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16. Abstract: Two tests each demonstrated the response of bermudagrass [Cynodon dactylon (Pers.)] on the roadside pavement edge and shoulder (1) to Roundup (glyphosate) alone and with 11 adjuvants and (2) with Arsenal (imazapyr) and Oust (sulfometuron). Treatments were sprayed in May and rated five times in the following 16 weeks. Researchers applied Roundup herbicide alone at 3.5, 4.7, 7.0, and 9.4 L/ha (1.5, 2, 3, and 4 qt/A) and at 3.5, 4.7, and 7.0 L/ha with 11 adjuvants including: Apsa-80, BioPlus, Cide-Kick II, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77, X-77+ammonium sulfate, HUK-12, and Agri-Dex. Bermudagrass control averaged 7% higher on the pavement than on the shoulder. Averaged over all adjuvants and ratings, Roundup rates at 3.5, 4.7, and 7.0 L/ha produced 49, 56, and 64% bermudagrass injury. Averaged over 38 treatments, bermudagrass injury was 54, 72, 73, 52, and 27% at 2, 4, 8, 12, and 16 weeks after treatment, respectively. Averaged over three Roundup rates and five rating dates, Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77+ammonium sulfate, and Agri-Dex increased bermudagrass control slightly from 57 to 62% compared with 53% with Roundup alone. BioPlus, Cide-Kick II, and X-77 had no effect on Roundup effectiveness; HUK-12 reduced Roundup effectiveness to 46%. Arsenal at 4.7 L/ha (2 qt/A or 1 lb ae/A) was the most effective treatment producing 69 and 90% bermudagrass control over a 16-week period at Flynn and Center, TX, respectively, and more than 95% at 4 to 8 weeks after spraying at both sites. Roundup+Arsenal at 2.3+2.3 L/ha (1+1 qt/A) produced 80 and 96% bermudagrass control at 8 weeks and 12 and 91% control 16 weeks after spraying at Flynn and Center, TX, respectively. Addition of Oust at the rate of 140 g/ha (2 oz product/A) to Roundup at 7.0 L/ha (3 qt/A) had no effect on bermudagrass control.

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INFLUENCE OF ROUNDUP® WITH ADJUVANTS AND OTHER HERBICIDES FOR CONTROL OF ROADSIDE BERMUDAGRASS

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IMPLEMENTATION STATEMENT

The responses of bermudagrass [Cynodon dactylon (L.) Pers.] along highway pavement edges to several rates of Roundup alone and with adjuvants and to two other herbicides at two locations were documented and compared. The most effective treatments in 1994 need to be repeated in 1995 to confirm the effectiveness of the three herbicides and the influence of adjuvants on the control of bermudagrass.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation/Symbol	Item
A	Acre
ae	Acid equivalent
ai	Active ingredient
AMS	Ammonium sulfate
C	Degrees centigrade
F	Degrees Farenheit
ft	Foot (feet)
FM	Farm to market road
g	Gram(s)
gal	Gallon(s)
gal/A	Gallon(s) per acre
ha	Hectare(s)
kg	Kilogram(s)
kPa	Kilopascal(s)
km	Kilometer(s)
L	Liter(s)
lb	Pound(s)
$LSD_{.05}$	Least Significant Difference (5%)
m	Meter(s)
mi	Mile(s)
ml	Milliliter(s)
mm	Millimeter(s)
oz	Ounce(s)

Abbreviation/Symbol	Item
%	Percent
psi	Pound(s) per square inch
qt	Quart(s)
WAT	Weeks after treatment
w/v	Weight/volume

SUMMARY

In one test, Roundup (glyphosate) was evaluated at four rates alone and at three rates with 11 adjuvants for the control of bermudagrass [Cynodon dactylon (L.) Pers.] along highways. In a second test, Researchers evaluated Roundup alone and in mixtures with Oust (sulfometuron methyl) and Arsenal (imazapyr) and Arsenal alone for the control of bermudagrass. Both tests joined along the pavement edges near Flynn and Center, Texas.

Over the 16-week period, bermudagrass injury averaged 7% higher on the pavement than on the soil. The highest injury ratings occurred 4 and 8 weeks after treatment (WAT). Bermudagrass injury, when averaged over 38 treatments, was 54, 72, 73, 52, and 27% at 2, 4, 8, 12, and 16 WAT, respectively. Over all 38 treatments and five rating dates, bermudagrass control was equal at Flynn and Center, Texas. However, control was better at Center 2 and 4 WAT and at Flynn 12 and 16 WAT.

Averaged over 11 adjuvants + no adjuvant, increasing Roundup rates at 3.5, 4.7, and 7.0 L/ha (1.5, 2, and 3 qt/A) caused progressively more bermudagrass injury at 49, 56, and 64%, respectively.

Averaged over three Roundup rates and five rating dates, Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77+AMS, and Agri-Dex increased bermudagrass control with Roundup slightly from 57 to 62% compared with 53% with Roundup without surfactant. Most of the increase occurred 12 WAT. Averaged over three Roundup rates and five rating dates, BioPlus, Cide-Kick II, and X-77 had no effect on Roundup effectiveness; whereas, HUK-12 reduced Roundup effectiveness. All herbicide treatments caused some bermudagrass injury compared with the untreated plants through 8 WAT.

Using other herbicides, the addition of Oust at 140 g/ha (2 oz product/A) to Roundup at 7.0 L/ha (3 qt/A) had no effect on bermudagrass control compared with Roundup at 7.0 L/ha (3 qt/A) alone. However, Arsenal at the rate of 4.7 L/ha (2 qt/A) controlled bermudagrass best of all to 69 to 90% in the 1994 treatments over 16 WAT. Roundup+Arsenal at 2.3+2.3 L/ha (1+1 qt/A) produced excellent bermudagrass control for 16 WAT at Center but only 12 WAT at Flynn. These two treatments and other mixtures of the two herbicides hold more promise for a practical treatment than the Roundup plus adjuvant combinations.

INFLUENCE OF ROUNDUP® WITH ADJUVANTS AND OTHER HERBICIDES FOR CONTROL OF ROADSIDE BERMUDAGRASS

INTRODUCTION

Vegetation is managed along roadsides to maintain integrity of the pavement surface, provide safety, prevent or reduce erosion, provide for efficiency of maintenance activities, and provide beauty. Bermudagrass [Cynodon dactylon (L.) Pers.] is a problem along highway edges in that the rhizomes (underground stems) and stolons (horizonal above-ground stems) grow under and on top of the pavement, root down in cracks in the pavement, and eventually cause breakdown of the pavement. Presently, Roundup (glyphosate) is the most effective herbicide for controlling bermudagrass. Monsanto Chemical Co. recommends a rate of 11.7 L/ha (5 qt/A) to control bermudagrass. The Texas Department of Transportation (TxDOT) uses a rate of 7.0 L/ha (3 qt/A) which controls bermudagrass for several months (Anonymous 1992, Anonymous 1993). There is interest for increasing, or at least maintaining, the same level of control with less Roundup. The emphasis for protecting the environment has brought about the need to maintain adequate vegetation management along highways using mowing and only a minimum amount of herbicides.

The seasonal development of bermudagrass has been described by Horowitz (1972). Fernandez and Bayer (1977) found a 3.6 g/L (1.28 fluid oz/gal[1]) solution of Roundup applied to selected parts of bermudagrass shoots did not kill the entire plant. However, phytotoxicity increased as more parts of the plant were treated. Aitken (1974) found two applications of 2.24 to 3.36 kg/ha (2 to 3 lb/A) of Roundup provided season-long control of bermudagrass.

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[1]In the literature, 1.36 kg (3 lb) acid equivalent glyphosate is considered to be in 3.785 L (1 gal) of Roundup.

Several chemical, physical, and environmental factors influence effectiveness of Roundup for controlling vegetation. In some cases, surfactants have increased Roundup phytotoxicity. An unpublished Amway report presented data that showed Roundup at 0.88 L/ha (0.75 pt/A) with or without Apsa-80 surfactant caused 95% bermudagrass control 3 weeks after treatment (WAT). However, the addition of Apsa-80 at the rate of 95 ml (3.2 oz) in 47 L/ha (5 gal/A) of spray solution resulted in 90% bermudagrass control through 10 weeks; whereas, Roundup alone failed to control bermudagrass more than 10% after 10 weeks.

Day and Jordan (1961) found that liquid retention by bermudagrass was greatest for distilled water and low concentrations of surfactant, and decreased by about one-fourth as surfactant concentration increased from 0.01 to 0.16%. Distribution of water on the shoots was significantly more uniform when surfactant was present. In four populations of bermudagrass studied, retention of 0.01% surfactant solution ranged from 2310 to 5013 L/ha (247 to 535 gal/A) with wide variations in the proportion of the liquid held by the green leaves, green stems, and dead tissues.

Jordan (1981) found that glyphosate toxicity to bermudagrass increased as 2.3 L/ha (1 qt/A) of herbicide occurred in decreasing volumes of diluent from 374 to 47 L/ha (40 to 5 gal/A). Visible injury to bermudagrass varied from 18 to 91% depending upon the spray solution formulation and diluent volume. The addition of surfactant at 0.2% by volume to glyphosate (MON 0139), a formulation without surfactant, increased bermudagrass injury at each diluent volume tested. Glyphosate commercially formulated with surfactant (MON 2139), however, was more toxic to bermudagrass than MON 0139 with or without surfactant. Regrowth of bermudagrass clipped at the soil surface 48 hours after treatment increased from 10% of the untreated control with MON 2139 at 47 L/ha (5 gal/A) to 100% of the control (no effect) with MON 0139 at 374 L/ha (40 gal/A). The MON 2139 formulation allowed as much as a six-fold increase in bermudagrass foliage regrowth when the diluent volume was increased from 47 to 374 L/ha (5 to 40 gal/A).

On quackgrass [Elytrigia repens (L.) Nevski], Turner and Loader (1980) found that additions of 1 to 10% ammonium sulfate and/or 0.1 to 2.5% surfactant increased the phytotoxicity of sprays containing 0.69 to 1.4 L/ha (9.4 to 19.2 oz/A) of Roundup. Higher ammonium sulfate concentrations were sometimes antagonistic. Additions of ammonium sulfate without surfactant generally had less effect on phytotoxicity. While several surfactants increased Roundup activity, the order of effectiveness of these products varied according to whether or not ammonium sulfate was also present. When used alone, relatively hydrophilic nonionic or cationic products increased the effect most. In mixtures with ammonium sulfate, however, more lipophilic surfactants gave superior results.

Carrier volume has a variable effect on Roundup activity. Buhler and Burnside (1983a and 1983b), Jordan (1981), Sandberg et al. (1978), and Stahlman and Phillips (1979) observed an increase in Roundup phytotoxicity with decreasing carrier volume on some species. However, Fernandez and Bayer (1977) found no carrier volume effect differences between 94 and 373 L/ha (10 and 40 gal/A) after spraying Roundup to bermudagrass at a 1.0 and 1.5% v/v solution. The reason given for this was that bermudagrass is difficult to wet and, therefore, responds to a larger volume of carrier.

Environmental factors including water availability and humidity have influenced Roundup activity. Buhler and Burnside (1983a) found that Roundup was more effective for controlling several actively growing grass weeds with adequate soil moisture and favorable temperatures than when the same plants were under moisture stress. Jordan (1977) found visible injury to bermudagrass with 1.56 L/ha (21.3 oz/A) Roundup was greater when relative humidity was 100% than 40% at both 22 C (72 F) and 32 C (90 F). Roundup at 1.40 L/ha (19.2 oz/A) was more toxic at 32 C (90 F) than at 22 C (72 F) at 40% relative humidity, but no difference was observed at 100% relative humidity.

In 1993, Meyer et al. (1994) found that pavement edge Roundup treatments caused about 6% more injury to bermudagrass than those applied on the shoulder. Higher injury ratings occurred 4 WAT than at 2, 8, or 12 WAT. Roundup applications were more effective in May than in June. Roundup at 7.0 L/ha (3 qt/A) was equal to 9.4

L/ha (4 qt/A) at 4, 8, and 12 WAT. Only the surfactant, Raider-TG, increased bermudagrass control at 7.0 L/ha (3 qt/A) of Roundup compared with Roundup alone at 7.0 L/ha (3 qt/A). Several adjuvants slightly increased the control of bermudagrass by Roundup at 3.5 and 4.7 L/ha (1.5 and 2 qt/A) in May treatments, but the increases were not consistent across tests.

This study was undertaken to develop an effective herbicide treatment on bermudagrass that would reduce both the cost and amount of herbicide released into the highway roadside environment. At two Texas locations, one test included three rates of Roundup alone or with eleven adjuvants of various types; the other test used Arsenal and Oust. The objectives of this study on bermudagrass were (1) to compare the effectiveness of Roundup applied to the shoulder versus the pavement, (2) to evaluate Roundup effectiveness at two locations, (3) to evaluate the phytotoxicity of various rates of Roundup, (4) to determine the influence of various adjuvants for increasing the effectiveness of Roundup, and (5) to evaluate the influence of two additional herbicides.

MATERIALS AND METHODS

Researchers conducted four tests on dense stands of bermudagrass growing along highways at two Texas locations. Two tests were established at each site in May 1994. One test area was situated along FM 977 about 7.9 km (4.9 mi) west of Flynn, Texas. We established the other test site at Center, Texas, on Loop 500 between State Highway 7 and US 96. The soil near Flynn was a sandy clay to a clay loam; whereas, the soil at Center was a sandy loam.

Both sites included two sets of plots. The plots were 18.2 m (60 ft) long and 1.5 m (5 ft) wide with half on the pavement edge (pavement) and half off the pavement (shoulder). Plots 1.5 m (5 ft) wide allowed coverage of all the bermudagrass both on the pavement and on a strip of shoulder at least 0.6 m (2 ft) wide. Three sets of plots (replicates) were set up per treatment in each test.

One test at each site included 38 treatments. Roundup {360 g/L [3 lb ae/gal] of the isopropylamine salt of glyphosate [N-(phophonomethyl)glycine]} alone was applied at 3.5, 4.7, 7.0, and 9.4 L/ha (1.5, 2, 3, and 4 qt/A). Roundup at 3.5, 4.7, and 7.0 L/ha (1.5, 2, and 3 qt/A) was applied with 11 adjuvants. Table 1 contains descriptions of the various adjuvants. The adjuvants, except Apsa-80, were added at the maximum recommended rate to the three rates of Roundup. Also, each test contained untreated plots.

The second test at each site had six treatments that included Roundup alone at 7.0 and 9.4 L/ha (3 and 4 qt/A), Roundup + Oust at 7.0 L+140 g/ha (3 qt+2 oz product/A), Roundup+Arsenal at 2.3+2.3 L/ha (1+1 qt/A), Arsenal alone at 4.7 L/ha (2 qt/A), and untreated plots. Oust is a dry flowable powder formulation containing 75% active ingredient of sulfometuron {2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]benzoic acid}. Arsenal contains 240 g/L (2 lb/gal) acid equivalent of the isopropylamine salt of imazapyr {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid}. All herbicide sprays contained the surfactant, X-77, at the concentration of 5.0 ml/L (16 oz/25 gal).

Table 1. Adjuvants used with Roundup sprays along highway pavement edges in one test each near Flynn and Center, Texas, in 1994 (Harvey 1992).

Adjuvant	Rate used per 234 L/ha (25 gal/A)	Activity type	Chemical composition		Manufacturer
			Percent ai[1]	Chemistry	
Apsa-80	91 ml/ha (1.25 oz/A)	Nonionic, spreader, activator, wetting agent	80%	Alkyl aryl alkoxylate, free fatty acids	Amway Corp, Ada, MI
BioPlus SS 100	183 ml/ha (2.5 oz/A)	Spreader, sticker, wetting agent	90%	Binary & tertiary copolymer alcohols, dimethicone, hydroxytricarballic acid, and PVP-VA Co-polymer	BioPlus Mfg, Inc., Hawkins, TX
Cide-Kick II	4676 ml/ha (64 oz/A)	Activator, penetrant, wetting agent	100%	d,l-limenene and related isomers plus selected emulsifiers	Brewer International Chemical, Inc. Vero Beach, FL
Exacto XL	292 ml/ha (4 oz/A)	Cationic/nonionic, spreader wetting agent	99%	Oxyalkylated alkamine constituents	Exacto Chemical Co., Richmond, IL
Kinetic	219 ml/ha (3 oz/A)	Nonionic penetrant, spreader, wetting agent	99%	Blend of polyalkyleneoxide modified polydimethylsiloxane, nonionic surfactants	Setre Chemical Co., Memphis, TN
Raider-TG	1169 ml/ha (16 oz/A)	Penetrant, activator	28%	Polymerized pyro-phosphatic surfactant-emulsifier blends, diglycol sterates, 5-phosphomevalonate isopentenyl farnesyl-pyrophosphate	ATS Research, Inc., Memphis, TN

Table 1. (Cont.)

Saturall 85	292 ml/ha (4 oz/A)	Wetting agent	86%	Alkylaryl polyoxyethylene glycol, glycol ethers, polyoxypropylene polyoxethylene oxide modified dimethyl polysiloxane, acetylene diol, dimethylpolysiloxane, fatty acids	Conklin Co., Inc., Shakopee, MN
X-77	1169 ml/ha (16 oz/A)	Spreader, activator	90%	Alkylarylpolyoxyethylene, glycols, free fatty acids, isopropanol	Valent USA Corp., Walnut Creek, CA
X-77+AMS	1169 ml/ha (16 oz/A) + 2% w/v, 4.68 kg/ha (4.2 lb/A)	Spreader, activator	90% + 100%	Same as above + reagent grade ammonium sulfate	Valent USA Corp., Walnut Creek, CA + Spectrum Chemical Mfg. Corp., Gardena, CA
HUK-12 HERBISPRAY	2338 ml/ha (32 oz/A)	Activator	35%	Leonardite, potassium hydroxide	Humus Products of America, Inc., Richmond, TX
Agri-Dex	2338 ml/ha (32 oz/A)	Crop oil concentrate	99%	Heavy range paraffin base petroleum oil, polyol fatty acid esters, polyethoxylated derivatives thereof	Helena Chemical Co., Memphis, TN

[1]Active ingredients. Values are rounded to nearest full percent.

A wheel-mounted experimental plot sprayer having a three-nozzle boom sprayed a swath 1.5 m (5 ft) wide. Sprays were applied at the rate of 234 L/ha (25 gal/A) using compressed air at 207 kPa (30 psi). The sprays were applied half on the pavement and half on the adjoining shoulder.

Vegetation at both sites thinly overshadowed the bermudagrass on the shoulder at spraying time in May. Herbaceous vegetation at Flynn consisted largely of rescuegrass (Bromus catharticus Vahl) and Texas wintergrass (Stipa leucotricha Trin. & Rupr.); whereas, the vegetation at Center was primarily bahiagrass (Paspalum notatum Fluegge). Consequently, both locations were mowed to a height of about 102 mm (4 inches) 1 week before spraying.

The plots were sprayed near Flynn and at Center on May 19 and 23, 1994, respectively. At this time the bermudagrass had stems with leaves 51 to 102 mm (2 to 4 inches) tall, and the plants were just beginning to produce stolons. Near Flynn, the sprays were applied from 6:30 a.m. to 6:20 p.m. with a temperature of 18 to 27 C (65 to 80 F), wind from the south at 0 to 13 km/hr (0 to 8 mph), and sky clear to partly cloudy. At Center, the sprays were applied from 10:45 a.m. to 7:30 p.m. with a temperature of 24 to 31 C (75 to 88 F), wind from the south at 0 to 13 km/hr (0 to 8 mph), and sky clear to partly cloudy. No rain fell within 48 hours after spraying at either site. Rainfall for the remainder of May and for June, July, August, and September was about 51, 51, 2.3, 86, and 69 mm (2.0, 2.0, 0.9, 3.4, and 2.7 inches) near Flynn and 74, 173, 94, 211, and 193 mm (2.9, 6.8, 3.7, 8.3, and 7.6 inches) at Center[2].

All plots in the four tests were rated 0, 2, 4, 8, 12, and 16 WAT. Bermudagrass in 10 areas 152 by 305 mm (6 by 12 inches) at approximately equal intervals through each plot were rated for percent plant injury from 0% = no injury to 100% = dead foliage both on the pavement and on the shoulder. Statistical analyses of variance were calculated on data of each test taken at individual dates as a randomized complete block

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[2]Rainfall was reported from Centerville, about 21 km (13 mi) from Flynn, and Center, Texas, weather stations as recorded for N.O.A.A., Asheville, South Carolina.

design for all treatments. The data for the Roundup x adjuvant tests were also calculated as a factorial design for herbicide rate x adjuvant interactions. Also, the same analyses were calculated for combined data from the same type tests at both sites at each rating date. The Least Significant Difference ($LSD_{.05}$) test at the 5% level separated means for treatments and herbicide rate x adjuvant interactions.

RESULTS

Percent bermudagrass control on the pavement consistently averaged 7% higher than that on the shoulder, so the data were averaged and the means are presented in the results.

ADJUVANT TESTS

Two statistical analyses were calculated. The first included effects of location, rating date in WAT, treatment, and all interactions. The average overall ratings for all treatments over all five dates resulted in 56% bermudagrass injury for both Flynn and Center, Texas (Table 2).

Overall ratings varied for WAT. At time of spraying in May, the bermudagrass averaged 7% injury (data not shown) mostly because of vehicular damage. Ratings at 2, 4, 8, 12, and 16 WAT averaged 54, 72, 73, 52, and 27%, respectively (Table 2). This indicated that maximum bermudagrass injury occurred at 4 through 8 WAT. Subsequently, the surviving plants had begun recovering, and plants from the adjoining shoulder area had begun producing stolons (horizontal stems) that encroached into the treated areas.

The treatments varied in effectiveness for controlling bermudagrass (Table 2). The most effective treatments, averaged over five rating dates, included Roundup alone at 9.4 L/ha (4 qt/A) averaging 68% control and Roundup at 7.0 L/ha (3 qt/A) combined with Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77+AMS, or Agri-Dex averaging 66 to 69% control. These treatments were all slightly better than 7.0 L/ha of Roundup alone at 56% control.

The treatment x rating date interaction was highly significant (Table 2). At 2 WAT, Exacto XL, Raider-TG, and Saturall 85 increased control with Roundup at 7.0/ha (3 qt/A) over the treatment average of 54%, but only Raider-TG (73%) was better than Roundup alone at 7.0 L/ha (3 qt/A) at 59%. At 4 WAT, Roundup alone at 9.4 L/ha (4

Table 2. Mean percent bermudagrass injury on the pavement and shoulder near Flynn and Center, Texas, after applying 38 treatments along the highway pavement edge with Roundup alone and with 11 adjuvants on May 19-23, 1994, and rated 2, 4, 8, 12, and 16 weeks later.

Treat. No.[1]	Roundup rate	Adjuvant		Weeks after treatment[2]					Location[3]		Mean[4]
		Chemical	Rate[5]	2	4	8	12	16	Flynn	Center	
	L/ha		ml/ha	Percent plant injury							
1	9.4	---	---	66	85	86	70	35	69	67	68 abc
2	7.0	---	---	59	80	71	41	27	50	61	56 g-l
3	4.7	---	---	55	73	76	56	25	54	60	57 g-k
4	3.5	---	---	52	64	59	37	20	45	48	47 pqr
5	7.0	Apsa-80	91	66	85	88	71	30	72	64	68 abc
6	4.7	Apsa-80	91	61	79	76	51	32	53	66	60 e-h
7	3.5	Apsa-80	91	52	68	77	48	23	49	58	54 i-m
8	7.0	BioPlus	183	63	84	73	48	25	62	56	59 f-i
9	4.7	BioPlus	183	50	71	78	50	25	54	55	55 h-m
10	3.5	BioPlus	183	45	61	66	43	21	42	52	47 o-r
11	7.0	Cide-Kick II	4676	57	80	82	51	27	55	64	59 e-h
12	4.7	Cide-Kick II	4676	48	61	55	44	20	40	51	46 qr
13	3.5	Cide-Kick II	4676	41	52	70	52	22	46	49	48 n-r

Table 2. (Cont.)

14	7.0	Exacto XL	292	67	88	80	58	34	78	53	66 a-d
15	4.7	Exacto XL	292	58	79	87	65	33	69	60	64 b-e
16	3.5	Exacto XL	292	55	70	67	35	21	45	54	50 m-q
17	7.0	Kinetic	219	66	84	87	71	38	75	64	69 ab
18	4.7	Kinetic	219	56	72	66	43	24	58	46	52 k-o
19	3.5	Kinetic	219	52	62	76	53	25	53	55	54 i-m
20	7.0	Raider-TG	1169	73	90	79	64	38	80	58	69 abc
21	4.7	Raider-TG	1169	51	75	81	59	26	58	59	58 f-j
22	3.5	Raider-TG	1169	49	66	59	42	22	40	54	47 o-r
23	7.0	Saturall 85	292	69	86	85	65	37	74	62	68 abc
24	4.7	Saturall 85	292	52	75	67	34	22	50	50	50 m-q
25	3.5	Saturall 85	292	48	67	76	50	24	53	53	53 j-n
26	7.0	X-77	1169	65	81	80	59	31	57	69	63 c-f
27	4.7	X-77	1169	45	64	73	53	23	47	57	52 k-p
28	3.5	X-77	1169	45	60	60	31	17	40	45	43 r
29	7.0	X-77+AMS[6]	1169+2%	57	85	90	69	34	66	67	67 abc

Table 2. (Cont.)

30	4.7	X-77+AMS[6]	1169+2%	57	82	81	58	28	62	60	61 d-g
31	3.5	X-77+AMS[6]	1169+2%	52	73	81	64	24	56	61	59 e-i
32	7.0	HUK-12	2338	55	75	69	40	22	55	50	52 k-o
33	4.7	HUK-12	2338	47	64	76	53	28	54	53	54 i-m
34	3.5	HUK-12	2338	35	45	40	29	18	31	36	34 s
35	7.0	Agri-Dex	2338	64	86	88	74	39	76	65	70 a
36	4.7	Agri-Dex	2338	59	78	83	63	35	68	60	64 c-f
37	3.5	Agri-Dex	2338	46	61	72	51	24	46	55	51 l-q
38	---	Untreated	---	8	10	21	17	14	14	14	14 t
Mean[4]				54 b	72 a	73 a	52 c	27 d	56	56	

[1]At time of spraying, bermudagrass was 51 to 102 mm (2 to 4 inches) tall.
[2]Least Significant Difference ($LSD_{.05}$) at the 5% level for weeks after treatment x treatment = 13.
[3]$LSD_{.05}$ for location x treatment = 8.
[4]Values in column or row followed by the same letter are not significantly different at the 5% level using the Least Significant Difference test.
[5]Spray was applied at 234 L/ha (25 gal/A). Metric-English conversions: 91, 183, 219, 292, 1169, 2338, and 4676 ml/ha = 1.25, 2.5, 3, 4, 16, 32, and 64 oz/A, respectively.
[6]AMS = Ammonium sulfate that was added at 2% w/v or 4.68 kg/ha (4.2 lb/A).

qt/A), and Roundup at 7.0 L/ha (3 qt/A) combined with Apsa-80, Exacto XL, Raider-TG, Saturall 85, X-77+AMS, or Agri-Dex were more effective than the treatment average. At 4 WAT, again no treatment was better than Roundup alone at 7.0 L/ha (3 qt/A). At 8 WAT, Roundup alone at 9.4 L/ha (4 qt/A) and Roundup at 7.0 L/ha (3 qt/A) with Apsa-80, Exacto XL, Kinetic, X-77+AMS, or Agri-Dex were more effective than the 8-week average. The same treatments plus Saturall 85 were more effective than Roundup alone at 7.0 L/ha (3 qt/A). For some reason, the results for Roundup alone at 7.0 L/ha (3 qt/A) at 12 WAT was lower than expected when compared with the rate of 4.7 L/ha (2 qt/A). Fourteen treatments were superior to Roundup alone at 7.0 L/ha (3 qt/A) at 41% control, but only four treatments were more effective than Roundup alone at 4.7 L/ha (2 qt/A). At 16 WAT, none of the treatments were more effective than either the 16-week treatment mean or Roundup alone at 7.0 L/ha (3 qt/A).

In all cases, the herbicide treatments caused more bermudagrass injury than that found in the untreated plots through 8 WAT (Table 2). Only HUK-12 at 3.5 L/ha (1.5 qt/A) was not statistically more effective than the untreated plots at 12 WAT. None of the plots treated with Roundup at 7.0 L/ha with adjuvants were less effective than those treated with Roundup alone at 7.0 L/ha (3 qt/A).

The location x treatment interaction was highly significant (Table 2). Eleven treatments were most effective at Center; whereas, nine were more effective at Flynn. However, there did not seem to be a consistent pattern affecting any particular adjuvant response by location. Ten and eight treatments at Flynn and Center, respectively, were superior to the overall treatment mean of 56%.

A second statistical analysis calculated was a factorial with 36 treatments composed of 11 adjuvants plus no adjuvant at three rates of Roundup. Weeks after treatment (WAT), Roundup rate, adjuvant, all two-way interactions except date x adjuvant, and location x rate x adjuvant were significant when the data were averaged through the five rating dates. WAT means were slightly different from those in Table 2 because the 9.4 L/ha (4 qt/A) and untreated plot data were omitted to make a balanced analysis.

Table 3. Mean percent bermudagrass injury along the pavement edge near Flynn and Center, Texas, including Roundup rate, location, and weeks after treatment means along with two interactions with weeks after spraying.

Item	Rating, weeks after treatment					Mean[1]
	2	4	8	12	16	
	---------- Percent plant injury ----------					
Roundup rate (L/ha)[2]						
3.5	48	62	67	45	22	49 c
4.7	53	73	75	52	27	56 b
7.0	63	84	81	59	32	64 a
Location[3]						
Flynn	53	67	74	57	29	56
Center	57	79	74	47	24	56
Mean[1]	55 b	73 a	74 a	52 c	27 d	

[1]Means in row or column by analysis followed by the same letter are not significantly different at the 5% level using the Least Significant Difference ($LSD_{0.5}$) test.

[2]After five ratings, Roundup alone at 9.4 L/ha (4 qt/A) = 68%; untreated plots = 14%. $LSD_{.05}$ for Roundup rate x weeks after treatment = 4%.

[3]$LSD_{.05}$ for location x weeks after treatment = 3%.

At all dates, increasingly higher Roundup rates from 3.5 L/ha (1.5 qt/A) to 7.0 L/ha (3 qt/A) progressively increased bermudagrass control (Table 3). The largest and smallest interval between rates was 11% and 5% that occurred at 4 and 16 WAT, respectively.

Although the overall control by all treatments at 2 through 16 WAT was 56% at both locations, there was a significant difference throughout the test (Table 3). At 2 and 4 WAT, the herbicide treatments were increasingly superior at Center; at 8 WAT, the treatment means overall were similar. At 12 and 16 WAT, the ratings were decreasing, but remained higher at Flynn than at Center. More rain fell at Center than Flynn (Centerville data). At Center, 0-2, 2-4, 4-8, 8-12 and 12-16 week rainfall was 95, 141, 69, 142, and 285 mm (3.75, 5.54, 2.73, 5.61, and 11.23 inches), respectively; whereas, near Flynn, rainfall in the same periods was 51, 20, 10, 56, and 61 mm (2.0, 0.8, 0.4, 2.2, and 2.4 in), respectively. Apparently, control was greater initially with abundant rainfall to provide good growing conditions, but later, abundant rainfall encouraged more regrowth from surviving plants and the encroachment of stolons from plants on the adjoining areas into the sprayed areas.

Table 4 presents the Roundup rate, location, adjuvant, Roundup rate x adjuvant interaction, and location x adjuvant interaction. Increasing Roundup rates progressively increased bermudagrass control. Over all Roundup rates and dates of rating, the adjuvants Apsa-80, Exacto XL, X-77+AMS, and Agri-Dex gave the best control at 60 to 62% over the 16-week period. Kinetic and Raider-TG also increased Roundup activity compared with Roundup sprays without adjuvant. HUK-12 was less effective than Roundup alone.

The Roundup rate x adjuvant interaction showed that Roundup at 3.5 L/ha (1.5 qt/A) with Apsa-80, Kinetic, Saturall 85, or X-77+AMS additions gave more control than Roundup alone at 3.5 L/ha (1.5 qt/A); whereas, HUK-12 reduced control (Table 4). At 4.7 L/ha (2 qt/A) of Roundup, Exacto XL and Agri-Dex increased control; whereas, Cide-Kick II and Saturall 85 reduced control compared with Roundup without adjuvant. At 7.0 L/ha (3 qt/A) of Roundup, Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77, X-77+AMS, and Agri-Dex increased bermudagrass control.

Table 4. Mean percent bermudagrass injury along the pavement edge near Flynn and Center, Texas, including Roundup rate, location, adjuvant, rate x adjuvant interaction, and location x adjuvant interaction for sprays applied May 19-23, 1994, and rated for plant injury at five intervals through 16 weeks after treatment.

Adjuvant		Roundup rate (L/ha)[1]			Location[2]		Mean[3]
Chemical	Rate in 234 L/ha[4]	3.5	4.7	7.0	Flynn	Center	
	ml/ha	Percent plant injury					
None	---	46	57	56	50	56	53 d
Apsa-80	91	54	60	68	58	63	60 ab
BioPlus	183	47	55	59	53	54	54 cd
Cide-Kick II	4676	48	46	59	47	55	51 d
Exacto XL	292	50	64	66	64	56	60 ab
Kinetic	219	54	52	69	62	55	58 b
Raider-TG	1169	47	58	69	59	57	58 b
Saturall 85	292	53	50	68	59	55	57 bc
X-77	1169	42	52	63	48	57	52 d
X-77 + AMS[5]	1169+2%	59	61	67	62	63	62 a
HUK-12	2338	34	54	52	46	46	46 e
Agri-Dex	2338	51	64	70	63	60	62 a
Mean[3]		49 c	56 b	64 a	56	56	

Table 4. (Cont.)

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[1]Metric-English conversion: 3.5, 4.7, and 7.0 L/ha = 1.5, 2, and 3 qt/A. Least Significant Difference at the 5% level ($LSD_{.05}$) for Roundup rate x adjuvant = 6%.

[2]$LSD_{.05}$ for location x adjuvant = 5%.

[3]Values in column or row followed by the same letter are not significantly different at the 5% level using the $LSD_{.05}$ test.

[4]Metric - English conversions: 234 L/ha = 25 gal/A; 91, 183, 219, 292, 1169, 2338, and 4676 ml/ha = 1.25, 2.5, 3, 4, 16, 32, and 64 oz/A, respectively.

[5]AMS = ammonium sulfate at the 2% concentration (w/v) at 4.68 kg/ha (4.2 lb/A).

HERBICIDE TESTS

A complete factorial statistical analysis was calculated for location treatment, weeks after treatment, and location x treatment x weeks after treatment on the pavement-shoulder mean data. All factors were highly significant.

The major finding was that Arsenal at 4.7 L/ha (2 qt/A) was superior to any other treatment in the study when results were averaged over the combined tests during the 16 week period after spraying (Table 5). Bermudagrass control by treatment over all rating dates in the two tests was 66, 62, 70, 74, 80, and 20% for Roundup at 9.4 L/ha (4 qt/A), Roundup at 7.0 L/ha (3 qt/A), Roundup at 7.0 L/ha+140 g/ha (3 qt+2 oz product/A) of Oust, Roundup at 2.3+2.3 L/ha (1 qt+1 qt/A) of Arsenal, Arsenal at 4.7 L/ha (2 qt/A), and untreated plots, respectively. Arsenal at 4.7 L/ha (2 qt/A) produced 61 and 88% bermudagrass control 16 WAT at Flynn and Center, Texas, respectively. The treatment of Roundup+Arsenal at 2.3+2.3 L/ha (1+1 qt/A) produced similar control at Center, but bermudagrass control at Flynn decreased to only 12% at 16 WAT. These two treatments should be investigated further for possible use on Texas highways. Bermudagrass control in the other three herbicide treatments decreased from 19 to 29 and 28 to 42% at Flynn and Center 16 at WAT, respectively.

Bermudagrass injury varied widely throughout the rating period. At time of spraying on May 19-23, the bermudagrass showed 6 to 8% injury from highway traffic. Over both tests, control was highest at 8 WAT (77%), with 4 and 12 WAT ratings of 69 to 71%, 2 WAT at 55%, and 16 WAT 38%. Over all treatments, the bermudagrass control was higher 2, 4, and 16 WAT at Center than at Flynn; whereas, control was about even at 8 and 12 WAT (LSD.05=7%).

At 2 WAT, the three treatments with Roundup alone produced more plant injury (64-76%) than Roundup+Arsenal or Arsenal alone (36 and 28%) at Flynn. All herbicide treatments caused similar injury (66-82%) at Center; however, the Arsenal treatments tended to be less injurious (66-68%) than Roundup alone (76-82%) at this time.

Table 5. Mean percent bermudagrass injury on the pavement and shoulder near Flynn and, Center, Texas after applying six treatments along the highway pavement edge with Roundup alone and/or with Oust and Arsenal on May 19-23, 1994, and rated 2, 4, 8, 12, and 16 weeks later.

Trt[1]	Chemical and rate[2]		Weeks after treatment[3]					Mean
	Roundup	Other herbicide	2	4	8	12	16	
	---------- Rate/ha[4] ----------		---------- Percent plant injury ----------					
Flynn, Texas								
1.	9.4 L/ha	---	76	85	75	54	19	62 ab
2.	7.0 L/ha	---	60	75	72	61	19	57 b
3.	7.0 L/ha	Oust 140 g/ha	64	77	87	76	29	67 a
4.	2.3 L/ha	Arsenal 2.3 L/ha	36	62	94	80	12	57 b
5.	---	Arsenal 4.7 L/ha	28	64	96	97	61	69 a
6.	Untreated	---	10	7	25	25	17	17 c
Mean			46 c	62 b	75 a	66 ab	26 d	

Table 5. (Cont.)

Center, Texas								
1.	9.4 L/ha	---	82	91	84	65	32	71 b
2.	7.0 L/ha	---	76	90	82	59	28	67 b
3.	7.0 L/ha	Oust 140 g/ha	81	86	84	67	40	73 b
4.	2.3 L/ha	Arsenal 2.3 L/ha	66	96	99	96	91	90 a
5.	---	Arsenal 4.7 L/ha	68	94	99	99	88	90 a
6.	Untreated	---	9	16	24	44	22	23 c
Mean			64 b	80 a	79 a	72 ab	50 c	

[1]At time of spraying, bermudagrass was 51 to 102 mm (2-4 inches) high on the pavement and shoulder.

[2]Chemicals were applied at the rate shown for 234 L/ha (25 gal/A). Roundup contains 360 g/L (3 lb/gal) acid equivalent of glyphosate; Arsenal contains 240 g/L (2 lb/gal) acid equivalent of imazapyr; Oust contains 75% active ingredient of sulfomethuron methyl [140 g/ha (2 oz/A) of product was applied]; X-77 was applied at the rate of 1169 ml/ha (16 oz/A) to all herbicide solutions.

[3]Mean values in columns or rows by location followed by the same letter are not significantly different at the 5% level using the Least Significant Difference test. $LSD_{.05}$ for values other than treatment or weeks after treatment means = 18%.

[4]Metric-English conversions: 9.4, 7.0, and 2.3 L/ha = 4, 3, and 1 qt/A; 140 g/ha = 2 oz product/A.

By 4 WAT, the treatments at Flynn produced 62 to 85% bermudagrass injury with the 7.0 and 9.4 L/ha (3 and 4 qt/A) Roundup treatments being most effective. Most herbicide treatments at Center were more effective (90-96%) than those at Flynn. All herbicide treatments were equally effective at Center at 4 WAT.

At 8 WAT, the Arsenal treatments and Roundup+Oust were most effective at Flynn. All herbicide treatments were equally effective at Center. However, the Arsenal treatments produced almost complete bermudagrass control (99%); whereas, treatments of Roundup alone or with Oust were less effective (82-84%).

At 12 WAT, the Arsenal treatments at Flynn produced 80 to 97% bermudagrass injury; whereas, Roundup alone at 7.0 or 9.4 L/ha (3 or 4 qt/A) maintained only 54 to 61% control. Likewise at Center, the Arsenal treatments maintained 96 to 99% control while the other three treatments maintained only 59 to 67% control.

Untreated plots had less plant injury than the herbicide treatments at 2, 4, 8, and 12 WAT. But bermudagrass control with Roundup alone was not better than the untreated plants at 16 WAT.

Thus, Arsenal is a promising herbicide for bermudagrass control along roadsides. It effectively controls bermudagrass over a longer summer period than either Roundup alone or with Oust.

DISCUSSION

Most results of the 1994 adjuvant study were similar to those in 1993 (Meyer et al. 1994). The pavement ratings averaged 7% higher than the shoulder ratings in 1994 compared with 6% in 1993. This is mostly due to vehicular traffic on the pavement, but higher temperature on the pavement may also contribute to the injury differential. Also, the highest injury ratings occurred at 4 WAT in both years, but the high level of control extended on to 8 WAT in 1994.

Differences in bermudagrass control occurred among locations, but generally, the treatments acted in a similar manner near Flynn, Center, and Leona over the 2 years. This gives confidence as to the use of Roundup over a wide range of soil types from the clay type soils of East Central Texas to the more sandy soils of East Texas.

In 1994, increasing rates of Roundup resulted in progressively increased bermudagrass control at 49, 56, and 64% at 3.5, 4.7, and 7.0 L/ha (1.5, 2, and 3 qt/A) rates averaged over all adjuvants and five rating dates through 16 WAT. The single 9.4 L/ha (4 qt/A) rate increased control to only 68%. Thus, each increase in rate resulted in 7 to 8% increase in bermudagrass control to 7.0 L/ha (3 qt/A). The 7.0 L/ha (3 qt/A) rate gives about the maximum efficiency in control per volume of Roundup used.

Addition of some adjuvants caused a slight increase in bermudagrass control with Roundup. Additions of Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77+AMS, and Agri-Dex averaged over three rates of Roundup and rated five times through 16 WAT increased control from 57 to 62% compared with 53% without adjuvant. It is questionable whether or not the cost of the adjuvant is worth increasing control from 4 to 9%. Only HUK-12, especially at 3.5 L/ha (1.5 qt/A), reduced the activity of Roundup compared with Roundup alone. The organic matter in the HUK-12 suspension probably partially deactivated the Roundup.

Other herbicides should be investigated for the control of bermudagrass along highways. In this study, Arsenal at 4.7 L/ha (2 qt/A) produced the most bermudagrass control at 69 to 90% over the 16 week rating period at Flynn and Center, respectively.

Actually, control 16 WAT was 61 and 88% compared with 19 to 40% with Roundup or Roundup+Oust.

The mixture of Roundup+Arsenal at 2.3+2.3 L/ha (1+1 qt/A) gave variable results. The mixture would be expected to give quick brown-out plus extended control. This occurred at Center; however, neither early injury nor sustained control through 16 WAT occurred at Flynn. The cause for the variability of results is not known unless the higher rainfall at Center leached the Arsenal more quickly to the root zone.

Further research is needed with Arsenal and other herbicides. It seems that large increases in bermudagrass control, especially for longer time periods, will require other approaches than simply adding adjuvants to Roundup.

CONCLUSIONS

1. Bermudagrass control averaged about 7% higher on the pavement than on the shoulder.
2. Over all 38 treatments and five rating dates, bermudagrass control was equal at Flynn and Center, Texas. However, control was better at Center 0-2 and 2-4 WAT and at Flynn 8-12 and 12-16 WAT.
3. Averaged over 11 adjuvants plus treatments without adjuvants, increasing Roundup rates at 3.5, 4.7, and 7.0 L/ha (1.5, 2, and 3 qt/A) caused progressively more bermudagrass control.
4. Bermudagrass control, when averaged over 38 treatments, was 54, 72, 73, 52, and 27% 2, 4, 8, 12, and 16 weeks after spraying. Maximum bermudagrass control occurred 4 to 8 weeks after treatment.
5. Averaged over three Roundup rates and five rating dates, Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, X-77+AMS, and Agri-Dex increased bermudagrass control with Roundup slightly from 57 to 62% compared to 53% with Roundup without surfactant. Most of the increases occurred at 12 WAT.
6. Averaged over three Roundup rates and five rating dates, BioPlus, Cide-Kick II, and X-77 had no effect on Roundup effectiveness; whereas, HUK-12 reduced Roundup effectiveness.
7. Arsenal at the rate of 4.7 L/ha (2 qt/A) controlled bermudagrass best of all the treatments over a 16-week period after spraying.
8. Roundup+Arsenal at 2.3+2.3 L/ha (1+1 qt/A) gave excellent bermudagrass control for 16 weeks after spraying at Center, but only 12 weeks after spraying at Flynn.
9. The addition of Oust at the rate of 140 g/ha (2 oz product/A) had no effect on bermudagrass control.
10. All herbicide treatments gave some bermudagrass control compared with the untreated plants.

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