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16. Abstract

Roundup (glyphosate) was evaluated at four rates alone and at three rates with 11 adjuvants for the control of bermudagrass [Cynodon dactylon (L.) Per.] along highways near Leona and Center, Texas, in May and June 1993. Over the 12-week rating period, bermudagrass injury averaged 6% higher on the pavement than on the shoulder. The highest ratings occurred 4 weeks after treatment (WAT). All herbicide rates were generally equally effective 2 WAT. The 7.0 L/ha (3 qt/A) rate was equally effective as the 9.4 L/ha (4 qt/A) rate and more effective than the 3.5 or 4.7 L/ha (1.5 or 2 qt/A) rates at 8 and 12 WAT. Averaged over four tests, adjuvants caused some small, but inconsistent increases in Roundup effect on bermudagrass. Roundup activity at 7.0 L/ha (3qt/A) alone was only increased slightly by Raider-TG at 2 WAT. Roundup activity at 3.5 and 4.7 L/ha (1.5 and 2 qt/A) was increased slightly by several adjuvants 8 and 12 WAT. Adjuvants had little effect by 12 WAT.

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INFLUENCE OF ADJUVANTS ON ROUNDUP® EFFECTIVENESS

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IMPLEMENTATION STATEMENT

The responses of bermudagrass [Cynodon dactylon (L.)] along highway pavement edges to several rates of Roundup alone and with adjuvants at two locations and two dates of treatment were documented and compared. The most effective treatments in 1993 should be repeated in 1994 to confirm the influence of adjuvants on the control of bermudagrass using several rates of Roundup.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation/Symbol	Item
A	Acre
ae	Acid equivalent
ai	Active ingredient
AMS	Ammonium sulfate
C	Degrees centigrade
DAT	Days after treatment
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)
I	Interstate (highway)
kg	Kilogram(s)
kPa	Kilopascal(s)
km	Kilometer(s)
km/hr	Kilometer(s)/hour
L	Liter(s)
lb	Pound(s)
m	Meter(s)
MAT	Month(s) after treatment
ml	Milliliter(s)
mm	Millimeter(s)

Abbreviation/Symbol (Cont.)	Item
mph	Mile(s) per hour
oz	Ounce(s)
ppm	Parts per million
%	Percent
pt	Pint(s)
psi	Pound(s) per square inch
qt	Quart(s)
WAT	Weeks after treatment
w/v	Weight/volume

SUMMARY

Researchers evaluated Roundup (glyphosate) at four rates alone and at three rates with 11 adjuvants for the control of bermudagrass [Cynodon dactylon (L.) Pers.] along highways near Leona and Center, Texas. Researchers conducted tests at each site in May and June in 1993. Bermudagrass injury was rated on the pavement and shoulder 2, 4, 8, and 12 weeks after each spraying.

Over the 12-week period, bermudagrass injury averaged 6% higher (75%) on the pavement than on the shoulder (69%). The highest injury ratings occurred 4 weeks after treatment (WAT). Roundup caused more bermudagrass injury at Center than near Leona. Roundup was more effective in May than June near Leona; whereas, the herbicide was about equally effective at both dates at Center.

All herbicide treatment rates were equally effective 2 WAT. The 7.0 L/ha (3 qt/A) rate was equal to the 9.4 L/ha (4 qt/A) rate at all rating dates. The 7.0 L/ha (3 qt/A) rate was more effective than the 3.5 or 4.7 L/ha (2 or 1.5 qt/A) rates at 8 and 12 WAT. The 3.5 and 4.7 L/ha (1.5 and 2 qt/A) rates without adjuvant were equal after all dates. With adjuvants, Roundup at the 4.7 L/ha (2 qt/A) rate was more effective than the 3.5 L/ha (1.5 qt/A) rate with adjuvants 4, 8, and 12 WAT.

Averaged over the four tests, surfactants caused some small, but inconsistent, increases in Roundup effect on bermudagrass. The most effective treatment was Roundup alone at 9.4 L/ha (4 qt/A). Roundup activity at 7.0 L/ha (3 qt/A) alone was only increased slightly by Raider-TG 2 WAT. Roundup activity at 4.7 L/ha (2 qt/A) alone was increased by Exacto XL, Kinetic, Raider-TG, X-77, and X-77+AMS at 4 WAT; and Apsa-80, Kinetic, and Raider-TG at 8 WAT. Roundup activity at 3.5 L/ha (1.5 qt/A) alone was increased by Raider-TG, Saturall 85, and X-77+AMS at 4 WAT and X-77+AMS at 8 WAT. Surfactants had little effect by 12 WAT.

When averaged over all three rates at 4 WAT, only the addition of X-77+AMS to Roundup, especially at Center, was more effective than Roundup alone. Roundup+Exacto XL and Roundup+HUK-12 were more effective at Center than near Leona. Roundup plus Kinetic, Raider-TG, Saturall 85, or X-77 were slightly more effective than Roundup alone in the May treatments. None of the adjuvants improved bermudagrass control in the June treatments.

INFLUENCE OF ADJUVANTS ON ROUNDUP® EFFECTIVENESS

INTRODUCTION

Bermudagrass [Cynodon dactylon (L.) Pers.] is a problem along highway pavement edges in that the rhizomes (underground stems) and stolons (horizontal above ground stems) grow under and on top of the pavement, root down in cracks in the pavement, and eventually cause breakup of the pavement. Presently, Roundup (glyphosate) is the most effective herbicide for controlling bermudagrass. Monsanto recommends a rate of 11.7 L/ha (5 qt/A) to kill 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). TxDOT is interested in increasing, or at least maintaining the same level of control, with less Roundup.

Horowitz (1972) decribed the seasonal development of bermudagrass. 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.

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 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

[1]In the literature, 1.36 kg (3 lb) ae glyphosate is considered to be present in 3.78 L (1 gallon) of Roundup.

through 10 weeks; whereas, Roundup alone failed to control bermudagrass more than 10% after 10 weeks. Surfactants, such as Tween 20, X-77, and Triton X-100 increased the effectiveness of low rates of Roundup for controlling barley (Hordeum vulgare L.), oats (Avena sativa L.), rape (Brassica campestris L.), and wheat (Triticum aestivum L); whereas, Renex 36, Cittowet Plus, and Dupont WK reduced Roundup phytotoxicity (O'Sullivan et al., 1981). Wyrill and Burnside (1977), using common milkweed (Asclepias syriaca L.) and hemp dogbane (Apocynum cannabinum L.), found ethoxylated amines were among the most effective groups of surfactants used with Roundup. Nonionic ether and ester ethyoxylates combined with a dimethyl amine or a quaternary ammonium salt were more effective than any of these surfactants alone. Changes in pH altered effectiveness of ethoxylated amine surfactants.

De Ruiter et al. (1990) reviewed spray retention by plants and suggested that surfactants enhance spray solution retention on species with a reflective, rough leaf surface such as pea (Pisum sativum L.) and barley, whereas retention on plants with a smooth leaf surface, such as radish (Raphanus sativus L.) and mustard [Brassica nigra (L.) Koch] does not change with inclusion of surfactants. The results suggest that the application rates of pesticides that have to cover the leaves of a monoculture (crops, trees, flowers, pot plants, etc.) might be reduced by adding more surfactant if the original formulation contains a small amount of surfactant, and the leaf surface is difficult to wet. However, increasing surfactant concentration in formulations may reduce herbicide selectivity.

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 was 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 2.34 L/ha (1 qt/A) of herbicide was applied 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 all diluent volumes tested. Glyphosate commercially formulated with surfactant (MON 2139), however, was more toxic to bermudagrass than MON 0139 with or without surfactant. Regrowth of bermudagrass following clipping 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) 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 Roundup was used alone, relatively hydrophilic nonionic or cationic products increased the effect most. In mixtures with ammonium sulfate, however, more lipophilic surfactants gave superior results.

Chemicals in the carrier have reduced Roundup activity. Nalewaja and Matysiak (1991) found that cation antagonism against Roundup activity decreased in the following order: iron > zinc > calcium ≥ magnesium > sodium > potassium. Nalewaja and Matysiak (1992) found that ammonium sulfate at 0.5% in a spray carrier containing calcium chloride (500 ppm calcium) partly overcame calcium antagonism of Roundup toxicity to kochia [Kochia scoparia (L.) Schrad.] and soybean [Glycine Max (L.) Merr.], overcame calcium antagonism of Roundup toxicity to wheat, and overcame antagonism and enhanced phytotoxicity to sunflower (Helianthus annuus L.).

Other herbicides have been antagonistic to Roundup activity. O'Donovan and O'Sullivan (1982) showed that a considerable reduction in absorption and translocation of ^{14}C-glyphosate occurred due to components in commercial formulations of 2,4-D [(2,4-dichlorophenoxy)acetic acid] amine, 2,4-D ester, or bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) when applied to the leaf surface . O'Sullivan and O'Donovan (1980) found tank mixtures of Roundup with several herbicides resulted in an initial reduction of Roundup activity on barley, oats, and wheat 5 days after treatment (DAT). At 34 DAT, the early differences had disappeared, and virtually all grass was dead. The early reduction in annual grass control with these mixtures was overcome in most cases by addition of surfactant.

Shea and Tupy (1984) showed Roundup phytotoxicity to wheat was greatly reduced by calcium salt in the carrier solution. Addition of the chelating agent, ethylenediamine tetraacetic acid (EDTA), restored Roundup phytotoxicity in hard water and increased phytotoxicity in deionized water. The phytotoxicity of 0.28 L/ha (3.8 oz/A) Roundup plus 1% EDTA was equal to that observed for 0.56 L/ha (7.7 oz/A) of the herbicide alone in deionized water or 1.12 L/ha (15.4 oz/A) in water containing 200 ppm calcium salt. EDTA increased Roundup phytotoxicity to wheat when applied in water that contained high levels of calcium and bicarbonate. Roundup activity was greater at pH 4 than at pH 6 or 10, but EDTA was equally effective at pH 4, 6, or 10 for all levels of calcium tested up to 800 ppm. Sodium bicarbonate probably reduced phytotoxicity by increasing the pH of the Roundup solution.

Carrier volume has had 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) when Roundup was applied to bermudagrass at a 1.0 and 1.5% v/v solution. However, greater herbicide phytotoxicity occurred at 373 L/ha (40 gal/A) than 94 L/ha (10 gal/A) when the Roundup rate was reduced to 0.5% v/v. The reason for this was that bermudagrass is difficult to wet, and, therefore, responds to a larger volume of carrier when a low rate of herbicide is applied.

Environmental factors including water availability and humidity have influenced Roundup activity. Buhler and Burnside (1983a) and Waldecker and Wyse (1985) found that Roundup was more effective for controlling actively growing volunteer oats, several grass weeds, and common milkweed plants because of adequate soil moisture and favorable temperatures than when the plants were under moisture stress.

Jordan (1977) found visible injury to bermudagrass with 1.56 L/ha (21.3 oz/A) of Roundup was greater at 100% than at 40% relative humidity 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.

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. Eleven adjuvants of various types were added to three rates of Roundup at two Texas locations at two times of the year. 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 compare May versus June treatments of Roundup, (4) to evaluate the phytotoxicity of various rates of Roundup, and (5) to determine the influence of various adjuvants for increasing the effectiveness of Roundup.

THE PROBLEM

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. Desirable vegetation should be low-growing to prevent visibility obstruction and should be viable throughout the growing season. A mixture of desirable species is usually preferred to a single species. Bermudagrass is considered a desirable grass when growing on the shoulder. However, grasses such as bermudagrass and johnsongrass readily produce rhizomes, and in the case of bermudagrass, stolons that can encroach under or onto the pavement. These horizontal growing stems produce buds which can root down and produce plants in pavement cracks, especially along the edge where traffic is light. Over a period of time, this vegetation can enlarge the fissures causing breakdown of the pavement. Thus, a method is needed to enhance vegetation growth on the shoulder without allowing the encroachment onto the pavement.

The Texas Department of Transportation uses the herbicide, Roundup, to control encroaching vegetation along pavement edges. The recent increased 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. Roundup is presently used along pavement edges at the rate of 7.0 L/ha (3 qt/A). There is a need to develop a maintenance procedure to attain the same, or better bermudagrass control with less herbicide. In other uses, adjuvants such as surfactants, spreaders, stickers, and oils have, at times, increased the activity of herbicides. The possibility of enhancing Roundup effectiveness for controlling bermudagrass encroachment on highway pavement edges was investigated in this study.

MATERIALS AND METHODS

Researchers conducted four tests on dense stands of bermudagrass growing along highways at two Texas locations. One test was established at each site in May and June 1993. One test area was situated along FM 2845 between Old San Antonio Road and FM 977 about 4.8 km (3 miles) west of Highway I-45 near Leona, Texas. The other test site was established on Loop 500 on the south and east side of Center, Texas. The soil near Leona was a sandy clay to a clay loam; whereas, the soil at Center was a sandy loam to a sandy clay loam.

Two sets of plots were established at both sites. The plots were 18.2 m (60 ft) long. Plots sprayed in May 1993 were 0.8 m (2.5 ft) wide with half on the pavement edge (pavement) and half off the pavement (shoulder). Plots sprayed in June were made 1.5 m (5 ft) wide because bermudagrass occurred more than 0.3 m (1 ft) onto the pavement. The wider plots in the June treatments 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.

All four tests included 38 treatments. Roundup {360 g/L [3 lb ae/gal] of the isopropylamine salt of glyphosate [N-(phosphonomethyl)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. Descriptions of the adjuvants are presented in Table 1. The adjuvants were added at the same maximum recommended rate to the three rates of Roundup. Also, untreated plots were included. Adjuvants and rates for sprays applied at a volume of 234 L/ha (25 gal/A) in ml/ha (oz/A) were Apsa-80 - 365 ml/ha (5 oz/A), BioPlus SS 100 (BioPlus) - 183 ml/ha (2.5 oz/A), Cide-Kick II - 4676 ml/ha (64 oz/A), Exacto XL - 292 ml/ha (4 oz/A), Kinetic - 877 ml/ha (12 oz/A) in May treatments and 219 ml/ha (3 oz/A) in June treatments, Raider-TG - 1169 ml/ha (16 oz/A), Saturall 85 - 292 ml/ha (4 oz/A), X-77 - 1169 ml/ha (16 oz/A), X-77+ ammonium sulfate (AMS) - 1169 ml/ha (16 oz/A) + 2% (4.68 kg/ha or 4.2 lb/A w/v), Huk-12 HERBISPRAY (HUK-12) - 2338 ml/ha (32 oz/A), and Agri-Dex - 2338 ml (32

Table 1. Adjuvants used with Roundup sprays along highway pavement edges in two tests each near Leona and Center, Texas, in 1993 (Harvey 1992).

Adjuvant	Rate used per 234 L/ha (25 gal/A)	Activity type	Chemical composition		Manufacturer
			Percent ai[1]	Chemistry	
Apsa-80	365 ml/ha (5 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	877 ml/ha in May (12 oz/A); 219 ml/ha in June (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 oxice 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 + 2% w/v (16 oz/A)	Spreader, activator	90% + 100%	Same as above + reagent grade diammonium 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 petroleium oil, polyol fatty acid esters, polyethoxylated derivatives thereof	Helena Chemical Co., Memphis, TN

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

oz).

Applications were made using a wheel-mounted experimental plot sprayer. May treatments were sprayed with a boom equipped with two 6503 Teejet nozzles giving a swath of 0.8 m (2.5 ft) using compressed air at 207 kPa (30 psi). June treatments were sprayed with a boom having three 8003 Teejet nozzles giving a 1.5 m (5 ft) swath. The sprays were applied half on the pavement and half on the adjoining shoulder.

The spring of 1993 was relatively cool and wet in Texas. The first test at each site was sprayed May 10-12, 1993. At this time the bermudagrass had just started to grow. The plants had stems with leaves 25 to 76 mm (1 to 3 inches) tall, and the plants were just beginning to produce stolons. The second set of tests were applied June 7-12, 1993. At this time to stems were 51 to 127 mm (2 to 5 inches) tall and stolons were up to 10 cm (4 inches) long.

Vegetation at both sites overshadowed the bermudagrass on the shoulder at spraying time in May. Herbaceous vegetation at Leona consisted largely of rescuegrass (Bromus catharticus Vahl) and Texas wintergrass (Stipa leucotricha Trin. & Rupr.); whereas, the vegetation at Center was almost entirely crimson clover (Trifolium incarnatum L.) in the blooming stage. Consequently, both locations were mowed to about a 102 mm (4-inch) height about 1 week before spraying. The dead mowed vegetation was removed from the plot areas by hand raking near Leona and by sweeping with a tractor-mounted rotating cleaner. The area at Center used for the June treatments also had to be mowed again before spraying because of the tall vegetation, primarily of bahiagrass, (Paspalum notatum Fluegge). Maximum and minimum temperatures the day of spraying were about 10 to 27 C (50 to 80 F) in May and 24 to 32 C (75 to 90 F) in June. Wind was from the southwest at 0 to 16 km/hr (0 to 10 mph). In May, no rain fell for more than 25 hours after spraying near Leona. At Center, however, about 4.6 mm (0.18 inch) of rain fell 4 to 8 hours after spraying treatments of Roundup alone, Roundup+Apsa-80, and Roundup+BioPlus; the remaining treatments were sprayed the next day. In June, about 15 mm (0.6 inch) of rain fell near Leona about 16 hours after spraying. No rain fell within 24 hours after spraying at Center in June.

Rainfall[2] 0-2, 3-4, 5-8, and 9-12 WAT in May was about 51, 30, 450, and 0 mm (2.0, 1.2, 17.7, and 0.0 inches) near Leona and 30, 0, 226, and 28 mm (1.2, 0.0, 8.9, and 1.1 inches) at Center, respectively. Rainfall at the same periods after the June treatments was 437, 8, 0, and 18 mm (17.2, 0.3, 0.0, and 0.7 inches) near Leona and 122, 124, 23, and 23 mm (4.8, 4.9, 0.9, and 0.9 inches) at Center, respectively.

Researchers rated all plots in the four tests 2, 4, 8, and 12 WAT. Bermudagrass plants in up to ten 152 x 305 mm (6 x 12-inch) areas both on the shoulder and pavement along the pavement edge at approximately equal intervals through each plot were rated for percent plant injury. Ratings were 0% for no injury to 100% for dead foliage. Statistical analyses of variance, using a general linear method to account for unequal size classes, were calculated on data of each test taken at individual dates both as a randomized complete block design for all treatments and as a factorial design for herbicide rate x adjuvant. Also, the same analyses were calculated for combined data from all four tests on the 4-week rating and on the combined mean of all four rating periods. Means for treatments and herbicide rate x adjuvant were separated by the Least Significant Difference test (LSD) at the 5% level.

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[2]Rainfall is reported from the Centerville [about 16 km (10 miles) from Leona] and Center, Texas, weather stations as recorded from N.O.A.A., Ashville, South Carolina.

RESULTS AND DISCUSSION

SHOULDER VERSUS PAVEMENT

Bermudagrass injury averaged 6% higher on the pavement than on the shoulder (75% verses 69%) when averaged over four rating periods in all treatments in four tests (Table 2). The differences were lowest 4 WAT and most pronounced 12 WAT. Bermudagrass was injured more on the pavement in 11 of the 16 interaction comparisons than on the shoulder in the four tests (Table 3). This presumably occurred because of the higher temperature of the pavement than the soil on the shoulder. Also, rain was most likely to flow off the pavement onto the shoulder, thus stimulating grass recovery there.

Because shoulder and pavement data generally followed the same pattern, all further results in the discussion are expressed as means of the two ratings.

DATE RESULTS

Injury ratings 4 WAT were the highest in all tests (Tables 2 and 3). Roundup had begun killing bermudagrass foliage within 2 weeks, but injury reached a maximum 4 WAT. By 8 and 12 WAT, regrowth had begun to occur. The difference between shoulder and pavement ratings was least 4 WAT and most 12 WAT. Bermudagrass recovery seemed to be directly related to the amount of rainfall following spraying. Injury ratings remained high through 12 weeks in three tests. In the June Leona test, however, more than 432 mm (17 inches) of rain fell in the 2-week period following treatment, apparently resulting in unusually low injury ratings, particularly 12 WAT.

INDIVIDUAL TESTS

Bermudagrass control was higher at Center than near Leona (Table 3). Mean control over four dates for all treatments was 78 and 75% for the May and June tests at

Table 2. Percent injury of bermudagrass on the shoulder and adjoining pavement at four periods after spraying, averaged over 38 treatments in two tests each near Leona and Center, Texas, in 1993.

Weeks after treatment	Highway area rated		Mean[1]
	Shoulder	Pavement	
	------------------------ Percent plant injury ------------------------		
2	70	74	72 b
4	83	84	84 a
8	67	74	70 b
12	56	68	62 c
Mean[1]	69 b	75 a	

[1]Values in column or row followed by the same letter are not statistically different at the 5% level using the Least Significant Different test. Least Significant Difference for highway area x weeks after treatment = 6.

Table 3. Percent injury of bermudagrass along highways from 38 Roundup treatments after four periods in two tests each near Leona and Center, Texas, in 1993[1].

Weeks after spraying	Leona, May test			Center, May test			Leona, June test			Center, June test		
	Shoul-der	Pave-ment	Mean	Shoul-der	Pave-ment	Mean	Shoul-der	Pave-ment	Mean	Shoul-der	Pave-ment	Mean
	---------- Percent plant injury ----------											
2	70	73	72	74	80	77	71	75	73	67	68	68
4	79	83	81	88	88	88	79	80	80	85	87	86
8	63	70	66	67	79	73	59	60	60	78	86	82
12	66	73	69	68	83	76	38	41	40	53	77	65

[1]Spraying dates were--Leona May test, May 10-11; Center May test, May 11-12; Leona June test, June 9; Center June test, June 7. Least Significant Difference at the 5% level for shoulder x pavement within test = 3%.

Center, respectively; whereas, bermudagrass injury in the May and June tests near Leona was 72 and 63% respectively. Control may have been higher at Center than near Leona because the soil was more sandy and thus, more subject to drought.

RATE RESULTS

Table 4 presents results of all Roundup rates with and without adjuvant averaged over all four tests. Data for treatments with adjuvants are means of the 11 different chemicals. The LSD values for rates with no adjuvant are not directly comparable with those with adjuvants because of the difference in numbers of entries. However, the numbers do give an indication of the overall adjuvant effect. Adjuvants increased control about 4, 6, and 5% at 2, 4, and 8 WAT, respectively, and had no effect at 12 WAT. Thus, overall, adjuvants averaged increasing control about 5% through 8 WAT.

All herbicide rates gave similar bermudagrass control 2 WAT (70 to 78%)(Table 4). The 7.0 and 9.4 L/ha (3 and 4 qt/A) rates were more effective than the 3.5 L/ha (1.5 qt/A) rate at 4 WAT (72 to 94%). The 7.0 and 9.4 L/ha (3 and 4 qt/A) rates were more effective than the 3.5 or 4.7 L/ha (1.5 or 2 qt/A) rates 8 WAT (59 to 82%). This finding supports the TxDOT recommendation of 7.0 L/ha (3 qt/A). By 12 WAT, bermudagrass had begun reinvading the treated areas, and herbicide rate differences had essentially disappeared (57 to 67%).

INDIVIDUAL TREATMENT EFFECTS OVER 12 WEEKS AFTER TREATMENT

Table 5 summarizes mean percent bermudagrass control recorded at 2, 4, 8, and 12 WAT by 38 treatments in two tests each at Center and near Leona. These data summarize the mean results of the four tests through the entire experimental period. Researchers calculated LSD's for each rating period.

At 2 WAT, only Raider-TG in Roundup at 7.0 L/ha (3 qt/A) was slightly better than the standard highway pavement edge treatment of Roundup at 7.0 L/ha (3 qt/A) without adjuvant (Table 5). No other treatment at any other date was superior to 7.0

Table 4. Percent injury of bermudagrass by five rates of Roundup alone and three rates with adjuvants 2, 4, 8, and 12 weeks after spraying, averaged over two tests each near Leona and Center, Texas, in 1993.

Weeks after treatment	Roundup rate	Bermudagrass control[1]		Control change with adjuvant
		No adjuvant	With adjuvant	
	L/ha (Qt/A)	---------------- Percent plant injury ----------------		
2	9.4 L/ha (4)	78 a		
	7.0 L/ha (3)	70 a	78 a	8
	4.7 L/ha (2)	70 a	74 ab	4
	3.5 L/ha (1.5)	71 a	70 b	-1
	0	20 b		
4	9.4 L/ha(4)	94 a		
	7.0 L/ha (3)	88 ab	91 a	3
	4.7 L/ha (2)	77 bc	86 b	9
	3.5 L/ha (1.5)	72 c	79 c	7
	0	30 d		
8	9.4 L/ha (4)	82 a		
	7.0 L/ha (3)	77 a	78 a	1
	4.7 L/ha (2)	62 b	71 b	9
	3.5 L/ha (1.5)	59 b	63 c	4
	0	46 c		
12	9.4 L/ha (4)	66 a		
	7.0 L/ha (3)	67 a	66 a	-1
	4.7 L/ha (2)	61 a	62 b	1
	3.5 L/ha (1.5)	58 ab	57 c	-1
	0	49 b		

[1]Values within columns by week of rating after treatment followed by the same letter are not significantly different at the 5% level using the Least Significant Difference test.

Table 5. Percent injury of bermudagrass by Roundup alone and with 11 adjuvants 2, 4, 8, and 12 weeks after spraying, averaged over May and June tests both near Leona and Center, Texas, in 1993.

Weeks after treat-ment	Round-up rate[1]	Adjuvant added to Roundup[2]											
		None	Apsa	BioPl	Cd-Kk	EX-XL	Kinet	Raid	Satul	X-77	X+ AMS	HUK	Agr-D
	L/ha	---------- Percent plant injury ----------											
2 Wk	9.4	78											
	7.0	70	75	78	72	75	79	83	78	77	80	77	78
	4.7	70	70	72	74	68	79	76	78	78	76	70	72
	3.5	71	64	58	60	71	68	75	76	74	77	71	73
	0	20											
Mean		70[3]	70	69	69	71	75	78	77	76	78	73	74
		At 2 Weeks, LSD for Adjuvant Mean = 7, Adjuvant x Rate = 12											
4 Wk	9.4	94											
	7.0	88	92	93	90	88	93	90	92	92	95	87	91
	4.7	77	85	81	82	88	89	89	87	90	88	80	86
	3.5	72	74	70	74	80	78	87	84	82	90	71	78
	0	30											
		79[3]	84	81	82	85	87	89	88	88	91	79	85
		At 4 Weeks, LSD for Adjuvant Mean = 6, Adjuvant x Rate = 11											

Table 5. (Cont.)

Weeks after treatment	Roundup rate	Adjuvant added to Roundup											
		None	Apsa	BioPl	Cd-Kk	EX-XL	Kinet	Raid	Satul	X-77	X+A MS	HUK	Agr-D
	L/ha	---Percent plant injury---											
8 Wk	9.4	82											
	7.0	77	78	76	68	79	78	83	87	76	79	76	80
	4.7	62	75	69	68	71	76	77	72	70	72	63	68
	3.5	59	60	60	58	66	60	70	68	66	75	56	59
	0	46											
Mean		66[3]	71	68	65	72	71	77	76	71	75	65	69
		At 8 Weeks, LSD for Adjuvant Mean = 7, Adjuvant x Rate = 12											
12 Wk	9.4	66											
	7.0	67	66	67	66	70	65	68	67	67	64	66	64
	4.7	61	66	65	62	64	64	63	64	63	63	56	58
	3.5	58	60	53	58	61	56	60	61	56	64	54	58
	0	49											
Mean		62[3]	64	62	62	65	62	64	64	62	61	59	60
		At 12 Weeks, LSD for Adjuvant Mean = 5, Adjuvant x Rate = 8											

Table 5. (Cont.)

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[1]9.4, 7.0, 4.7, and 3.5 L/ha = 4, 3, 2, and 1.5 qt/A.

[2]Adjuvants are: None=Roundup alone, Apsa=Apsa-80 at 365 ml/ha (5 oz/A), BioPl=BioPlus SS 100 at 183 ml/ha (2.5 oz/A), Cd-Kk=Cide-Kick II at 4676 ml/ha (64 oz/A), EX-XL=Exacto XL at 292 ml/ha (4 oz/A), Kinet=Kinetic at 219 or 877 ml/ha (3 or 12 oz/A), Raid=Raider-TG at 1169 ml (16 oz/A), Satul=Saturall 85 at 292 ml/ha (4 oz/A), X-77=X-77 at 1169 ml/ha (16 oz/A), X-77+AMS= X-77+ammonium sulfate at 1169 ml (16 oz/A)+2% w/v, HUK=HUK-12 at 2338 ml (32 oz/A), and Agr-D=Agri-Dex at 2338 ml/ha (32 oz/A) all at a 234 L/ha (25 gal/A) rate. LSD = Least Significant Difference test at the 5% level.

[3]Means for 7.0, 4.7, and 3.5 L/ha (3, 2, and 1.5 qt/A) rates.

L/ha (3 qt/A) of Roundup alone. Only the untreated plants had less injury than the 7.0 L/ha (3 qt/A) rate of Roundup alone at 2 WAT.

At 2 WAT, Raider-TG in Roundup at 7.0 L/ha 3 qt/A) was more effective than Roundup alone at 4.7 L/ha (2 qt/A) (Table 5). Roundup at 3.5 L/ha (1.5 qt/A) with Raider-TG was slightly more effective than Roundup alone at 3.5 L/ha (1.5 qt/A). Otherwise, Roundup alone at 3.5 L/ha (1.5 qt/A) was equal to all other treatments, except the untreated plants. The untreated plots had less plant injury than any herbicide treatment.

At 4 WAT, no treatments were superior to Roundup alone at 7.0 L/ha (3 qt/A), but Roundup alone at 4.7 L/ha (2 qt/A); Roundup at 3.5 L/ha (1.5 qt/A) alone or with Apsa-80, BioPlus, Cide-Kick II, or HUK-12 were less effective (Table 5). Roundup alone at 9.4 L/ha (4 qt/A); Roundup at 7.0 L/ha (3 qt/A) with all adjuvants except HUK-12; Roundup at 4.7 L/ha 2 qt/A) with Exacto XL, Kinetic, Raider-TG, X-77, and X-77+AMS; and Roundup at 3.5 L/ha (1.5 qt/A) with X-77+AMS were superior to Roundup alone at 4.7 L/ha (2 qt/A). Roundup at 9.4 L/ha (4 qt/A); Roundup at 7.0 L/ha (3 qt/A) with all adjuvants; and Roundup at 3.5 L/ha (1.5 qt/A) with Raider-TG, Saturall 85, and X-77+AMS were more effective than Roundup alone at 3.5 L/ha (1.5 qt/A). The untreated plots had less bermudagrass injury than any herbicide treatment.

At 8 WAT, no treatment was more effective than Roundup alone at 7.0 L/ha (3 qt/A) (Table 5). Roundup at 4.7 L/ha (2 qt/A) alone or with HUK-12; Roundup at 3.5 L/ha (1.5 qt/A) with no adjuvant or with Apsa-80, BioPlus, Cide-Kick II, Kinetic, HUK-12, or Agri-Dex were less effective than Roundup alone at 7.0 L/ha (3 qt/A). Roundup at 9.4 L/ha (4 qt/A) alone; Roundup at 7.0 L/ha (3 qt/A) alone or with all adjuvants, except Cide-Kick II; Roundup at 4.7 L/ha (2 qt/A) with Apsa-80, Kinetic, and Raider-TG; and Roundup at 3.5 L/ha (1.5 qt/A) with X-77+AMS were more effective than Roundup alone at 4.7 L/ha (2 qt/A). Roundup at 9.4 L/ha (4 qt/A); Roundup at 7.0 L/ha (3 qt/A) with all adjuvants except Cide-Kick II; Roundup at 4.7 L/ha (2 qt/A) with Apsa-80, Exacto XL, Kinetic, Raider-TG, Saturall 85, and X-77+AMS; and Roundup with X-77+AMS were more effective than Roundup alone at 3.5 L/ha (1.5 qt/A). The untreated plots had less bermudagrass injury than in any other treatment, except Roundup with Cide-Kick II or HUK-12 in Roundup at 3.5 L/ha (1.5 qt/A).

At 12 WAT, no treatments were more effective than Roundup at 7.0 L/ha (3 qt/A) alone, but Roundup at 4.7 L/ha (2 qt/A) with HUK-12 or Agri-Dex; all treatments with Roundup at 3.5 L/ha (1.5 qt/A), except Apsa-80, Exacto XL, Raider-TG, Saturall 85, or X-77+AMS were less effective (Table 5). Roundup at 7.0 L/ha (3 qt/A) with Exacto XL was superior to Roundup alone at 4.7 L/ha (2 qt/A). Roundup at 9.4 L/ha (4 qt/A); Roundup at 7.0 L/ha (3 qt/A) alone or with all adjuvants except X-77+AMS or Agri-Dex; and Roundup at 4.7 L/ha (2 qt/A) with Apsa-80 or BioPlus were more effective than Roundup alone at 3.5 L/ha (1.5 qt/A). The untreated plots had less bermudagrass injury than any other treatments.

Because of the increasing air temperature and reduction in effective rainfall during the growing season, bermudagrass injury in the untreated plots increased progressively at 20, 30, 46, and 49% at 2, 4, 8, and 12 WAT, respectively (Table 5).

Thus, throughout the study, there were some bermudagrass control increases due to the addition of adjuvants. But the increases were generally small and not consistent. Roundup caused maximum control at 4 WAT, but the bermudagrass began reinvading the treated areas. Consequently, the adjuvants failed to extend the effectiveness of Roundup alone. Therefore, it appears that Roundup can be used to kill the foliage of bermudagrass rapidly; however, another herbicide with residual activity will need to be applied also to provide year-long bermudagrass control. The additional herbicide should be applied at a rate sufficient to kill the existing bermudagrass without leaving the shoulder devoid of vegetation.

HERBICIDE EFFECTS 4 WEEKS AFTER TREATMENT

The highest injury ratings occurred 4 WAT. These ratings were considered most significant to show effectiveness of the treatments.

Table 6 shows results of location and test date x adjuvant data summarized over three herbicide rates. Over all rates, only X-77+AMS, of all the adjuvants, was

Table 6. Percent injury of bermudagrass 4 weeks after treatment with Roundup alone and with 11 adjuvants at two locations and at two dates in 1993, averaged over three rates.

Adjuvant	Location		Test date		Mean[1]
	Leona	Center	May	June	
Apsa-80	86	82	80	87	84 ab
BioPlus	84	79	80	83	81 ab
Cide-Kick II	80	85	83	82	82 ab
EXACTO XL	78	92	85	85	85 ab
Kinetic	81	92	91	82	87 ab
Raider-TG	86	91	93	84	89 ab
Saturall 85	82	92	91	84	87 ab
X-77	85	91	90	86	88 ab
X-77+AMS	86	96	89	92	91 a
HUK-12	72	87	85	73	79 b
Agri-Dex	80	90	87	83	85 ab
None	78	79	76	81	79 b
Mean[1]	81 b	88 a	86 a	84 a	

[1]Values in column or row followed by the same letter are not significantly different at the 5% level using the Least Significant Difference test. Least Significant Difference for location or test date x adjuvant = 14.

more effective than Roundup without an adjuvant, and this occurred primarily at Center. Over three herbicide rates and all adjuvants in two tests, herbicide treatments caused more bermudagrass injury at Center than near Leona. Exacto XL and HUK-12 were more effective at Center than near Leona. This was probably due to the more sandy soil at Center than near Leona.

Over three herbicide rates at two locations, ratings for the May test were similar to those made in the June test (Table 6). By adjuvant, however, Kinetic, Raider-TG, Saturall 85, and X-77 caused more injury than Roundup alone in May; no adjuvant treatment was more effective than Roundup alone in June treatments.

Table 7 presents the mean percent bermudagrass injury results 4 WAT in two tests each near Leona and at Center, Texas, that indicates the adjuvant x Roundup rate effect. Over all rates, only X-77+AMS added to Roundup was more effective than Roundup alone.

Increasing Roundup rates progressively increased overall bermudagrass injury from 78 to 91% (Table 7). Roundup was more effective at Center, causing 83, 88, and 93% bermudagrass plant injury at 3.5, 4.7, and 7.0 L/ha (1.5, 2, and 3 qt/A) rates, respectively; whereas, the same rates caused 73, 82, and 89% plant injury near Leona. Rate results by WAT of test showed the same trends as the means (Table 4).

Table 7. Percent injury of bermudagrass 4 weeks after treatment by three rates of Roundup alone or with 11 adjuvants, averaged over May and June tests near Leona and Center, Texas, in 1993.

Adj No.	Adjuvant	Adjuvant rate at 234 L/ha (25 gal/A)	Roundup rate[1]			Mean
			7.0 L/ha (3 qt/A)	4.7 L/ha (2 qt/A)	3.5 L/ha (1.5 qt/A)	
			---------- Percent plant injury ----------			
1.	Apsa-80	365 ml/ha (5 oz/A)	92	85	74	84 ab
2.	BioPlus	183 ml/ha (2.5 oz/A)	93	81	70	81 ab
3.	Cide-Kick II	4676 ml/ha (64 oz/A)	90	82	74	82 ab
4.	Exacto XL	292 ml/ha (4 oz/A)	88	88	80	85 ab
5.	Kinetic	877 ml/ha (12 oz/A)	93	89	78	87 ab
6.	Raider-TG	1169 ml/ha (16 oz/A)	90	89	87	89 ab
7.	Saturall 85	292 ml/ha (4 oz/A)	92	87	84	87 ab
8.	X-77	1169 ml/ha (16 oz/A)	92	90	82	88 ab
9.	X-77+AMS[2]	1169 ml/ha+2% (16 oz/A)	95	88	90	91 a
10.	HUK-12	2338 ml/ha (32 oz/A)	87	80	71	79 b
11.	Agri-Dex	2338 ml/ha (32 oz/A)	91	86	78	85 ab
12.	None		88	77	72	79 b
Mean			91 a	85 b	78 c	

[1]Percent plant injury for 9.4 L/ha (4 qt/A) without adjuvant = 94%, and untreated plots = 30%. Values in mean column or row, respectively, followed by the same letter are not significantly different at the 5% level using the Least Significant Difference test. Least Significant Difference for rate x adjuvant = 15%.
[2]Ammonium sulfate (AMS), reagent grade was added at 2% (w/v).

CONCLUSIONS

1. Pavement ratings averaged 6% higher (75% vs 69%) compared with shoulder ratings over a 12-week period after spraying.
2. The highest injury ratings occurred 4 WAT compared with those taken 2, 8, or 12 WAT.
3. Roundup caused more bermudagrass injury at Center (May 78%; June 75%) than near Leona (May 72%; June 63%) when averaged over four rating periods.
4. Roundup was more effective in May than June near Leona; whereas, it was about equally effective at both dates at Center when data were averaged over four rating periods.
5. All herbicide rates were equally effective 2 WAT. The 7.0 L/ha (3 qt/A) rate was equal to the 9.4 L/ha (4 qt/A) rate at 4, 8, and 12 WAT. The 3.5 and 4.7 L/ha (1.5 and 2 qt/A) rates without adjuvant were equal after all dates, but they were less effective than the 7.0 L/ha (3 qt/A) rate 8 WAT. By 12 WAT, all rates had similar activity.
6. Roundup at 3.5 L/ha (1.5 qt/A) with adjuvants was less effective than at the 4.7 L/ha (2 qt/A) rate 4, 8, and 12 WAT.
7. Over the 12-week period, Roundup activity at 7.0 L/ha (3 qt/A) alone was only increased by Raider-TG 2 WAT.
8. Activity of Roundup at rates of 3.5 and 4.7 L/ha (1.5 and 2 qt/A) was increased slightly by some adjuvants 4 and 8 WAT, but the increases were not consistent throughout the study.
9. When averaged over all three rates at 4 WAT, only the addition of X-77+AMS to Roundup, especially at Center, was more effective than Roundup alone. Roundup+Exacto XL and Roundup+ HUK-12 were more effective at Center than near Leona. Roundup+Kinetic, Raider-TG, Satural 85, or X-77 were slightly more effective than Roundup alone in the May treatments. None of the adjuvants improved bermudagrass control in the June treatments.

10. None of the herbicide treatments with or without adjuvants controlled bermudagrass completely even to 12 WAT.

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