, AB T2Y 7E8 Canada.
[8] Wilthin™, Entek 6835 Deerpath Road, Elkridge, MD 21075.
[9] SuperQuik™, Entek 6835 Deerpath Road, Elkridge, MD 21075.
[10] CottonQuik®, Griffin LLC, P.O. Box 1847, Valdosta, GA 31603.

MATERIALS AND METHODS

Plant Material. Corn (*Zea mays* L; 'Triumph 1416') was planted in a soil mixture[11] supplemented with slow-release fertilizer pellets (Osmocote[11] 19-6-12) in 10 × 10 × 10 cm pots, grown under greenhouse conditions (26/14 C day/night temperatures), 14-h photoperiod, 500 μM/·m²/s) and watered twice daily by an automatic overhead sprinkler system. The corn was treated when the third leaf was just emerging from the whorl. After herbicide application, plants were returned to the greenhouse and were not watered overhead for 24 h after treatment except for the rainfastness studies.

Chemicals. Three different commercial formulations of glyphosate were used: IPA,[12] K,[13] and A.[14] The AMADS[6] solution contained 79% w/v (1,091 g/L) of the active ingredient. The AMADS solution was used at 2% v/v in the spray solution or approximately 2.18 g AMADS per 100 ml of final spray volume.

AMADS and Glyphosate Efficacy. Corn was sprayed with 93 L/ha at 280 kPa using a moving nozzle sprayer equipped with one 8001E nozzle.[15] Adjuvants added to the spray included a nonionic surfactant[16] (NIS) at 0.25% (v/v) or AMADS at 2% (v/v) or both. Control plants were treated with the adjuvants alone without glyphosate. Glyphosate rates varied from 4 to 140 g/ha, depending on the formulation tested and the experiment. In one experiment the AMADS concentration was varied from 0.5% to 2% (v/v) with varying concentrations of glyphosate-IPA ranging from 4 to 140 g/ha.

The length of the third leaf was measured by cutting

[11] Metromix 250®, Scotts Sierra Horticultural Products Co., Marysville, OH 43041.
[12] Roundup Ultramax®, isopropylamine salt of glyphosate with surfactant, Monsanto Company, 800 N. Lindbergh Boulevard, St Louis, MO 63167.
[13] Roundup Weathermax®, potassium salt of glyphosate with surfactant, Monsanto Company, 800 N. Lindbergh Boulevard, St. Louis, MO 63167.
[14] Engame, an acid formulation of glyphosate dissolved in AMADS, Entek, 6835 Deerpath Road, Elkridge, MD 21075.
[15] Teejet Spraying Systems, Wheaton, IL 60189-7900.
[16] Liberate™, adjuvant containing lecithin, esters of fatty acids and alcohol ethoxylates, Loveland Industries, Inc., P.O. Box 189, Greeley, CO 80632-1289.

the tip of the leaf to create a square end and then measuring the distance from the top of the pot to the end of the leaf at 1 and 7 d after treatment (DAT). The change in length between these two time points was used to determine the herbicidal effect of the various treatments. In two experiments, plants were allowed to grow for 21 DAT and then the shoots were harvested, dried at 60 C, and dry weight was determined.

Interaction of AMADS and AMS. The effect of hard water (200 parts per million [ppm] Ca^{+2}, in the form of $CaCl_2$) on glyphosate-K efficacy with or without AMS or AMADS, or both, was determined. Glyphosate formulations at 21 to 140 g ae/ha were dissolved in hard water and sprayed in 93 L/ha as described previously. AMS at 2% w/v was added by dissolving 2 g of AMS per 100 ml of spray solution. AMADS was added at a rate of 2% v/v either alone or with AMS at 2% w/v in the spray solution.

AMADS and Rainfastness. Rainfastness was measured by spraying the plants with glyphosate-IPA or glyphosate-A at 70 and 140 g/ha plus adjuvants. At 1 h after treatment (HAT), the plants were treated with 7 mm of simulated rainfall in a 15 to 20 min period with a moving nozzle sprayer equipped with a Teejet[15] 8004 nozzle. Leaf elongation was measured between 1 DAT and 7 DAT. In a second set of experiments, plants were sprayed with either glyphosate-K at 94 g/ha with no adjuvant or at 47 g/ha with AMADS at 2% v/v in the spray solution. The rates of the two glyphosate formulations were chosen to give approximately equivalent biological activity. Treated plants were exposed to 7 mm of simulated rainfall at 0.5, 1, 2, 4 or 24 HAT or were not exposed to rainfall. Leaf elongation was measured between 1 and 7 DAT.

Statistical Analyses. The experiment was a factorial arrangement of glyphosate rate and adjuvant addition in a randomized complete block design with six replicates. All experiments were conducted at least twice. Leaf elongation between 1 and 7 DAT versus glyphosate rate was subjected to regression analysis and fitted to a log-logistic dose equation (Seefeldt et al. 1995) to estimate the IC_{50} values. The IC_{50} values were analyzed as described by Saxton (1998), which is a method for determining mean separations of nonlinear equations at $P = 0.05$. In the rainfastness study, data were analyzed by analysis of variance and means were separated by Fisher's protected least significant difference at the 0.05 level of significance.

RESULTS AND DISCUSSION

The effect of glyphosate on leaf elongation was rapid and quantitative. Harker and Blackshaw (2003) used this method to determine the effectiveness of low herbicide rates on wild oats (*Avena fatua* L.) and concluded that leaf elongation rate was a good indicator of herbicide efficacy. The inhibition of leaf elongation between 1 and 7 DAT with glyphosate correlated ($R^2 = 0.88$) with the inhibition of dry weight at 21 DAT.

AMADS and Glyphosate Efficacy. Glyphosate-IPA and glyphosate-K formulations contain proprietary surfactants and, as a low rate is applied, a low surfactant concentration is also applied. In contrast, glyphosate-A requires the addition of a surfactant. To compensate for these differences, additional NIS at 0.25% (v/v) was included as one of the adjuvants. This surfactant did not affect the herbicidal efficacy of glyphosate-IPA and glyphosate-K, but it did increase the efficacy of glyphosate-A (Table 1).

The IC_{50} for all the glyphosate formulations applied with AMADS at 2% v/v decreased by twofold to fourfold (Table 1). AMADS alone at 2% v/v did cause necrotic spotting on the leaves but did not inhibit leaf elongation (data not shown). A spray solution containing 2% AMADS increased the efficacy of glyphosate-A, even though this formulation already contained AMADS (Table 1). At the glyphosate rates used in this study, the concentration of AMADS from the Engame formulation ranged from 0.6 to 9.9 g/L, whereas the addition of AMADS at 2% (v/v) resulted in final concentrations of 22.4 to 33.7 g/L. These results indicate that the level of AMADS in glyphosate-A at low application rates became too dilute to be effective.

To determine the AMADS concentration needed for the greatest glyphosate efficacy, various concentrations were added to the spray solution with glyphosate-IPA. The greatest efficacy occurred with 2% v/v AMADS (Table 1).

Interaction of AMADS and AMS. The addition of AMS can increase the efficacy of glyphosate on certain species when the herbicide is mixed in hard water (Ramsdale et al. 2003). Because AMADS is used to dissolve calcium salts in drip irrigation lines (Alama and Broner 2003), it is possible that the AMADS effect is similar to that of AMS by preventing formation of glyphosate-calcium complexes (Ramsdale et al. 2003). This hypothesis was tested by mixing glyphosate-K in water containing 200 ppm Ca^{+2} and then adding AMS, AMADS, or both.

Table 1. Log-logistic equations and estimated IC_{50} on the effect of different adjuvants on efficacy of three glyphosate formulations on corn leaf elongation.[a]

Formulation	Adjuvant[b]	R^2	Equation	IC_{50}^{c}
Glyphosate-IPA	None	0.97	$y = 0 + 18/(1 + [x/77])^{2.3})$	77 a
	NIS	0.98	$y = 0 + 18/(1 + [x/83]^{1.9})$	83 a
	AMADS	0.98	$y = 0 + 18/(1 + [x/20]^{1.5})$	20 b
	NIS + AMADS	0.99	$y = 2.4 + 16/(1 + [x/20]^{2.6})$	10 b
Glyphosate-K	None	0.99	$y = 2.3 + 17/(1 + [x/54]^{4.7})$	54 a
	NIS	0.98	$y = 0.2 + 19/(1 + [x/76]^{4.1})$	76 a
	AMADS	0.99	$y = 3.4 + 16/(1 + [x/18]^{4.9})$	18 b
	NIS + AMADS	0.99	$y = 2.3 + 17/(1 + [x/12]^{2.1})$	12 b
Glyphosate-A	None	0.99	$y = 2.1 + 22/(1 + [x/53]^{2.1})$	53 a
	NIS	0.97	$y = 2.4 + 22/(1 + [x/27]^{3.3})$	27 b
	AMADS	0.96	$y = 1.8 + 22/(1 + [x/21]^{2.0})$	21 b
	NIS + AMADS	0.95	$y = 2.1 + 22/(1 + [x/14]^{2.1})$	14 b
Glyphosate-IPA	0.5% AMADS	0.97	$y = 0 + 21/(1 + [x/41]^{5.1})$	41 a
	1% AMADS	0.98	$y = 0 + 22/(1 + [x/27])^{3.0})$	27 b
	2% AMADS	0.98	$y = 1.7 + 21/(1 + [x/17]^{2.9})$	17 c

[a] Leaf elongation was measured on the third leaf of corn between 1 and 7 days after treatment.

[b] Abbreviations: IC_{50}, the concentration of glyphosate that inhibited growth 50%; R^2, correlation coefficient of fit of log-logistic curve to the leaf elongation data; glyphosate-IPA, formulated isopropylamine salt of glyphosate with surfactant; glyphosate-K, formulated potassium salt of glyphosate with surfactant; AMADS, 1-aminomethanamide dihydrogen tetraoxosulfate; glyphosate-A, formulated glyphosate acid dissolved in AMADS.

[c] The IC_{50} was estimated using the log-logistic regression equation: $y = 0 + a/(1 + [x/IC_{50}]^b)$, where b is slope of curve around IC_{50}. IC_{50} values within a formulation followed by the same letter are not significantly different ($P = 0.05$).

Glyphosate-K at 140 g/ha applied in water containing 200 ppm Ca^{+2} did not inhibit corn growth if AMS or AMADS were not included (Figure 1). When AMS (2% w/v) was added to the spray solution, corn growth was inhibited by glyphosate at 140 g/ha, but not at 100 g/ha or less (Figure 1). AMADS (2% v/v) in hard water increased glyphosate-K efficacy twofold to threefold, and combining AMS with AMADS did not increase the efficacy over AMADS alone (Figure 1). The effect of AMS on the efficacy of glyphosate is consistent with that reported by other researchers (Hall et al. 2000; Pratt et al. 2003; Ramsdale et al. 2003; Satchivi et al. 2000; Young et al. 2003). AMADS may have been acting in a manner similar to AMS, but it appeared to be more effective, indicating that other processes may be involved.

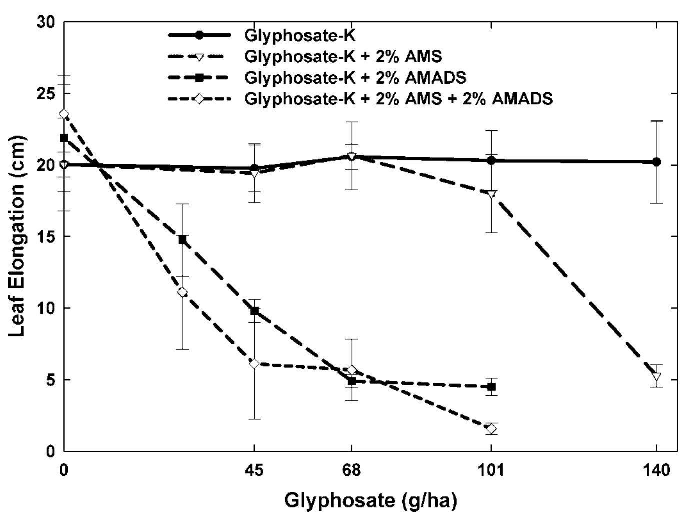

Figure 1. Effects of ammonium sulfate (2% w/v) and AMADS (2% v/v) on glyphosate-K inhibition of corn leaf elongation when applied in hard water (200 ppm Ca^{+2}). Leaf elongation was measured between 1 and 7 DAT. Bars indicate ± 1 standard deviation. Abbreviations: AMADS, 1-aminomethanamide dihydrogen tetraoxosulfate; DAT, days after treatment.

AMADS and Rainfastness. When simulated rain was applied 1 HAT AMADS at 2% v/v increased the rainfastness of both rates of glyphosate-IPA (Table 2). Glyphosate-A at the 140 g/ha rate was rainfast without additional AMADS, but AMADS at 2% v/v did increase the rainfastness of the glyphosate-A at 70 g/ha (Table 2). Another study was conducted with glyphosate-K in which simulated rainfall was applied at different intervals. Glyphosate-K at 94 g/ha was rainfast at 24 HAT,

Table 2. Effect of AMADS on rainfastness of two glyphosate formulations on corn.[a]

		Leaf elongation[b,c]	
Formulation	Rate	No adjuvant	With AMADS
	g/ha	cm	
Untreated	—	15.5 a	15.5 a
Glyphosate-IPA	70	15.3 a	4.7 b
	140	12.0 a	3.1 b
Gyphosate-A	0	14.1 a	5.0 b
	140	4.9 b	3.8 b

[a] Abbreviations: AMADS, 1-aminomethanamide dihydrogen tetraoxosulfate at 2% v/v; glyphosate-IPA, formulated isopropylamine salt of glyphosate; glyphosate-A, formulated glyphosate acid dissolved in AMADS.

[b] Elongation of third leaf of corn was measured between 1 and 7 days after treatment. Plants were treated with 7 mm of simulated rainfall delivered in 15 to 20 min 1 hour after treatment.

[c] Data were subjected to three-way analysis of variance. Values followed by the same letter are not significantly different ($P = 0.05$).

Table 3. Effect of AMADS on rainfastness of K-glyphosate.[a]

Simulated rainfall[b]	Leaf elongation Glyphosate rate 94 g/ha No adjuvant[c]	47 g/ha AMADS[c,d]
Untreated	14.0 a	13.0 a
No rainfall	4 c	4.4 d
0.5	12.5 ab	10.4 ab
1	11.7 ab	8.9 bc
2	10 b	7.6 bcd
4	10.3 b	6.1 d
24	5.3 c	4.1 d

[a] Abbreviations: AMADS, 1-aminomethanamide dihydrogen tetraoxosulfate; K-glyphosate, potassium salt of glyphosate with surfactant.

[b] Simulated rainfall was 7 mm of water applied in 15 to 20 min with a moving nozzle. Figures are hours after treatment.

[c] Means within a column followed by the same letter are not different according to Fisher's protected least significant difference test at P = 0.05. Leaf elongation is indicated in centimeters.

[d] AMADS rate was 2% v/v.

whereas glyphosate-K at 47 g/ha with AMADS at 2% v/v was rainfast at 2 HAT (Table 3).

Rainfastness is a function of how rapidly a lethal dose of the herbicide is absorbed before being washed off the leaf. Feng et al (2000) found that Roundup Ultra was more rainfast than Roundup Original and glyphosate-TMS, and attributed this phenomenon to the more rapid absorption of the Roundup Ultra formulation compared with the other two formulations. Belles et al. (2004) suggested that AMADS increased the glyphosate efficacy on velvetleaf by accelerating the initial rate of herbicide absorption. The effects of AMADS on the rainfastness of these formulations of glyphosate support the conclusions of Belles et al. (2004).

Preliminary results showed that AMADS at 2% v/v also increased the efficacy of different formulations of glyphosate on a variety of weeds under field conditions (data not presented). AMADS could be an effective adjuvant to increase the herbicidal efficacy of glyphosate and could help overcome antagonism caused by hard water, as well as increase the rainfastness of glyphosate formulations. Because adjuvants can have differing effects on the efficacy of herbicides on different species, further research should be conducted on other weeds to determine whether AMADS can be an effective adjuvant for other herbicides.

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LITERATURE CITED

Alama, M. and I. Broner. 2003. Subsurface Drip. Colorado State University, Coop. Exten. Bull. 4.716. 3 p.

Belles, D., D. Shaner, P. Westra, and G. Brunk. 2004. Comparison of efficacy, absorption and translocation of an isopropylamine salt and acid formulation of glyphosate in velvetleaf. Proc. 57th West. Soc. Weed Sci. 57: 38.

Feng, C.C.P., J. S. Ryerse, and R. D. Sammons. 1998. Correlation of leaf damage with uptake and translocation of glyphosate in velvetleaf (*Abutilon theophrasti*). Weed Technol. 12:300–307.

Feng, P. C., J. J. Sandbrink, and R. D. Sammons. 2000. Retention, uptake and translocation of ^{14}C-glyphosate from track-spray applications, and correlation to rainfastness in velvetleaf (*Abutilon theophrasti*). Weed Technol. 14:127–132.

Hall, G. J., C. A. Hart, and C. A. Jones. 2000. Plants as sources of cations antagonistic to glyphosate efficacy. Pest. Manag. Sci. 56:351–368.

Harker, K. N. and R. E. Blackshaw. 2003. Leaf extension rate may help determine when low wild oat herbicide rates will be effective. Weed Technol. 17:839–835.

Krausz, R. F. and B. G. Young. 2001. Response of glyphosate-resistant soybean (*Glycine max*) to trimethylsulfonium and isopropylamine salts of glyphosate. Weed Technol. 15:745–749.

Leaper, C. and P. J. Holloway. 2000. Adjuvants and glyphosate efficacy. Pest Manag. Sci. 56:313–319.

Martin, J. R. and J. D. Green. 2004. Confusing issues about glyphosate. Web page: http://www.uky.edu/Ag/Agronomy/Weeds. Accessed: February 25, 2004.

Molin, W. T. and K. Hirase. 2004. Comparison of commercial glyphosate formulations for control of prickly sida, purple nutsedge, morningglory and sicklepod. Weed Biol. Manag. 4:136–141.

Norris, J. L., D. R. Shaw, and C. E. Snipes. 2001. Weed control from herbicide combinations with three formulations of glyphosate. Weed Technol. 15: 522–558.

Pratt, D., J. J. Kells, and D. Penner. 2003. Substitutes for ammonium sulfate as additives with glyphosate and glufosinate. Weed Technol. 17:576–581.

Ramsdale, B. K., C. G. Messersmith, and J. D. Nalawaja. 2003. Spray volume, formulation, ammonium sulfate, and nozzle effects on glyphosate efficacy. Weed Technol. 17:589–598.

Richardson, R. J., W. A. Bailey, G. R. Armel, C. M. Whaley, H. P. Wilson, and T. E. Hines. 2003. Responses of selected weeds and glyphosate-resistant cotton and soybean to two glyphosate salts. Weed Technol. 17: 560–564.

Ryerse, J. S., R. A. Downer, R. D. Sammons, and P.C.C. Feng. 2004. Effect of glyphosate spray droplets on leaf cytology in velvetleaf (*Abutilon theophrasti*). Weed Sci. 52:302–309.

Satchivi, N. M., L. M. Wax, E. W. Stoller, and D. P. Briskin. 2000. Absorption and translocation of glyphosate isopropylamine and trimethylsulfonium salts in *Abutilon theophrasti* and *Setaria faberi*. Weed Sci. 48:675–679.

Saxton, A. M. 1998. A macro for converting mean separation output to letter groupings in PROC MIXED. Proc. 21st SAS® Users Group International Meeting. Nashville, TN. Pp. 1243–1246.

Seefeldt, S. S., J. E. Jensen, and E. P. Fuerst. 1995. Log-logistic analysis of herbicide dose-response relationships. Weed Technol. 9:218–227.

U.S. Department of Agriculture–National Agricultural Statistics Service, 1998. Agricultural chemical usage: 1997 Field Crop Summary. USDA-NASS-ERS Report May 1998. 97 p.

U.S. Department of Agriculture–National Agricultural Statistics Service, 2004. Agricultural chemical usage: 2003 field crop summary. USDA-NASS-ERS Report May 2004. 158 p.

Young, B. G., A. W. Knepp, L. M. Wax, and S. E. Hart. 2003. Glyphosate translocation in common lambsquarters (*Chenopodium album*) and velvetleaf (*Abutilon theophrasti*) in response to ammonium sulfate. Weed Sci. 51:151–156.