EFFECTS OF ADDITIVES ON GLYPHOSATE ACTIVITY IN PURPLE NUTSEDGE

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Abstract

Effects of additives on ^{14}C-glyphosate penetration into purple nutsedge leaves were examined in the laboratory. and efficacy of glyphosate for purple nutsedge control was studied in the greenhouse and field. The addition of $(NH_4)_2$ SO_4 at 1.0% (v/v) + diesel oil at 1.0% (v/v) + Tendal at 1.0% (v/v) increased ^{14}C-glyphosate penetration into nutsedge leaves more than the addition of either one alone. $(NH_4)_2SO_4$ at 1.0% + diesel oil at 1.0% + Tendal at 0.12 or 0.25% increased the phytotoxicity of glyphosate at 0.5 and 0.75 kg a.e./ha on nutsedge plants in the greenhouse but not in the field. Additives did not enhance glyphosate activity by reducing the number of nutsedge tubers.

1. INTRODUCTION

Purple nutsedge (*Cyperus rotundus*) was ranked as one of the most serious weeds in the world [1]. It is an important weed in corn, sorghum, soybean, mungbean, peanut, cotton, upland rice, and vegetables. Mechanical control of this weed is not successful because it can sprout new shoots from tubers. Various selective pre-emergence herbicides cannot control this weed.

Glyphosate is a non-selective, translocated, foliar applied herbicide [2]. Which has been reported to control purple nutsedge [3]. However. application of glyphosate for weed control is restricted by cost. Appropriate adjuvants or additives might be used in combination with glyphosate to maintain its optimum activity but at a reduced rate.

Ammonium sulfate has been reported to increase activity of glyphosate for purple nutsedge control [3]. Furthermore, calcium antagonism of glyphosate has been overcome with $(NH_4)_2SO_4$ [4, 5], citric acid, and an organosilicone adjuvant [6].

Various additives including nonionic surfactants [7], the organosilicone Silgard 309 [8], and both petroleum and seed oils [9] were reported to increase glyphosate activity. The organosilicone Silwet 77 enhanced ^{14}C-glyphosate uptake into bean (*Vicia faba*) leaf [10]. Furthermore, oils also increased glyphosate penetration [9].

The objectives of these experiments were to determine the effect of the various additives, $(NH_4)_2SO_4$, Tendal (surfactant), and diesel oil at appropriate concentrations on ^{14}C-glyphosate penetration into purple nutsedge leaves, and to determine the effect of additives on glyphosate efficacy for purple nutsedge control.

2. MATERIALS AND METHODS

2.1. Laboratory experiments

^{14}C-glyphosate and glyphosate at 1.5 kg a.e./ha with several additives in a spray volume of 200 L/ha were applied when the purple nutsedge plants were 5-6 leaves (approximately 2

weeks after planting). Eight drops of 0.5 µl 7.7 kBq (0.02 μCi) of ^{14}C-glyphosate were applied on the same leaf of each plant. Plants were harvested at 2 and 24 hours after application. Cellulose acetate (6.0%) in 9:1 acetone/water was painted on the ^{14}C-glyphosate treated area, 2 minutes after application, dried cellulose acetate was removed and mixed with 2 ml glacial acetic acid. Two hundred µL solution of cellulose acetate in glacial acetic acid was mixed with scintillation cocktail to determine the amount of ^{14}C-glyphosate by liquid scintillation spectrometry.

The additive, Sunlite®, is a local detergent. The surfactant, Tendal®, is a blend of 60% alkyl aryl polyethoxylate and sodium salt of dialkyl sulfosuccinate plus 40% solubilizer and couplers. Triton X-100® is dioctyl sulfonosuccinate, sodium salt. The herbicide, Roundup®. contains 36% a.e. glyphosate.

Experiments were carried out in a Randomized Complete Block Design with 6 replications. The temperature and relative humidity during application of first, second, and third experiments were 32°C, 65%, 30°C, 70% and 28°C, 80% respectively.

2.2. Greenhouse experiments

Three purple nutsedge tubers were planted in polyethylene pots containing clay soil. The pots were 14 cm. in diameter and 15 cm. high . Plants were watered from the surface every day. At 2 weeks after germination, glyphosate was applied alone and in combination with additives.

Herbicide was applied by laboratory sprayer at a spray volume of 200 L/ha and pressure of 87 kg /cm^2. The nozzle was a T-jet, flat fan No 8001. During application the temperature was 28°C with 75% relative humidity.

The number of nutsedge shoots and tubers in each pot were recorded at 21 and 60 days after application. The experiment was carried out in a Randomized Complete Block Design with 4 replications.

2.3. Field experiment

The field experiment was conducted at the National Corn and Sorghum Research Institute at Pakchong, Nakornrachima. Glyphosate at 0.5,0.75 and 1.5 kg a.e./ha was applied alone and in combination with various additives. The herbicide was applied when naturally grown purple nutsedge was at the 5–6 leaves stage or approximately 2 weeks after cultivation. Herbicide was applied either before 9 a.m. or after 4.p.m. The size of each treated plot was 5 × 5 m cropped and 5 × 3 uncropped. Corn was planted at 3 days after herbicide application.

At 1, 2, 4, and 8 weeks after application, a visual weed control rating was recorded. Dry weights of nutsedge plants were recorded at 4 and 8 weeks after application in the uncropped area. The number of nutsedge plants was recorded at 6 and 10 weeks after application in the uncropped area. The yield of corn, dry weight, and number of nutsedge plants in the cropped area were recorded at harvesting.

Experiments were carried out in a Randomized Complete Block Design with 4 replications. Herbicide was applied by knapsack sprayer, with a spray volume of 200 L/ha. The nozzle was

a T-jet, flat fan No 8001. The pressure was 87 kg/cm^2. The temperature before 9.0 a.m. was 27°C with 70% relative humidity and after 4.0 p.m. was 32 °C with 65% relative humidity.

3. RESULTS AND DISCUSSION

3.1. Laboratory experiments

Tendal + diesel oil + $(NH_4)_2SO_4$ greatly increased penetration of ^{14}C-glyphosate at 2 hours after application. The other treatments gave similar results but the increases were lower (Table 1)

TABLE 1. EFFECTS OF VARIOUS ADDITIVES ON ^{14}C-GLYPHOSATE PENETRATION INTO PURPLE NUTSEDGE LEAVES AT 2 HOURS AFTER APPLICATION

Treatment	% absorption
Glyphosate 1.5 kg a.e./ha $(NH_4)_2SO_4$ 1.0%	6.2 d[1]
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 0.25%	24.8 bcd
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 0.5%	35.2 abc
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 1.0%	26.5 bcd
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 2.0%	26.7 bcd
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 4.0%	29.9 bcd
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 0.25% + diesel oil 0.25%	15.5 cd
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 0.5% + diesel oil 0.5%	38.6 abc
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 1.0% + diesel oil 1.0%	58.0 a
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 2.0% + diesel oil 2.0%	39.6 abc
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 4.0% + diesel oil 4.0%	46.9 ab
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Triton X-100 1.0% + diesel oil 1.0%	47.4 ab

[1]Means in the same column followed by different letters are significantly different ($p < 0.05$).

TABLE 2. EFFECTS OF VARIOUS ADDITIVES ON ^{14}C-GLYPHOSATE PENETRATION INTO PURPLE NUTSEDGE LEAVES AT 24 HOURS AFTER APPLICATION

Treatment	% absorption
Glyphosate 1.5 kg a.e./ha	63.8 bc[1]
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0%	68.2 ab
Glyphosate 1.5 kg a.e./ha + Triton X-100 2.0%	66.2 b
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Triton X-100 2.0%	78.2 a
Glyphosate 1.5 kg a.e./ha + Trion x-100 2.0%+diesel oil 1.0%	66.3 b
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Triton X-100 2.0% + diesel oil 1.0%	72.7 ab
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Sunlite 4.0%	63.7 bc
Glyphosate 1.5 kg a.e./ha + Sunlite 4.0% + diesel oil 1.0%	54.5 c
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Sunlite 4.0% + diesel oil 1.0%	65.9 b

[1]Means in the same column followed by different letters are significantly different ($p < 0.05$).

At 24 hours after application, $(NH_4)_2SO_4$ alone increased ^{14}C-glyphosate penetration into purple nutsedge leaves but not Triton X-100 or Triton X-100 + oil (Table 2).

However, $(NH_4)_2SO_4$ in combination with Triton X-100 increased ^{14}C-glyphosate penetration into nutsedge leaves more than $(NH_4)_2SO_4$ or Triton X-100 alone or Triton X-100 + oil

(Table 2). $(NH_4)_2SO_4$ + Triton X-100 + oil increased ^{14}C-glyphosate penetration into nutsedge leaves to the same degree as $(NH_4)_2SO_4$ + Triton X-100 (Table 2). Sunlite in combination with $(NH_4)_2SO_4$ or diesel oil or both did not increase ^{14}C-glyphosate penetration into nutsedge leaves (Table 1).

At 2 hours after application, with the concentration of $(NH_4)_2SO_4$ at 1.0%, Tendal at 1.0% increased ^{14}C-glyphosate penetration more than Tendal at 0.5% (Table 3).

TABLE 3. EFFECTS OF $(NH_4)_2SO_4$, TENDAL, AND DIESEL OIL ON ^{14}C-GLYPHOSATE PENETRATION INTO PURPLE NUTSEDGE LEAVES AT 2 HOURS AFTER APPLICATION

Treatment	% absorption
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 0.5%	21.6 b[1]
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 1.0%	29.8 ab
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 1.0% + diesel oil 0.25%	19.5 b
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 1.0% + diesel oil 0.5%	25.7 b
Glyphosate 1.5 kg a.e./ha + $(NH_4)_2SO_4$ 1.0% + Tendal 1.0% + diesel oil 1.0%	42.4 a

[1]Means in the same column followed by different letters are significantly different ($p < 0.05$).

Furthermore, when the concentration of $(NH_4)_2SO_4$ was at 1.0% and Tendal was at 1.0%, oil at 1.0% increased ^{14}C-glyphosate penetration more than oil at 0.25 or 0.5% (Table 3).

The increase in ^{14}C-glyphosate penetration into nutsedge leaves when using $(NH_4)_2SO_4$ might be due to a change of the glyphosate molecule to a more readily absorbed form. NMR spectroscopy showed that NH_4^+ from $(NH_4)_2SO_4$ complexed directly with the glyphosate molecule through the phosphonate and carboxylate groups and resulted in a more readily absorbed form of glyphosate [5]. It was also found that a nonionic organosilicone adjuvant increased ^{14}C-glyphosate absorption into sunflower leaves However, the organosilicone adjuvant did not directly interact with glyphosate [6]. The organosilicone adjuvants might alter the physical properties of the spray solution or the leaf cuticle to the point where ^{14}C-glyphosate could readily penetrate the leaf.

Oils have seldom been tested with water soluble herbicides, although glyphosate efficacy against wheat was increased by both petroleum and seed oils The main action of adjuvant oils was increasing herbicide penetration but, the mechanisms involved are poorly understood [9].

3.2. Greenhouse experiment

At 7 days after application, $(NH_4)_2SO_4$ at 1.0% + oil 1.0% + Tendal at 0.12% or 0.25% increased nutsedge control by glyphosate at 0.75 kg a.e./ha . However, additives did not increase the activity of glyphosate at the higher rate (Table 4).

At 14 days after application, $(NH_4)_2SO_4$ at 1.0% + oil at 1.0% + Tendal at 0.12 or 0.25 or 1.0% increased the activity of glyphosate at 0.5 and 0.75 kg a.e./ha However, at 21 days after application, the additives increased activity of glyphosate only at 0.5 kg a.e./ha (Table 4).

TABLE 4. PURPLE NUTSEDGE CONTROL WITH GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES UNDER GREENHOUSE CONDITIONS

Glyphosate	$(NH_4)_2SO_4$	Diesel oil	Tendal	Days after application[1]			
(kg a.e./ha)	(% v/v)	(% v/v)	(% v/v)	4	7	14	21
0.5	-	-	–	18 d[2]	45 e	59 c	81 b
0.75	–	–	–	23 bcd	43 e	69 bc	83 a
1.5	–	–	–	28 a–d	65 abc	98 a	100 a
0.5	1	1	0.12	20 cd	45 e	89 a	93 ab
0.75	1	1	0.12	28 a–d	63 a–d	90 a	95 ab
1.5	1	1	0.12	35 ab	75 a	100 a	100 a
0.5	1	1	0.25	25 a–d	53 cde	83 ab	90 ab
0.75	1	1	0.25	30 abc	68 abc	95 a	100 a
1.5	1	1	0.25	33 abc	73 ab	99 a	100 a
0.5	1	1	1	23 bcd	58 b–c	79 ab	93 ab
0.75	1	1	1	25 a–d	48 d–e	82 ab	90 ab
1.5	1	1	1	38 a	73 ab	91 a	91 ab
Nontreated	–	–	–	0 e	0 f	0 d	0 c

[1]% Weed control ; 0 = no control, 100 = complete control.
[2]Means in the same column followed by different letters are significantly different ($p < 0.05$).

The additives increased glyphosate phytotoxicity on nutsedge plants, but dry weight and number of tubers were not affected (Table 5).

TABLE 5. EFFECT OF GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES ON DRY WEIGHT AND NUMBER OF PURPLE NUTSEDGE TUBERS UNDER GREENHOUSE CONDITIONS

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (% v/v)	Diesel oil (% v/v)	Tendal (% v/v)	Dry weight[1] (g/pot)	Number[2] of tubers/pot
0.5	–	–	–	0.43 b[3]	6 b
0.75	–	–	–	0.64 b	8 b
1.5	–	–	–	0.79 b	4 b
0.5	1	1	0.12	0.31 b	7 b
0.75	1	1	0.12	0.39 b	5 b
1.5	1	1	0.12	0.44 b	3 b
0.5	1	1	0.25	0.31 b	5 b
0.75	1	1	0.25	0.53 b	6 b
1.5	1	1	0.25	0.43 b	4 b
0.5	1	1	1	0.64 b	4 b
0.75	1	1	1	0.45 b	6 b
1.5	1	1	1	0.34 b	4 b
Nontreated	–	–	–	4.31 a	23 a

[1]At 21days after application.
[2]At 60 days after application.
[3]Means in the same column followed by different letters are significantly different ($p < 0.05$).

3.3. Field experiments

At 1, 2, and 4 weeks after application, all combinations of $(NH_4)_2SO_4$ + diesel oil and Tendal did not increase the control of nutsedge by glyphosate in either cropped or uncropped plots (Tables 6–8). However, the treatment which contained all the additives increased

TABLE 6. PURPLE NUTSEDGE CONTROL WITH GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES AT 1 WEEK AFTER APPLICATION

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (% v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	% Weed control[1] with corn	% Weed control[1] without corn	T-test
1.5	–	–	–	9.00 a.m.	53 ab[2]	53 ab	ns[3]
1.5	–	–	–	4.00 p.m.	60 a	60 a	ns
0.5	1	1	1	9.00 a.m.	43 b	43 b	ns
0.5	1	1	1	4.00 p.m.	41 b	41 b	ns
0.75	1	1	1	9.00 a.m.	48 ab	48 ab	ns
0.75	1	1	1	4.00 p.m.	41 b	41 b	ns
1.5	1	1	1	9.00 a.m.	59 a	59 a	ns
1.5	1	1	1	4.00 p.m.	40 b	40 b	ns
Weeded	–	–	–	–	0c	0c	ns
Nonweeded	–	–	–	–	0c	0c	ns

[1]% weed control ; 0 = no control, 100 = complete control.
[2]Means in the same column followed by different letters are significantly different ($p < 0.05$).
[3]Comparison of means within the same line; ns = not significantly different ($p > 0.05$).

TABLE 7. PURPLE NUTSEDGE CONTROL WITH GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES AT 2 WEEKS AFTER APPLICATION

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (% v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	% Weed control[1] with corn	% Weed control[1] without corn	T-test
1.5	–	–	–	9.00 a.m.	63 bc[2]	63 bc	ns[3]
1.5	–	–	–	4.00 p.m.	74 b	71 b	ns
0.5	1	1	1	9.00 a.m.	43 d	41 e	ns
0.5	1	1	1	4.00 p.m.	44 d	45 de	ns
0.75	1	1	1	9.00 a.m.	50 cd	48 cde	ns
0.75	1	1	1	4.00 p.m.	46 d	43 e	ns
1.5	1	1	1	9.00 a.m.	70 b	68 b	ns
1.5	1	1	1	4.00 p.m.	61 bc	59 bcd	ns
Weeded	–	–	–	–	100 a	100 a	ns
Nonweeded	–	–	–	–	0e	0f	ns

[1]% weed control ; 0 = no control, 100 = complete control.
[2]Means in the same column followed by different letters are significantly different ($p < 0.05$).
[3]Comparison of means within the same line; ns = not significantly different ($p > 0.05$).

TABLE 8. PURPLE NUTSEDGE CONTROL WITH GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES AT 4 WEEKS AFTER APPLICATION

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (% v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	% Weed control[1] with corn	% Weed control[1] without corn	T-test
1.5	–	–	–	9.00 a.m.	62 abc[2]	59 abc	ns[3]
1.5	–	–	–	4.00 p.m.	79 a	75 a	ns
0.5	1	1	1	9.00 a.m.	35 d	38 d	ns
0.5	1	1	1	4.00 p.m.	43 cd	40 cd	ns
0.75	1	1	1	9.00 a.m.	41 d	40 cd	ns
0.75	1	1	1	4.00 p.m.	35 d	33 d	ns
1.5	1	1	1	9.00 a.m.	68 ab	63 ab	ns
1.5	1	1	1	4.00 p.m.	54 bcd	48 bcd	ns
Weeded	–	–	–	–	34 d	28 d	ns
Nonweeded	–	–	–	–	0e	0e	ns

[1]% weed control ; 0 = no control, 100 = complete control.
[2]Means in the same column followed by different letters are significantly different ($p < 0.05$).
[3]Comparison of means within the same line; ns = not significantly different ($p > 0.05$).

TABLE 9. EFFECT OF GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES ON DRY WEIGHT AND NUMBER OF PURPLE NUTSEDGE PLANTS IN UNCROPPED AREA

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (%v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	Dry weight[1] (g/0.25m^2)	% reduction of plant number[2]	Dry weight[3] (g/0.25m^2)	% reduction of plant number[4]
1.5	–	–	–	9.00 a.m.	7.6 b[5]	–32.6	20.8	–15.0
1.5	–	–	–	4.00 p.m.	8.3 b	–18.6	20.3	7.6
0.5	1	1	1	9.00 a.m.	26.7 ab	–182.4	26.3	–103.4
0.5	1	1	1	4.00 p.m.	29.4 ab	–122.0	32.3	–50.7
0.75	1	1	1	9.00 a.m.	15.8 b	–115.0	23.1	–54.2
0.75	1	1	1	4.00 p.m.	18.3 b	–202..5	35.9	–147.3
1.5	1	1	1	9.00 a.m.	23.0 ab	–42.0	19.4	–19.5
1.5	1	1	1	4.00 p.m.	13.2 b	–129.8	25.7	–91.5
Weeded	–	–	–	–	19.7 b	–204.8	37.8	–147.7
Nonweeded	–	–	–	–	44.5 a	–194.4	45.9	–79.5
					–	NS	NS	NS

[1]At 4 weeks after application.
[2]At 6 weeks after application.
[3]At 8 weeks after application.
[4]At 10 weeks after application.
[5]Means in the same column followed by different letters are significantly different ($p < 0.05$).

nutsedge control in the cropped plots more than uncropped plots, at 8 weeks after application (Table 10), presumably because of the effect of crop competition. With one exception, there was no difference between the application in the morning and the afternoon (Tables 6–9).

The additives did not increased activity of glyphosate as measured by either dry weight at 4 and 8 weeks after application or number of nutsedge shoots at 6 and 10 weeks after application (Table 9) and at harvesting (Table 11). Glyphosate alone or in combination with additives increased the weight of corn grain and corn yield (Table 12).

TABLE 10. PURPLE NUTSEDGE CONTROL WITH GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES AT 8 WEEKS AFTER APPLICATION

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (% v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	% Weed control[1]		T-test
					with corn	without corn	
1.5	–	–	–	9.00 a.m.	38 bcd[2]	30 bcd	ns[3]
1.5	–	–	–	4.00 p.m.	61 a	51 a	ns
0.5	1	1	1	9.00 a.m.	15 ef	10 ef	ns
0.5	1	1	1	4.00 p.m.	21 de	13 def	ns
0.75	1	1	1	9.00 a.m.	31 de	21d–e	ns
0.75	1	1	1	4.00 p.m.	29 de	18c–f	ns
1.5	1	1	1	9.00 a.m.	50 abc	31 bc	*
1.5	1	1	1	4.00 p.m.	55 ab	36 ab	*
Weeded	–	–	–	–	24 cd	30 bcd	ns
Nonweeded	–	–	–	–	0 f	0	ns

[1]% weed control ; 0 = no control, 100 = complete control.
[2]Means in the same column followed by different letters are significantly different ($p < 0.05$).
[3]Comparison of means within the same line;* = significantly different ($p < 0.05$).
ns = not significantly different ($p > 0.05$).

TABLE 11. EFFECT OF GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES ON DRY WEIGHT AND NUMBER OF PURPLE NUTSEDGE PLANTS IN CORN AREA AT HARVESTING

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (%v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	Dry weight (g/0.25m^2)	% reduction of plant number
1.5	–	–	–	9.00 a.m.	3.0	51.0
1.5	–	–	–	4.00 p.m.	1.1	72.7
0.5	1	1	1	9.00 a.m.	6.3	42.6
0.5	1	1	1	4.00 p.m.	3.3	57.1
0.75	1	1	1	9.00 a.m.	4.0	48.1
0.75	1	1	1	4.00 p.m.	4.7	38.3
1.5	1	1	1	9.00 a.m.	2.9	57.4
1.5	1	1	1	4.00 p.m.	3.0	48.7
Weeded	–	–	–	–	2.0	37.6
Nonweeded	–	–	–	–	3.9	49.3

TABLE 12. EFFECT OF PURPLE NUTSEDGE CONTROL WITH PREPLANTING APPLICATION OF GLYPHOSATE IN COMBINATION WITH VARIOUS ADDITIVES ON YIELD OF CORN

Glyphosate (kg a.e./ha)	$(NH_4)_2SO_4$ (%v/v)	Diesel oil (%v/v)	Tendal (%v/v)	Time of application	Weight of grain from 10 ears (g)	Yield (kg/ha)
1.5	–	–	–	9.00 a.m.	1,270 a[1]	4,270 a
1.5	–	–	–	4.00 p.m.	1,360 a	4,640 a
0.5	1	1	1	9.00 a.m.	1,210 a	3,850 a
0.5	1	1	1	4.00 p.m.	1,310 a	4,230 a
0.75	1	1	1	9.00 a.m.	1,080 a	3,810 a
0.75	1	1	1	4.00 p.m.	1,210 a	4,460 a
1.5	1	1	1	9.00 a.m.	1,230 a	4,250 a
1.5	1	1	1	4.00 p.m.	1,310 a	4,710 a
Weeded	–	–	–	–	1,130 a	3,760 a
Nonweeded	–	–	–	–	799 b	2,250 b

[1]Means in the same column followed by different letters are significantly different ($p < 0.05$).

In the field experiment the additives did not affect glyphosate activity. This might be due to the quality of the water. Well water from the field was used for mixing the spray solution. That water might have contained cations such as Ca^{+2} and Mg^{+2}. Even though, $(NH_4)_2SO_4$ was added to spray solution, the molar ratio necessary to overcome Ca^{+2} must be 3:1 $(NH_4)_2SO_4$:$CaCl_2$) [5]. Furthermore, glyphosate does not have soil activity, and nutsedge tubers in the field did not germinate at the same time, so late germinating tubers did not come into contact with spray droplets.

4. CONCLUSIONS

The addition of $(NH_4)_2SO_4$ at 1.0% + oil at 1.0% + Tendal at 1.0% increased ^{14}C-glyphosate penetration into nutsedge leaves more than the addition of either one alone.

The addition of $(NH_4)_2SO_4$ at 1.0% + oil at 1.0% + Tendal at 0.12 or 0.25 or 1.0% increased phytotoxicity of glyphosate at 0.5 and 0.75 kg a.e./ha at 7 and 14 days after application in the greenhouse, but not in the field. Additives in combination with glyphosate did not reduce the number of nutsedge tubers compared with glyphosate alone.

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