Original Research Article

Influence of Water Quality and Ammonium Sulfate on Glyphosate Efficacy

ABSTRACT

Aims. The objectives of these studies were to 1) determine west Texas water hardness values, 2) determine if glyphosate efficacy is affected by water carrier source, 3) determine if there is a benefit using reverse osmosis water as the carrier when applying glyphosate, and 4) determine if ammonium sulfate will improve glyphosate control regardless of water quality.
Study design. All trials were arranged in a randomized complete block design.
Place and duration of study. Four studies were conducted in 2012 near Lubbock, TX, two using winter wheat (*Triticum aestivum* L.) and two using Palmer amaranth (*Amaranthus palmeri* S. Wats.) as the target species. Two winter wheat studies also were conducted in 2013 near Lubbock, TX.
Methodology. Water from five pre-selected sources, ranging in total water hardness from 185 to 1046 ppm plus an RO water source (11 ppm), was used as carriers for the following four herbicide treatments: glyphosate applied at 430 and 860 g ae ha^{-1} with and without dry ammonium sulfate. The rate of AMS was 2 kg 100 L^{-1} of water.
Results. West Texas water hardness values were highly variable, ranging from 91 to 1046 ppm. Water source affected glyphosate control in seven of the ten assessments over six trials conducted in two years. The reverse osmosis water source (11 ppm) was the top performing water source or was in the top performing group of sources in five of six assessments where water source impacted results. However, in several instances, water sources with cation concentrations over 800 ppm also were in the top performing group of water sources.
Conclusion. In all assessments, glyphosate at 860 g ae ha^{-1} and ammonium sulfate improved glyphosate efficacy, regardless of plant species tested. Continued work needs to be conducted in order to further evaluate the use of reverse osmosis water as a spray carrier for glyphosate.

Keywords: Reverse osmosis, hard water, antagonism, cations.

1. INTRODUCTION

The quality of water used as the spray carrier can play an important role in herbicide performance, especially for weak acid herbicides such as glyphosate. Glyphosate antagonism caused by hard water (water containing cations) has been well-documented in a number of weed species. Cations that create complexes with glyphosate and ultimately decrease its effectiveness include aluminum, calcium, iron, magnesium, potassium, and zinc [1-12].

Hard water antagonism of glyphosate often can be overcome by increasing the glyphosate rate, decreasing the carrier volume [4,5,11,13-16], acidifying the spray solution [5,9], and/or adding a strong chelator or water conditioner [1,8,9,13,14,18,19]. Additionally, some growers in west Texas have been using reverse osmosis (RO) water as a spray carrier to prevent potential antagonism of glyphosate due to poor water quality. However, no studies documenting the benefit of RO water as the carrier for glyphosate have been reported. To better understand the relationship between water quality and glyphosate efficacy in west Texas, research was conducted to: 1) determine west Texas water hardness values, 2) determine if glyphosate efficacy is affected by water carrier source, 3) determine if there is a benefit using RO water as the carrier when applying glyphosate, and 4) determine if ammonium sulfate (AMS) will improve glyphosate control regardless of water quality.

2. MATERIAL AND METHODS

2.1 WATER COLLECTION AND EXPERIMENTAL SITE. In the fall of 2011, water from 23 on-farm wells in 14 counties in west Texas was collected (Table 1). The water was stored in the dark at room temperature in sealed five gallon, 0.70 milliliter polyethylene buckets. Water samples were analyzed by A&L Plains Agricultural Laboratories (Lubbock, TX) for concentrations of calcium, magnesium, sodium, manganese, iron, and zinc. Water from five of the 23 sources, with cation concentrations of 185 to 1046 ppm, was used as carriers in six field trials conducted in 2012 and 2013 near the Texas A&M AgriLife Research and Extension Center (33.415°N, -101.483°W, 1,001 m elevation) in Lubbock, TX. An RO water source, collected from a greenhouse at the Texas A&M AgriLife Research and Extension Center, also was included. It had a total cation concentration of 11 ppm (Table 1).

Table 1. Twenty three water sources collected from 14 counties in west Texas, including the six water sources selected to evaluate.

Water Sample ID	Ca^{2+}	Mg^{2+}	Na^{+}	Mn^{2+}	Fe^{2+}	Zn^{2+}	Total Water Hardness
	ppm						
*Reverse Osmosis	< 0.01	< 0.01	11	< 0.01	< 0.01	< 0.01	11
Bailey County I	41	33	30	<0.01	<0.01	0.03	104
Bailey County II	86	98	40	<0.01	<0.01	0.01	224
Castro County	46	27	24	<0.01	<0.01	0.2	97
Collingsworth County	93	17	138	<0.01	<0.01	0.03	248
Crosby County	60	51	37	<0.01	<0.01	0.06	148
Dawson County I	133	224	103	<0.01	<0.01	0.01	460
*Dawson County II	150	197	171	<0.01	0.78	0.02	519
Gaines County I	55	28	39	<0.01	<0.01	0.02	122
Gaines County II	49	58	63	<0.01	<0.01	0.02	170
*Garza County I	144	180	480	0.02	0.05	0.06	804
*Garza County II	160	229	656	0.04	0.46	0.01	1046
Hale County	26	33	32	<0.01	<0.01	0.01	91
Hockley County I	66	81	99	<0.01	<0.01	0.01	246
Hockley County II	54	54	57	<0.01	<0.01	0.27	165
Lubbock County I	50	55	86	<0.01	<0.01	0.04	191
*Lubbock County II	54	63	68	<0.01	<0.01	0.04	185
Parmer County	30	27	49	<0.01	<0.01	0.18	106
*Reeves County	118	35	686	<0.01	<0.01	0.03	839
Swisher County I	30	29	51	<0.01	<0.01	<0.01	110

Swisher County II	53	37	26	<0.01	<0.01	0.2	116
Terry County I	49	68	126	<0.01	0.09	0.02	243
Terry County II	32	57	163	<0.01	<0.01	0.02	252
Yoakum County	72	20	34	<0.01	<0.01	0.02	126

*Selected water source.

2.2 EXPERIMENTAL DESIGN AND DATA COLLECTION. Four studies were conducted in 2012 in Lubbock, TX, two using winter wheat (*Triticum aestivum* L.) and two using Palmer amaranth (*Amaranthus palmeri* S. Wats.) as the target species. In 2012, at time of application, winter wheat plants were 15 or 20 cm in height, trials 1 and 2, respectively. Palmer amaranth plants were 61 and 105 cm at the time of application in 2012, trials 5 and 6, respectively. Two winter wheat studies also were conducted in 2013 in Lubbock, TX. Winter wheat plants at the time of application in 2013 were 20 and 30 cm tall, trials 3 and 4, respectively. For winter wheat trials, 'TAM 111' [20] was planted with a standard Tye grain drill with 25 cm row spacing on September 9, 2011 and on September 19, 2012 at a density of 56 kg ha^{-1}. Natural populations of glyphosate-susceptible Palmer amaranth were used from non-crop, rain-fed areas that contained emergence densities estimated at 100 plants m^{-2}. The soil type was an Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs). All studies were arranged in a randomized complete block design with four replications. Each replication was 21.3 by 24.4 m and each plot was 3.0 by 6.1 m.

Water from five pre-selected sources, ranging in total water hardness from 185 to 1046 ppm plus an RO water source (11 ppm), was used as carriers for the following four herbicide treatments: glyphosate, in the form of its potassium salt, (Roundup PowerMAX herbicide, Monsanto Company, St. Louis, MO) was applied at 430 and 860 g ae ha^{-1} with and without dry AMS. The rate of AMS was 2 kg 100 L^{-1} of water. When mixing, three liter bottles were filled with 1.5 liters of water. Next, if the treatment included AMS, dry AMS was dissolved in the water. Glyphosate was then added followed by additional water needed to bring the total mix size to three liters. All applications were made with a CO_2-pressurized backpack sprayer equipped with TT110015-VP Turbo TeeJet Wide Angle Flat Spray Tips calibrated to deliver 94 L ha^{-1} at 165 kPa. Nontreated checks did not receive a herbicide application. In 2012, trials 1 (15 cm wheat), 2 (20 cm wheat), 5 (61 cm Palmer amaranth), and 6 (105 cm Palmer amaranth) were sprayed March 13, April 10, August 30, and September 10, respectively. In 2013, trials 3 (20 cm wheat) and 4 (30 cm wheat) were sprayed March 29 and April 15, respectively. Winter wheat control was rated 21 and 28 days after treatment. Palmer amaranth control was rated 14 and 21 days after treatment using a scale of 0 to 100 percent, where 0 was no control and 100 was complete control (Frans et al. 1986). Foliar chlorosis, necrosis, tissue distortion, and plant stunting were considered when determining visual estimates.

2.3 STATISTICAL ANALYSIS. A univariate analysis was performed on all responses in order to test for stable variance. No datasets were transformed as transformation did not increase stabilization. Data sets were analyzed using PROC MIXED with pdmix 800 macro included [21] and treatments were separated by Fisher's Protected LSD at an alpha level of 0.05 using SAS 9.4 software (SAS Institute Inc., SAS Campus Drive, Cary, North Carolina 27513).

3. RESULTS AND DISCUSSION

Winter wheat trials 2 and 3 were averaged over year due to no significant year effect (P = 0.05); however, all other trials were analyzed independently. No two-way or three way-interactions were significant; therefore, main effects were pooled over all other factors and are discussed below.

3.1 2012 – TRIAL 1 (15 CM WINTER WHEAT). Water source, glyphosate rate, and AMS affected control of 15 cm winter wheat (Table 2). In general, control of winter wheat was similar for all water sources; however, RO (11 ppm), Lubbock (185 ppm), and Reeves (839 ppm) water sources were more effective in controlling winter wheat compared to Garza I (804 ppm) and Garza II (1046) water sources. Winter wheat control following glyphosate treatments ranged from 75 to 80% and was similar for all water sources when evaluated 21 DAT (Table 2). Glyphosate at 860 g ae ha^{-1} plus AMS improved control from 66 to 86% and from 72 to 85%, respectively. At 28 DAT, winter wheat control was 81 to 85% and was similar for all water sources. The greater glyphosate rate and AMS improved control from 73 to 93% and from 76 to 90%, respectively.

3.2 2012/2013 – TRIALS 2 and 3 (20 CM WINTER WHEAT). Water source, glyphosate rate, and AMS affected control of 20 cm winter wheat when averaged across trials 2 and 3 21 DAT (Table 2). Winter wheat control was most effective (80%) when the Lubbock II water source (185 ppm) was used as the carrier compared to when the RO (11 ppm) and Garza II (1046 ppm) water sources were used (73 to 74%). Glyphosate at 860 g ae ha^{-1} plus AMS improved control from 64 to 90% and from 69 to 85%, respectively. At 28 DAT, winter wheat control was 78 to 84% and was similar across all water sources. The greater glyphosate rate AMS improved control from 69 to 94% and from 74 to 90%, respectively.

3.3 2013 – TRIAL 4 (30 CM WINTER WHEAT). At 21 DAT, the greatest winter wheat control (70%) was observed when the RO water source (11 ppm) was used as the carrier while control was less for all other water sources (44 to 57%, Table 2). Glyphosate rate and AMS improved winter wheat control from 29 to 78% and from 43 to 66%, respectively. At 28 DAT, water source, glyphosate rate, and AMS affected control. Winter wheat control ranged from 51 to 60% for all water sources and was similar with the exception of the RO source (11 ppm), which controlled winter wheat the greatest (72%). The greater glyphosate rate and AMS improved control from 34 to 83% and from 50 and 67%, respectively.

Table 2. Effects of water source, glyphosate rate, and ammonium sulfate on winter wheat control in 2012 and 2013 in Lubbock, TX.

Factor		Winter wheat control					
		2012 (15 cm)		2012/2013 (20 cm)		2013 (30 cm)	
		21 DAT[a]	28 DAT	21 DAT	28 DAT	21 DAT	28 DAT
		%					
Water source (water hardness)	RO (11 ppm)	80 ab	85	74 b	80	70 a	72 a
	Lubbock II (185 ppm)	80 ab	84	80 a	84	52 bc	60 b
	Dawson II (519 ppm)	79 abc	82	78 ab	82	44 c	55 b
	Garza I (804 ppm)	76 bc	82	77 ab	83	52 bc	55 b
	Reeves (839 ppm)	80 a	84	78 ab	83	57 b	58 b
	Garza II (1046 ppm)	75 c	81	73 b	78	46 bc	51 b
	P-value	.045	.245	.009	.141	.014	.011
Glyphosate rate g ae ha^{-1}	430	66 b	73 b	64 b	69 b	29 b	34 b
	860	90 a	93 a	90 a	94 a	78 a	83 a
	P-value	.003	.0004	.001	.001	< .0001	.0001
AMS kg 100 L^{-1}	0	72 b	76 b	69 b	74 b	43 b	50 b
	2	85 a	90 a	85 a	90 a	66 a	67 a
	P-value	.001	.001	.001	.001	.003	.004

[a]. Abbreviations: DAT, days after treatment; AMS, ammonium sulfate.

[b]. Water source means pooled over glyphosate rate or AMS for each observation date followed by the same lower case letter (a, b, c) are not significantly different from each other (P = .05).

3.4 2012 – TRIAL 5 (61 CM PALMER AMARANTH). Water source, glyphosate rate, and AMS affected Palmer amaranth control when evaluated 14 and 21 DAT (Table 3). The greatest Palmer amaranth control (85 to 90%) was observed when RO, Lubbock II, Dawson II, and Reeves water sources (11, 185, 519, and 839 ppm, respectively) were used as carriers and the poorest control (77 to 78%) was observed when the Garza I water source (804 ppm) was used as the carrier. The greater glyphosate rate and AMS improved control from 75 to 94% and from 77 to 92%, respectively, at 14 DAT and from 75 to 96% and from 78 to 93%, respectively, at 21 DAT.

3.5 2012 – TRIAL 6 (104 CM PALMER AMARANTH). Water source, glyphosate rate, and AMS affected the control of Palmer amaranth 14 DAT (Table 3). Palmer amaranth control was greatest with the least hard water sources, RO and Lubbock II water sources (11 and 185 ppm, respectively), when compared to all other water sources except one (the Reeves water source, 839 ppm). Palmer amaranth control for all other sources ranged from 21 to 24%. The greater glyphosate rate improved control from 12 to 45%, while AMS improved control from 23 to 33%. At 21 DAT, Palmer amaranth control ranged from 32 to 44% for all water sources while glyphosate rate and AMS continued to positively affect control. The greater glyphosate rate and AMS improved control from 24 to 54% and from 34 to 44%, respectively.

Table 3. Effects of water source, glyphosate rate, and ammonium sulfate on Palmer amaranth control in 2012 and 2013 in Lubbock, TX.

Factor		Palmer amaranth			
		2012 (61 cm)		2013 (104 cm)	
		14 DAT[a]	21 DAT	14 DAT	21 DAT
		%			
Water source (water hardness)	RO (11 ppm)	86 ab	90 a	37 a	42
	Lubbock II (185 ppm)	89 ab	88 ab	37 a	44
	Dawson II (519 ppm)	90 a	88 ab	21 b	33
	Garza I (804 ppm)	77 c	78 c	24 b	32
	Reeves (839 ppm)	85 ab	86 ab	28 ab	38
	Garza II (1046 ppm)	80 bc	83 bc	23 b	44
	P-value	.023	.022	.012	.053
Glyphosate rate g ae ha^{-1}	430	75 b	75 b	12 b	24 b
	860	94 a	96 a	45 a	54 a
	P-value	.006	.006	< .0001	.004
AMS kg 100 L^{-1}	0	77 b	78 b	23 b	34 b
	2	92 a	93 a	33 a	44 a
	P-value	.0002	.002	.0003	< .0001

[a]Abbreviations: DAT, days after treatment; RO, reverse osmosis; AMS, ammonium sulfate.

[b]Water source means pooled over glyphosate rate or AMS for each observation date followed by the same lower case letter (a, b, c) are not significantly different from each other (P = .05).

Overall, west Texas water hardness values were highly variable, ranging from 91 to 1046 ppm. Water source affected glyphosate control in seven of the ten assessments over six trials conducted in two years. The RO water source (11 ppm) was the top performing water source or was in the top performing group of sources in five of the six, significant assessments. However, in several instances, water sources with cation concentrations over 800 ppm (Garza I and Reeves) also were in the top performing group of water sources.

In a greenhouse study conducted in Knoxville, TN, control and fresh weight of Palmer amaranth was not reduced until calcium and magnesium concentrations reached greater than 250 or equal to 500 ppm, respectively [22]. Additionally, Gurinderbir et al. [23] found that glyphosate efficacy was not affected by most water sources collected from various locations across North Carolina, when compared with deionized water, although the response was inconsistent across weed species. Weed species included cereal rye (*Secale cereale* L.), common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.), goosegrass (*Eleusine indica* L.), Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (lam.) Husnot), large crabgrass (*Digitaria sanguinalis* L.), Palmer amaranth, tall morningglory (*Ipomoea purpurea* (L.) Roth), and wheat. Although total cation concentrations for the six selected water sources used in this study reached 1046 ppm, individual values for calcium and magnesium never exceeded 229 ppm. Inconsistencies in top performing water sources could have been a result of low and varying calcium, magnesium, and sodium concentrations. Conversely, effects of glyphosate rate and AMS were consistent. Glyphosate at 860 g ae ha^{-1} and AMS improved glyphosate efficacy, regardless of plant species tested.

4. CONCLUSION

Continued work needs to be conducted to further evaluate the use of RO water as a spray carrier for glyphosate; however, these studies do suggest that AMS can improve glyphosate efficacy when water quality is poor and even when it is not. Others have observed benefits of AMS that are not related to the offsetting of antagonistic salts [9, 24-28]. Furthermore, dry ammonium sulfate, which was used in these experiments, is a relatively inexpensive cost at around $1.10 per hectacre when used at the maximum suggested rate per the Roundup PowerMAX label (2 kg per 100 L of water) and might be a worthwhile investment for those applying glyphosate, especially when water is hard.

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