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MSMA Antagonizes Glyphosate and Glufosinate Efficacy on Broadleaf and Grass Weeds

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Field and greenhouse studies were conducted to investigate the compatibility of MSMA in a tank mixture with glyphosate or glufosinate for broadleaf and grass weed control. Glyphosate, glufosinate, and MSMA were evaluated at 0.5×, 1×, and 2× rates, with 1× rates of 0.84 kg ae/ha, 0.5 kg ai/ha, and 2.2 kg ai/ha, respectively. Glyphosate and glufosinate provided similar levels of control for most weed species and were often more efficacious than MSMA alone. Glyphosate controlled Palmer amaranth better than glufosinate. Glufosinate controlled hemp sesbania, pitted morningglory, and ivyleaf morningglory better than glyphosate at one location. Weed control was not improved with the addition of MSMA to glyphosate or glufosinate when compared with either herbicide alone. MSMA antagonized glyphosate efficacy on barnyardgrass, browntop millet, hemp sesbania, Palmer amaranth, and redroot pigweed. MSMA antagonized glufosinate efficacy on browntop millet, hemp sesbania, ivyleaf morningglory, johnsongrass, Palmer amaranth, pitted morningglory, prickly sida, redroot pigweed, and velvetleaf. Antagonism of glyphosate or glufosinate by MSMA was often overcome by applying the 2× rate of either herbicide alone. MSMA is not a compatible tank-mixture partner with glyphosate or glufosinate for weed control in cotton.

Nomenclature: Glyphosate; glufosinate; MSMA; common barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv. ECHCG; browntop millet, *Brachiaria ramosa* (L.) Stapf PANRA; hemp sesbania, *Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill SEBEX; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. IPOHE; johnsongrass, *Sorghum halepense* (L.) Pers. SORHA; palmer amaranth, *Amaranthus palmeri* S. Wats. AMAPA; pitted morningglory, *Ipomoea lacunosa* L. IPOLA; prickly sida, *Sida spinosa* L. SIDSP; redroot pigweed, *Amaranthus retroflexus* L. AMARE; velvetleaf, *Abutilon theophrasti* Medik. ABUTH; cotton, *Gossypium hirsutum* L.

Key words: Herbicide interactions, pesticide interactions, synergism, tank mixtures, glufosinate-resistant cotton, glyphosate-resistant cotton.

Glyphosate and glufosinate provide broad-spectrum, nonresidual, POST control of broadleaf, grass, and sedge weeds in noncrop and row-crop production systems (Askew and Wilcut 1999; Askew et al. 1997; Ateh and Harvey 1999; Faircloth et al. 2001; Hydrick and Shaw 1995; Johnson et al. 2000; Koger et al. 2004, 2005; Norris et al. 2002; Reddy and Whiting 2000). With the advent of glyphosate- and glufosinate-resistant cultivars in recent years, both herbicides have been widely used to control annual and perennial weeds in corn (*Zea mays* L.), cotton, and soybean [*Glycine max* (L.) Merr.].

Cotton cultivars resistant to glyphosate or glufosinate have been widely adopted by growers in the southern United States. The number of U.S. hectares planted to glyphosate- or glufosinate-resistant varieties is difficult to measure. However, approximately 79% of U.S. cotton hectares were planted to herbicide-resistant varieties in 2004 (NASS 2005), with glyphosate-resistant varieties being planted on the majority of this hectarage. It is estimated that 7,405 t of glyphosate were used worldwide in 1997 (Woodburn 2000), and that amount has increased substantially with the advent of glyphosate-resistant soybean, cotton, and corn in 1996, 1997, and 1998, respectively. Crop varieties resistant to glufosinate have not been adopted by growers to the degree of glyphosate-resistant varieties; however, increases in adoption are likely because glyphosate-tolerant or -resistant weed populations increase over time (Owen and Zelaya 2005). Glufosinate-resistant cotton has been planted on considerable hectarage in parts of the southeast United States because of glufosinate's enhanced efficacy on species difficult to control with glyphosate and because glufosinate is capable of controlling glyphosate-resistant horseweed [*Conyza canadensis* (L.) Cronq.] (CDMS 2007). Glufosinate controls a number of species, such as *Ipomoea* spp. and hemp sesbania, that are typically difficult to control with glyphosate alone (Askew et al. 1997; Corbett et al. 2004; Hydrick and Shaw 1995; Norris et al. 2002). Conversely, glyphosate often provides better control of some *Amaranthus* spp. and several annual grass species that are difficult to control with glufosinate alone (Jones et al. 2001; Steckel et al. 1997a, 1997b; Tharp and Kells 2002).

Widespread use of glyphosate- or glufosinate-resistant cotton is due, in part, to the potential for reducing or eliminating soil-applied herbicides and reducing total herbicide use (Culpepper et al. 2004; Smith and Branson 2000). Glyphosate is rapidly adsorbed to soil (Sprankle et al. 1975), and glufosinate is readily degraded by soil microorganisms

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(Tebbe and Reber 1991). Thus, neither herbicide has residual soil activity, resulting in greater flexibility in crop rotations. Glyphosate and glufosinate also provide growers the ability to produce more hectares of cotton with less labor and time inputs (Smith et al. 2003).

Glyphosate can be applied POST over-the-top of glyphosate-resistant cotton up to the four-leaf growth stage (Monsanto 2005). Beyond the four-leaf growth stage, glyphosate must be applied POST-directed (PD) to glyphosate-resistant cotton to minimize contact with leaf and stem tissue. Sequential applications must be spaced at least 10 d apart, and cotton must have at least two nodes of incremental growth between applications (Monsanto 2007). The commercial release of glyphosate-resistant 'Flex' cotton varieties in 2006 allowed POST over-the-top glyphosate applications as registered for glyphosate-resistant cotton to Flex cotton beyond the four-leaf growth stage. Glyphosate can be applied POST over-the-top of glyphosate-resistance Flex cotton from cracking to 60% open bolls (CDMS 2007). Multiple glufosinate applications can be applied over-the-top or PD to glufosinate-resistant cotton from emergence to early bloom growth stages (Bayer 2007).

Residual herbicides applied PRE and MSMA plus residual herbicides applied PD in conjunction with mechanical cultivation constituted the mainstay of weed control programs before the introduction of glyphosate- and glufosinate-resistant cotton (Snipes and Mueller 1992; Snipes et al. 1992). Glyphosate and glufosinate have effectively reduced the need for these inputs in cotton. However, growers continue to seek information about reducing herbicide costs, reducing crop injury, and improving control of weeds by using other herbicides in conjunction with glyphosate or glufosinate for weeds that are difficult to control with glyphosate and glufosinate alone.

MSMA is registered for suppression or control of sedge, grass, and broadleaf weeds in cotton (Askew et al. 2002; Burke and Wilcut 2004; Culpepper et al. 2004; Porterfield et al. 2002). Herbicides such as MSMA applied over-the-top of cotton were often used for salvage treatments when early season broadleaf weed control failed (Monks et al. 1999). MSMA is registered for POST over-the-top and PD weed control in cotton. Over-the-top applications of MSMA can cause significant cotton injury and delay in maturity (Byrd and York 1987; Guthrie and York 1989). However, MSMA applied PD to glyphosate-resistant and conventional cotton varieties is still widely used because of the concern for boll abortion following glyphosate applications during reproductive development (Pline-Srnic et al. 2004). Growers also seek information regarding crop safety and the potential for mixing MSMA with glyphosate or glufosinate for improving PD weed control of species difficult to control with either glyphosate or glufosinate. Specifically, growers seek economical herbicide alternatives that can be mixed with glyphosate to improve control of *Ipomoea* spp., *Amaranthus* spp., and late-season flushes of browntop millet in glyphosate-resistant cotton (authors' personal observation).

Even though MSMA is not registered for tank mixtures with glyphosate or glufosinate, information is needed to determine whether MSMA improves weed control with glyphosate and glufosinate and whether MSMA is a compatible with glyphosate and glufosinate before a possible registration amendment can be explored. The objectives of this research were to investigate interactions between MSMA, glyphosate, and glufosinate mixtures on control of broadleaf and grass weed species.

Materials and Methods

Field Study. An experiment was conducted in 2003 at the Southern Weed Science Research Unit farm near Stoneville, MS (33°N) and the Northeast Research Station located near St. Joseph, LA (31°N). Soil at the Mississippi location was a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs) with 1.1% organic matter and pH 7.0. Soil at the Louisiana location was a Mhoon silt loam soil (fine-silty, mixed nonacid, thermic Typic Fluvaquent) with 0.75% organic matter and pH 5.8. The field at Stoneville was disked twice in the fall of 2002, cultivated with an S-tine cultivator and rolling-basket harrows in March 2003, and existing vegetation was controlled with glyphosate[1] at 0.84 kg ae/ha on May 10, 2003. The field at St. Joseph was treated with 0.84 kg/ha glyphosate[1] in late March 2003, followed by disking twice, and development of 100-cm-wide beds in mid-April 2003.

The experimental design was a randomized complete block with four treatment replications. Plot size was 4 m wide and 12 m long. Treatments included no herbicide, glyphosate[1] at 0.84 kg ae/ha, glufosinate[2] at 0.5 kg ai/ha, MSMA[3] at 2.2 kg ai/ha, glyphosate (0.84 kg/ha) plus MSMA (2.2 kg/ha), and glufosinate (0.5 kg/ha) plus MSMA (2.2 kg/ha). A nonionic surfactant[4] was added at 0.25% v/v to all treatments containing MSMA. Treatments were applied on May 28, 2003, in Mississippi and in Louisiana to weeds 7 to 10 cm tall and in the one- to three-leaf growth stage. Existing populations of hemp sesbania, pitted morningglory, and ivyleaf morningglory were present in experiments at both locations. Redroot pigweed was also present in the Louisiana experiment; whereas velvetleaf, johnsongrass, barnyardgrass, and prickly sida were also present in the Mississippi experiment. Treatments were applied with a tractor-mounted sprayer using 8004 standard flat-fan spray nozzles[5] delivering 187 L/ha water at 180 kPa.

Percentage of control of weeds was estimated visually 2 wk after treatment (WAT) at both locations. Control ranged from 0 to 100%, where 0 indicates no control and 100 indicates death (Frans et al. 1986). Visual estimates were based on foliar chlorosis, necrosis, and plant stunting.

Greenhouse Study. An experiment was conducted in greenhouse facilities of the USDA-ARS Southern Weed Science Research Unit, Stoneville, MS, and the Crop Science Department of North Carolina State University, Raleigh, NC. Seeds of browntop millet and palmer amaranth were planted in 9-cm-diam pots containing a mixture of soil and potting soil[6] (1:1 v/v). The soil used at Stoneville was a Bosket sandy loam (fine-loamy, mixed thermic Molic Hapludalfs). The soil used at Raleigh was a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults). A second planting of

Table 1. Visual control of hemp sesbania (SEBEX), redroot pigweed (AMARE), pitted morningglory (IPOLA), and ivyleaf morningglory (IPOHE) at 2 wk after treatment with glyphosate, glufosinate, and MSMA tank mixtures in Louisiana field experiment.[a,b]

Herbicide[c]	Activity ae	Activity ai	SEBEX	AMARE	IPOLA	IPOHE
	kg/ha		%			
Glyphosate	0.84		48	94	90	95
Glufosinate		0.5	58	70	94	95
MSMA		2.2	39	76	89	95
Glyphosate + MSMA	0.84 + 2.2		58 (69)	86 (99)	95 (99)	95 (99)
Glufosinate + MSMA	0.5 + 2.2		40 (75)	53 (93)	88 (99)	91 (99)
LSD (0.05)			10	8	10	NS

[a] Weeds were 7 to 10 cm tall at time of application.

[b] Means within parenthesis are expected control values of the adjacent observed control. Expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value. NS, nonsignificant.

[c] Herbicides were applied at 140 L/ha, and a nonionic surfactant (0.25% v/v) was added to MSMA treatments.

browntop millet was done so that different growth stages at time of application could be evaluated. Plants were grown in a greenhouse with 32/25 C (± 3 C) day/night temperatures. Natural light was supplemented with light from sodium vapor lamps to provide a 14-h photoperiod. After emergence, plants were thinned to one plant per pot. Pots were subirrigated as needed.

Herbicide treatments consisted of 0.5×, 1×, and 2× rates of glyphosate,[1] glufosinate,[2] and MSMA[3] applied alone and in tank mixture with one another. Treatments were glyphosate at 0, 0.42, 0.84, and 1.68 kg/ha; glufosinate at 0, 0.25, 0.5, and 1.0 kg/ha; MSMA at 1.1, 2.2, and 4.4 kg/ha; glyphosate plus glufosinate at 0 + 0, 0.42 + 0.25, 0.84 + 0.5, and 1.68 + 1.0 kg/ha; glyphosate plus MSMA at 0 + 0, 0.42 + 1.1, 0.84 + 2.2, and 1.68 + 4.4 kg/ha; and glufosinate plus MSMA at 0 + 0, 0.25 + 1.1, 0.5 + 2.2, and 1.0 + 4.4 kg/ha. A nonionic surfactant[4] was added at 0.25% (v/v) to all treatments containing MSMA as suggested by the manufacturer. Additional treatments of 0.84 kg/ha glyphosate and 0.5 kg/ha glufosinate plus surfactant were included to determine the effects of surfactant on glyphosate efficacy.

Treatments were applied to browntop millet and Palmer amaranth in the four-leaf growth stage. Treatments were also applied 2 wk later to a second set of tillered browntop millet plants that were in the seven-leaf growth stage and had two tillers approximately 8 cm in height. Treatments were applied using an air-pressurized indoor spray chamber equipped with an 8002E flat-fan nozzle[5] calibrated to deliver a spray volume of 190 L/ha at 140 kPa. After spraying, plants were returned immediately to the greenhouse. Percentage control was visually assessed 2 WAT in the same manner as in the field study described previously.

The experimental design was a randomized complete block with a factorial arrangement of treatments. Factors were herbicide combination and herbicide rate. Treatments were replicated four times, and the experiment was repeated. Applying treatments several weeks apart to browntop millet in different growth stages resulted in treating browntop millet in different growth stages as separate experiments.

Statistical Analysis. Data were subjected to arcsine square-root transformations. Interpretations were not different from nontransformed data; therefore, nontransformed data are presented. Nontreated control data of all studies were deleted before statistical analysis to stabilize variance. The method described by Colby (1967) was used to calculate the expected response for herbicide combinations. To determine the potential for interaction, expected and observed values were compared at the 0.05 level of significance using Fisher's protected LSD calculated for the observed data (Hicks et al. 1998; Wehtje and Walker 1997). If the observed response of an herbicide combination was either significantly lower or greater than the expected value, the combination was declared antagonistic or synergistic, respectively. Combinations were considered to be additive (no interaction) when the observed and expected responses were similar. Data were subjected to ANOVA using the general linear models procedure in SAS (SAS 2001). Means were separated using Fisher's protected LSD test at $P \leq 0.05$.

Results and Discussion

Field Study. Data from each location are presented separately because of significant location-by-herbicide treatment interaction and different weed species present at each location.

Louisiana. Glyphosate and glufosinate provided similar levels of control of pitted morningglory and ivyleaf morningglory (Table 1). Glufosinate controlled hemp sesbania better than glyphosate. Glyphosate was more efficacious than glufosinate on redroot pigweed. Incomplete control of *Amaranthus* spp. with glufosinate has been reported previously (Jones et al. 2001; Steckel et al. 1997a, 1997b; Tharp and Kells 2002). Environmental conditions and application rate influence glufosinate efficacy (Mersey et al. 1990; Steckel et al. 1997a; Van Wychen et al. 1999). Absorption and metabolism of ^{14}C-glufosinate is slowed with decreasing environmental temperature (Pline et al. 1999). MSMA provided similar levels of control of pitted morningglory and ivyleaf morningglory compared with glyphosate and glufosinate. Control of redroot pigweed and hemp sesbania was higher with glyphosate and glufosinate, respectively, than with MSMA. The addition of MSMA to glyphosate and glufosinate antagonized control of

Table 2. Visual control of hemp sesbania (SEBEX), pitted morningglory (IPOLA), ivyleaf morningglory (IPOHE), velvetleaf (ABUTH), seedling johnsongrass (SORHA), barnyardgrass (ECHCG), and prickly sida (SIDSP) at 2 wk after treatment with glyphosate, glufosinate, and MSMA tank mixtures in Mississippi field experiment.[a,b]

	Activity								
Herbicide[c]	ae	ai	SEBEX	IPOLA	IPOHE	ABUTH	SORHA	ECHCG	SIDSP
	kg/ha		%						
Glyphosate	0.84		41	51	61	90	99	99	95
Glufosinate		0.5	95	90	92	84	92	92	96
MSMA		2.2	21	52	50	10	68	0	10
Glyphosate + MSMA	0.84 + 2.2		47 (56)	78 (77)	82 (80)	88 (91)	95 (99)	90 (99)	95 (95)
Glufosinate + MSMA	0.5 + 2.2		92 (99)	90 (95)	81 (96)	67 (85)	91 (97)	90 (92)	90 (96)
LSD (0.05)			6	8	7	8	5	3	2

[a] Weeds were 7 to 10 cm tall at time of application.

[b] Means within parenthesis are expected control values of the adjacent observed control. Expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[c] Herbicides were applied at 140 L/ha, and a nonionic surfactant (0.25% v/v) was added to MSMA treatments.

hemp sesbania and redroot pigweed compared with glyphosate or glufosinate alone. MSMA also antagonized glufosinate control of pitted morningglory.

Mississippi. Glufosinate controlled hemp sesbania, pitted morningglory, and ivyleaf morningglory better than glyphosate (Table 2). Variable and limited control of hemp sesbania and *Ipomoea* spp. with glyphosate have been reported previously (Jordan et al. 1997; Koger et al. 2004; Koger et al. 2005; Shaw and Arnold 2002). Inadequate control of pitted morningglory with glyphosate may be attributed to limited absorption of glyphosate through the plant cuticle (Norsworthy et al. 2001). Levels of control of velvetleaf, johnsongrass, barnyardgrass, and prickly sida were similar between glyphosate and glufosinate. Glyphosate and glufosinate were more efficacious on all species, except pitted morningglory, than MSMA. Glyphosate and MSMA provided similar and less control of pitted morningglory than glufosinate. Mixing MSMA with glyphosate antagonized control of hemp sesbania and barnyardgrass compared with glyphosate alone. The addition of MSMA to glufosinate antagonized control of all weed species except pitted morningglory and barnyardgrass.

Table 3. Visual control of four-leaf browntop millet at 2 wk after treatment with 0.5×, 1×, and 2× rates of glyphosate, glufosinate, and MSMA tank mixtures, averaged across greenhouse experiments conducted in North Carolina and Mississippi.

	Herbicide rate[a,b]			
Herbicide[c]	0.5×	1×	2×	Mean
	%			
Glyphosate	89	95	100	95
Glufosinate	68	98	98	88
MSMA	29	41	62	44
Glyphosate + glufosinate	86 (96)	99 (99)	98 (99)	94
Glyphosate + MSMA	63 (93)	74 (98)	69 (99)	69
Glufosinate + MSMA	51 (77)	77 (99)	91 (99)	73
Mean	65	81	86	
LSD (0.05) for herbicide		7		
LSD (0.05) for herbicide rate		5		
LSD (0.05) for herbicide × herbicide rate		12		

[a] Glyphosate rates of 0.5×, 1×, and 2× were 0.42, 0.84, and 1.68 kg ae/ha; 0.5×, 1×, and 2× rates of glufosinate were 0.25, 0.5, and 1 kg ai/ha; 0.5×, 1×, and 2× rates of MSMA were 1.1, 2.2, and 4.4 kg ai/ha.

[b] Means within parenthesis are expected control values of the adjacent observed control. Expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[c] Herbicides were applied at 140 L/ha, and a nonionic surfactant (0.25% v/v) was added to MSMA treatments.

Greenhouse Study. Data were averaged across experiments because there was no significant experiment-by-treatment interaction or experiment effect. Glyphosate was more efficacious on four-leaf and tillered browntop millet than glufosinate at the 0.5× rates of both herbicides (Tables 3 and 4). At 1× rates, glyphosate and glufosinate provided similar levels of control of four-leaf and tillered browntop millet. Glyphosate and glufosinate provided better control of four-leaf and tillered browntop millet than MSMA at all rates. Mixing glufosinate with glyphosate was antagonistic on control of tillered browntop millet when compared with glyphosate alone at the 0.5× rate. MSMA antagonized control of four-leaf and tillered browntop millet with glyphosate across all rates. Glufosinate efficacy on four-leaf and tillered browntop millet was antagonized by the addition of MSMA at the 0.5× and 1× rates. MSMA antagonism of glyphosate was overcome by applying the 2× rate of glufosinate.

Glyphosate controlled Palmer amaranth better than glufosinate at the 0.5× rates of each herbicide (Table 5). Glyphosate and glufosinate were similar with respect to efficacy on Palmer amaranth at the 1× and 2× rates. Glyphosate and glufosinate controlled Palmer amaranth better than MSMA across all rates. Mixing glyphosate and glufosinate antagonized control of Palmer amaranth when compared with glyphosate alone at the 0.5× and 1× rates and glufosinate alone at the 1× rate. MSMA antagonized efficacy of glyphosate and glufosinate on Palmer amaranth at the 0.5× and 1× rates. Antagonism of glyphosate and glufosinate by MSMA was overcome by applying the 2× rates of each herbicide.

Overall, glyphosate and glufosinate provided similar levels of control for most weed species and were often more

Table 4. Visual control of tillered browntop millet at 2 wk after treatment with 0.5×, 1×, and 2× rates of glyphosate, glufosinate, and MSMA tank mixtures, averaged across greenhouse experiments conducted in North Carolina and Mississippi.[a]

Herbicide[c]	Herbicide rate[b] 0.5×	1×	2×	Mean
	%			
Glyphosate	91	100	99	96
Glufosinate	68	94	99	86
MSMA	23	38	46	35
Glyphosate + glufosinate	70 (97)	91 (99)	99 (99)	
Glyphosate + MSMA	25 (93)	79 (99)	79 (99)	
Glufosinate + MSMA	35 (75)	64 (96)	94 (99)	
Mean	52	78	86	
LSD (0.05) for herbicide		11		
LSD (0.05) for herbicide rate		7		
LSD (0.05) for herbicide × herbicide rate		18		

[a] Means within parenthesis are expected control values of the adjacent observed control. Expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[b] 0.5×, 1×, and 2× rates of glyphosate were 0.42, 0.84, and 1.68 kg ae/ha; 0.5×, 1×, and 2× rates of glufosinate were 0.25, 0.5, and 1 kg ai/ha; and 0.5×, 1×, and 2× rates of MSMA were 1.1, 2.2, and 4.4 kg ai/ha.

[c] Herbicides were applied at 140 L/ha, and a nonionic surfactant (0.25% v/v) was added to MSMA treatments.

Table 5. Visual control of four-leaf palmer amaranth at 2 wk after treatment with 0.5×, 1×, and 2× rates of glyphosate, glufosinate, and MSMA tank mixtures, averaged across greenhouse experiments conducted in North Carolina and Mississippi.

Herbicide[c]	Herbicide rate[a,b] 0.5×	1×	2×	Mean
	%			
Glyphosate	93	98	100	97
Glufosinate	74	88	91	84
MSMA	41	58	72	57
Glyphosate + glufosinate	66 (98)	54 (99)	94 (99)	72
Glyphosate + MSMA	58 (96)	77 (99)	84 (99)	74
Glufosinate + MSMA	52 (84)	70 (94)	83 (98)	68
Mean	64	74	87	
LSD (0.05) for herbicide			9	
LSD (0.05) for herbicide rate			6	
LSD (0.05) for herbicide × herbicide rate			15	

[a] Glyphosate rate of 0.5×, 1×, and 2× were 0.42, 0.84, and 1.68 kg ae/ha; 0.5×, 1×, and 2× rates of glufosinate were 0.25, 0.5, and 1 kg ai/ha; 0.5×, 1×, and 2× rates of MSMA were 1.1, 2.2, and 4.4 kg ai/ha.

[b] Means within parenthesis are expected control values of the adjacent observed control. Expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[c] Herbicides were applied at 140 L/ha and a nonionic surfactant (0.25% v/v) was added to MSMA treatments.

efficacious than MSMA alone. In the field, glyphosate controlled redroot pigweed better than glufosinate, and glufosinate controlled hemp sesbania, pitted morningglory, and ivyleaf morningglory better than glyphosate at one location. Mixing glyphosate and glufosinate at the 0.5× rates resulted in antagonism of browntop millet and Palmer amaranth compared with applying the herbicides alone. MSMA antagonized glyphosate and glufosinate efficacy on several broadleaf and grass weed species both in the field and greenhouse. Often times, the antagonism could be overcome by applying an increased or 2× rate of either herbicide alone.

Antagonism of glyphosate by glufosinate may be attributed to the quicker activity of glufosinate compared with glyphosate. Glufosinate controls plants within 24 to 48 h after treatment (Wendler et al. 1990); whereas, glyphosate is a slower-acting herbicide than glufosinate, and phytotoxic symptoms develop within 4 to 7 d after treatment. The quicker activity from glufosinate may have hindered the full activity of glyphosate. Mixing certain chemicals or herbicides with glyphosate has been shown to affect glyphosate efficacy. Absorption of glyphosate into glyphosate-resistant soybean plants was reduced with the addition of pelargonic acid, a naturally occurring nine-carbon fatty acid that causes extremely rapid and nonselective desiccation of plant tissue (Pline et al. 1999). The addition of oxyfluorfen to glyphosate decreased absorption of ^{14}C-glyphosate in yellow nutsedge (*Cyperus esculentus* L.) plants (Pereira and Crabtree 1986). Fomesafen has been shown to decrease absorption and translocation of ^{14}C-glyphosate in barnyardgrass, pitted morningglory, and velvetleaf (Starke and Oliver 1998). DSMA, a herbicide similar to MSMA, has been shown to antagonize asulam activity on johnsongrass (Richard and Griffin 1993).

Mixing glyphosate with glufosinate is a compatible tank mixture for weed control in glufosinate-resistant cotton because efficacy of glufosinate was not antagonized when mixed with glyphosate. Glyphosate is a registered POST-directed tank-mixture partner with glufosinate in glufosinate-resistant cotton (CDMS 2007). MSMA often antagonized efficacy of glyphosate and glufosinate on several broadleaf and grass weeds. Thus, MSMA is not compatible in tank mixtures with either glyphosate or glufosinate. The mode of action of MSMA is not well known; however, MSMA does cause cell disruption where it comes in contact with susceptible plant material (Duke 1992). Herbicides that cause cell disruption reduce the absorption and translocation of other herbicides applied in mixture (Croon et al. 1989; Culpepper et al. 1999; Olson 1982; Pereira and Crabtree 1986). Studies are needed to examine the absorption and translocation of glyphosate and glufosinate applied alone and in mixture with MSMA to determine the cause of the observed antagonism.

Sources of Materials

[1] Roundup WEATHERMAX™, Monsanto Company, 800 North Linbergh Boulevard, St. Louis, MO 63167.

[2] Ignite® Herbicide, Bayer CropScience, P.O. Box 12014, 2 T. W. Alexander Drive, Research Triangle Park, NC 27709

[3] MSMA 6 Plus, Loveland Products Inc., P.O. Box 1286, Greeley, CO 80632.

[4] Induce® nonionic low-foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylaryl and alcohol ethoxylate surfactants) and fatty acids and 10% water. Helena Chemical Company, Suite 500, 6075 Popular Avenue, Memphis, TN 38119.

[5] TeeJet, P.O. Box 7900, Wheaton, IL 60189-7900.
[6] Jiffy mix, Jiffy Products of America Inc., Batavia, IL 60510.

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