AN ABSTRACT OF THE THESIS OF

Luis Carlos Salazar for the degree of Master of Science

in Crop Science presented on July 9, 1981

Title: EFFECT OF GLYPHOSATE WHEN APPLIED TO GRASS AND LEGUME SEEDS OR PREEMERGENCE TO BENTGRASS (*AGROSTIS TENUIS* SIBTH.)

Abstract approved: Redacted for privacy

Dr. Arnold P. Appleby

Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) and glyphosate [*N* (phosphonomethyl)glycine] are herbicides utilized for chemical seedbed preparation in the establishment of grass and legume seed crops. When these herbicides are applied after seeding the crop, seeds which are not protected by a layer of soil could be exposed to the herbicide. Effects of paraquat on exposed seeds have been studied previously, but more information was needed on effects from glyphosate.

Greenhouse studies were conducted using direct applications of glyphosate and paraquat over exposed seeds of six grass species: Kentucky bluegrass, perennial ryegrass, bentgrass, tall fescue, fine fescue, and orchardgrass; and two legume species, alfalfa and red clover.

Glyphosate tended to be toxic to all species tested, reducing germination and particularly seedling growth. Paraquat was toxic

only to grasses and did not affect legumes. The major detrimental effect of glyphosate on legume seeds and seedlings was caused by direct contact of the herbicide with seeds, but a minor effect was detected when untreated seeds were transferred to treated soil, indicating that glyphosate was not inactivated in soil as fast as paraquat. These results indicate that the use of glyphosate in chemical seedbed preparation may be detrimental to the new crop if the herbicide is applied directly to exposed seeds.

Glyphosate has been reported by many research workers to be inactivated almost immediately upon contact with the soil. However, a few growers in western Oregon have reported phytotoxic effects on grass seedlings when glyphosate applications were made shortly before emergence of the crop. Greenhouse studies were conducted to determine whether glyphosate could have herbicidal activity when applied directly to soil prior to bentgrass emergence (from 1 to 5 days) and to examine some soil factors involved.

Soil activity of glyphosate differed considerably among three high-organic soils and one mineral soil. The soils in which glyphosate was most active contained the highest levels of organic matter (64% and 28%), but there was no strong correlation with organic matter content in the other soils or in soil blends containing various levels of organic matter. Varying phosphorus levels did not significantly influence activity of glyphosate.

There was no evidence that glyphosate formed an inactive complex with Fe or Al. The two soils in which glyphosate was most active, organic soils No. 3 and 4, contained the highest levels of Fe and at least equal levels of Al.

Increasing pH increased glyphosate activity markedly in the mineral soil and one high-organic soil, while slightly decreasing activity in two high-organic soils. Although none of these soil factors proved conclusively to be entirely responsible for variations in glyphosate soil activity, general results from the series of experiments indicated that glyphosate can definitely be taken up from soil by crop plants and produce injury. The herbicide remained available in the soil solution for sufficient time to cause significant plant growth reduction. Consequently, a waiting period of several days should elapse from glyphosate treatment to emergence of a crop.

EFFECT OF GLYPHOSATE WHEN APPLIED TO GRASS AND LEGUME SEEDS OR PREEMERGENCE TO BENTGRASS (*AGROSTIS TENUIS* SIBTH.)

by

Luis Carlos Salazar

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 1981

Commencement June 1982

APPROVED:

Redacted for privacy

Professor of Crop Science in charge of major

Redacted for privacy

Head of Department of Crop Science

Redacted for privacy

Dean of Graduate School

Date thesis is presented July 9, 1981

Typed by Gloria M. Foster for Luis Carlos Salazar

DEDICATION

I would like to dedicate this thesis to my lovely wife, Vilma, for her love, unending patience, understanding, and faithful support. As ever, she was a constant source of encouragement and inspiration. Her supportive and encouraging attitude has impressed me to a great extent.

Special recognition goes to my parents, Carmen María and Julio César Salazar, my brothers, sister, and family who, although far away from here, I have always kept in my mind; they were a source of moral support.

ACKNOWLEDGMENTS

My sincere appreciation to Dr. Arnold P. Appleby for his guidance, patient counseling, and encouragement throughout the period of my Master's program as well as for his critical review and constructive suggestions concerning the writing of this thesis.

A special thanks is expressed to Mr. Larry Burrill, Dr. Kenton L. Chambers, and Dr. David C. Church for serving on my graduate committee.

I am grateful to the staff members of the weed control project and International Plant Protection Center for their assistance and friendship, and to my fellow graduate students for their constant support and companionship.

I thank the Latin American Scholarship Program of American Universities (LASPAU) which provided financial support during my studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

EFFECT OF GLYPHOSATE WHEN APPLIED TO GRASS AND LEGUME SEEDS OR PREEMERGENCE TO BENTGRASS (*AGROSTIS TENUIS* SIBTH.)

GENERAL INTRODUCTION

Paraquat and glyphosate are herbicides which have been utilized successfully for chemical seedbed preparation in the establishment of grass seed crops. This technique involves the mechanical preparation of a seedbed, allowing weeds to germinate, and then killing the weeds chemically, either prior to seeding the crop or after crop seeding but before emergence.

When herbicides are applied after seeding the crop, some crop seeds may not be covered by a layer of soil and, therefore, could be exposed to direct contact with the herbicide. Appleby and Brenchley (1) reported that direct application of paraquat to seeds of several grass species was detrimental to germination and growth. However, more information is needed on the effects of glyphosate applied in this manner.

In general, paraquat and glyphosate are considered to be inactive when applied to soil. Either of these materials may be legally applied any time before emergence of the crop. However, Brewster and Appleby (4) showed that glyphosate can affect emerging shoots of wheat when applied prior to emergence. Growers have reported unexpected effects on grass seedlings when glyphosate applications were made shortly before emergence of the crop.

The objectives of this study were to: (a) evaluate the influence of glyphosate on germination and seedling growth of grass and legume species in comparison to paraquat, (b) determine whether or not glyphosate could have herbicidal activity when applied directly to soil, and (c) examine some soil factors which might influence the soil activity of glyphosate.

Objective (a) is addressed in Section I. Objectives (b) and (c) are addressed in Section II. Both sections are written in the general format of the WEED SCIENCE journal.

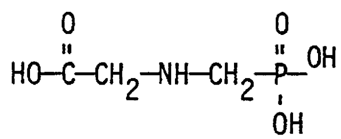
SECTION I

Effect of Glyphosate and Paraquat Application to Exposed Seeds

INTRODUCTION

General Properties of Glyphosate and Paraquat

Glyphosate [N-(phosphonomethyl)glycine], formulated as the isopropylamine salt, is a non-selective postemergence herbicide. It has a high degree of herbicidal activity, effectively controlling both annual and perennial herbaceous plants. It has been reported to be inactivated by soil components and its toxicity to mammals is low (2). It is relatively immobile and does not readily leach or move downward with subsequent water application (19, 21). It is susceptible to biodegradation and decomposition in the soil (19, 21, 23). The molecular configuration of glyphosate is as follows:



Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) is registered for weed control during establishment of grass seed crops (grass seedbed weed control). An important and unique property of paraquat is its very rapid and complete inactivation upon contact with soil. This results from strong reaction between the double positively charged paraquat cation and the negatively charged sites on the clay minerals or organic matter present in the soil (25).

Chemical Seedbed

The use of herbicides as an aid to seedbed preparation has been described by Lee (13). In Oregon the chemical seedbed technique is commonly and successfully used by growers for the establishment of grass seed crops. The seedbed first is prepared by mechanical means, creating a favorable environment for germination of many weed seeds. After the weeds have emerged, they are killed by application of such herbicides as paraquat or glyphosate, either just before seeding the crop or after the crop is seeded but before it emerges.

When herbicides are applied after seeding, the possibility exists that the herbicides could cause a detrimental effect on the germination of exposed crop seeds that remain on the soil surface and are not protected by a layer of soil. More information is needed on such effects, primarily to assure safety to the crop, but information on reduction in seed germination or seedling growth of weeds may also be practical.

Several effects caused by paraquat and glyphosate on germination, emergence, seedling growth, phytotoxicity and establishment of certain crops have been reported (1, 6, 11, 15, 22).

Paraquat has been found to be toxic to a number of grass species and non-toxic to some legume species when applied directly over the seeds (1, 6, 11). Glyphosate applied in the same fashion has been reported to have detrimental effects on some seed grass crops in some cases (22) but not in others (11, 15).

The purpose of this study was to evaluate the toxicity of glyphosate to seeds and seedling development of six grass and two legume species when the herbicide was applied directly to seeds on the soil surface. Paraquat also was included in the experiments as a point of reference.

MATERIALS AND METHODS

Two experiments were conducted at the Oregon State University greenhouses in Corvallis, Oregon, between July 1980 and January 1981. Temperatures during the greenhouse tests ranged from 18 to 24 C. No artificial light was used. The greenhouse soil employed was a sandy loam soil (a greenhouse mix in which peat was added to a sandy loam soil) with approximately 3.7% organic matter and a pH of 6.2. Soil was screened through a 3- by 3-mm mesh sieve to exclude large particles, placed in 10- by 10- by 10-cm plastic pots, and leveled and firmed. One hundred crop seeds were scattered as uniformly as possible on the soil surface of each pot, leaving a 1-cm strip around the edge.

Commercial formulations of glyphosate and paraquat were applied directly to the seeds. Herbicide rates used were 1.0 and 3.0 kg a.e./ha of glyphosate and 0.56 kg a.i./ha of paraquat. Both herbicides were applied with a track sprayer in 280 L/ha of water with a TeeJet 80015E nozzle tip at 2.25 kg/cm^2 of pressure. Paraquat was applied in combination with X-77 wetting agent (mixture of alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol) at 0.5% (v/v).

Seeds remained on the soil surface throughout the experiments. All pots were placed in shallow watering pans and the soil was kept wet for the duration of the test. Approximately 1 week before harvest, the water was drained out of the pans to facilitate the harvest process. Plants were cut at soil level, dried in an oven at 60 C for 24 h, and weighed to the nearest milligram. All greenhouse data were analyzed as a randomized block design.

Experiment I. Effect of glyphosate and paraquat on germination and seedling growth of grass and legume species. A trial was set up on July 16, 1980, and repeated on November 29, 1980. Six grass and two legume species were included in the experiment (Table 1). Germination percentages were recorded and aboveground portions of the plants were harvested at 4.5 and 7 weeks after treatment, respectively, in the two trials.

Table 1. Species used in Experiment I

Kentucky bluegrass	*Poa pratensis* L. 'Baron'
Perennial ryegrass	*Lolium perenne* L. 'Manhattan'
Bentgrass	*Agrostis tenuis* Sibth. 'Penncross'
Tall fescue	*Festuca arundinacea* Schreb. 'Fawn'
Fine fescue	*Festuca rubra* L. 'Banner Red'
Orchardgrass	*Dactylis glomerata* L. 'Napier'
Alfalfa	*Medicago sativa* L. 'Vernal'
Red clover	*Trifolium pratense* L. 'Kenstar'

Experiment II. Influence of glyphosate and paraquat on germination and growth of two legume species. Germination and growth of alfalfa and red clover were affected by glyphosate treatments in Experiment I. These effects may have been due to direct contact of the herbicide to the seeds of the two legumes or from uptake from the soil by the emerging radicle, or both. An experiment was established on August 28, 1980, and repeated on October 11, 1980, to obtain more information on these effects. Seeds were distributed on the soil surface as described previously. Three different methods were used to treat the seeds with the herbicides:

Method 1: The seeds were placed in lids of 11- by 11- by 3.5 cm plastic petri dishes, sprayed directly with herbicides, dried at room temperature for 3 h, and placed on a clean soil surface.

Method 2: Wet soil was sprayed with herbicides, then after 3 h, untreated seeds were placed on the treated soil surface.

Method 3: Seeds were placed on a clean soil surface and sprayed directly with herbicides without further movement of the seeds.

Germination percentages were recorded and aboveground parts of the plants were harvested after 6 and 5 weeks in the two experiments, respectively.

RESULTS

Experiment I. Effect of glyphosate and paraquat on germination and seedling growth of grass and legume species. In the first trial in Experiment I, none of the glyphosate rates reduced germination except in perennial ryegrass (Table 2, Appendix Tables 1 and 5). Paraquat reduced germination of grass species except for bentgrass and tall fescue and had no effect on legume species. In the second trial, the results were much more dramatic; both rates of glyphosate significantly reduced germination of both legumes and four of the six grass species. It did not reduce germination of Kentucky bluegrass and bentgrass at the lowest rate (1.0 kg/ha). Inhibition from paraquat was more severe than from glyphosate on all grasses. Once again it did not reduce germination of legume species. This trend was consistent in both trials and is in general agreement with the results of Appleby and Brenchley (1).

Although several glyphosate treatments did not reduce germination percentage significantly, some visible effects were noted in many seedlings. This was reflected in the data obtained from dry weight of foliage (Table 3, Appendix Tables 2 and 6). Paraquat markedly decreased the production of dry matter of all but one grass species. The exception was Kentucky bluegrass in the first trial. Paraquat apparently reduced dry weight of this species but differences were not significantat the 5% level. This might be explained by the high variability among treatments (C.V. = 55.1%). Paraquat caused no detrimental effect on red clover

Table 2. Effect of glyphosate and paraquat on the germination of six grass and two legume species when seeds were exposed directly to the spray.

Species	Germination[a] Glyphosate (kg a.e./ha) 1.0	Glyphosate (kg a.e./ha) 3.0	Paraquat (kg a.i./ha) 0.56	Check
	(%)			
First trial				
Kentucky bluegrass	37	34	14*	35
Perennial ryegrass	73	52**	40**	71
Bentgrass	60	54	58	50
Tall fescue	63	57	42	54
Fine fescue	77	63	22**	70
Orchardgrass	59	58	18**	59
Alfalfa	37	37	33	44
Red clover	30	32	51	35
Second trial				
Kentucky bluegrass	61	47*	5**	64
Perennial ryegrass	60**	42**	6**	95
Bentgrass	73	57**	36**	74
Tall fescue	63**	32**	16**	86
Fine fescue	71**	45**	4**	87
Orchardgrass	38	26**	1**	44
Alfalfa	13**	8**	54	56
Red clover	31**	34**	80	78

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the LSD.

Table 3. Effect of glyphosate and paraquat on the growth of six grass and two legume species when seeds were exposed directly to the spray.

Species	Dry foliage weight[a] Glyphosate (kg a.e./ha) 1.0	3.0	Paraquat (kg a.i./ha) 0.56	Check
	mg			
First trial				
Kentucky bluegrass	82	60	61	122
Perennial ryegrass	513**	371**	426**	1117
Bentgrass	211**	175**	406**	732
Tall fescue	550*	278**	402**	830
Fine fescue	394	243**	209**	608
Orchardgrass	240**	181**	198**	628
Alfalfa	199	59*	355	388
Red clover	84	31*	616	410
Second trial				
Kentucky bluegrass	137*	96**	6**	224
Perennial ryegrass	326**	130**	19**	603
Bentgrass	256	78**	120**	233
Tall fescue	305**	101**	100**	666
Fine fescue	243**	68**	16**	458
Orchardgrass	164**	83**	5**	461
Alfalfa	34**	18**	277	312
Red clover	101**	101**	875	647

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the LSD.

and alfalfa. In fact, it consistently promoted seedling growth of red clover. Glyphosate at the lowest rate of 1.0 kg/ha also decreased dry matter production of the grasses as well as the legume species, although differences were not always statistically significant. At the rate of 3.0 kg/ha, glyphosate markedly affected dry foliage weight of all species.

Fine fescue, tall fescue, and orchardgrass developed particular symptoms to glyphosate treatments, especially at 3.0 kg/ha. Their leaves acquired a whitish coloration through most of the leaves (from the top to bottom); this white color contrasted with the rest of the green parts of the leaves. They also exhibited some yellow coloration and a general growth retardation as compared to the controls. These effects are similar to those reported by Brewster in wheat.[1]

Experiment II. Influence of glyphosate and paraquat on germination and growth of two legume species. Since the individual statistical analyses for each trial were not identical, results for each trial are reported separately (Tables 4 and 5, Appendix Tables 9, 10, 13, and 14).

Applications of glyphosate directly over the seeds, whether the seeds were subsequently moved to clean soil or not (Methods 1 and 3), reduced germination of alfalfa and red clover, particularly at the highest rate (3.0 kg/ha). The effect of glyphosate treatments was much less obvious when the herbicide was applied to the soil before

[1]Personal communication, 1981, Bill Brewster, Dept. of Crop Science, Oregon State University, Corvallis, Oregon.

Table 4. Effect of glyphosate and paraquat on germination of two legume species when applied under three different methods.

	Germination[d] Glyphosate (kg a.e./ha) 1.0	3.0	Paraquat (kg a.i./ha) 0.56	Check
	(%)			
First trial				
Alfalfa				
M_1[a]	46	34*	65	65
M_2[b]	61*	51**	68	75
M_3[c]	36	19*	72	59
Red clover				
M_1	48**	48**	71	84
M_2	66	63	67	59
M_3	59**	48**	83	89
Second trial				
Alfalfa				
M_1	27	9**	49	43
M_2	43	37	36	46
M_3	26*	4**	39	49
Red clover				
M_1	33	22	38	41
M_2	32	29	28	38
M_3	25**	12**	49	52

[a]M_1 = seeds sprayed directly with herbicides, dried for 3 h and placed on clean soil.

[b]M_2 = wet soil sprayed with herbicides; after 3 h, untreated seeds were placed on the treated soil surface.

[c]M_3 = seeds were placed on soil surface and sprayed directly with herbicides.

[d]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the LSD.

Table 5. Effect of glyphosate and paraquat on growth of two legume species when applied under three different methods.

	Dry foliage weight[d]			
	Glyphosate (kg a.e./ha)		Paraquat (kg a.i./ha)	
	1.0	3.0	0.56	Check
	mg			
First trial				
Alfalfa				
M_1[a]	163*	78**	347	359
M_2[b]	374**	208**	509	642
M_3[c]	85*	58*	469	441
Red clover				
M_1	144**	131**	656	722
M_2	596	439*	577	596
M_3	177**	135**	802	864
Second trial				
Alfalfa				
M_1	79**	24**	307	253
M_2	243	240	228	307
M_3	95*	14**	275	340
Red clover				
M_1	94*	47**	226	196
M_2	136	105	104	121
M_3	103**	24**	346	239

[a]M_1 = seeds sprayed directly with herbicides, dried for 3 h and placed on clean soil.

[b]M_2 = wet soil sprayed with herbicides; after 3 h untreated seeds were placed on the treated soil surface.

[c]M_3 = seeds were placed on soil surface and sprayed directly with herbicides.

[d]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the LSD.

placing the legume seeds (Method 2). Alfalfa germination from this treatment was affected significantly in the first trial, but was not in the second trial. Glyphosate exposure by Method 2 had little effect on germination of red clover.

In none of the three methods did paraquat display any detrimental effect on germination of alfalfa and red clover.

Effects of direct applications of glyphosate to seeds (Methods 1 and 3) on subsequent seedling growth followed a similar pattern as for germination (Table 5). But even at the lower rate, plant growth was suppressed markedly by the herbicide. Paraquat data from Method 3 was variable in both trials. This prevented differences from being highly significant, but glyphosate clearly reduced dry weights of alfalfa.

When glyphosate was applied to soil before the placement of seeds as described for Method 2, alfalfa growth was significantly reduced. However, in the second trial this effect was much less obvious. The same was true for red clover at the highest rate of glyphosate, but differences between the trials were less.

No paraquat treatments inhibited growth of seedlings to any significant degree.

DISCUSSION

Although there were minor differences in results between the two trials in Experiment I, paraquat applied directly to grass seeds lying on the soil surface reduced germination and, therefore, reduced total dry weight production of the seedlings. It was not harmful to red clover and alfalfa. These results are in general agreement with other workers (1, 6, 11). One unexpected result from paraquat was an apparent growth-promoting effect on red clover. This appeared in both trials of the experiment. Wiedman and Appleby (26) have shown that sublethal rates of many herbicides can stimulate plant growth. Perhaps this is another example of such an effect.

Effects on germination of grasses were less severe from glyphosate than from paraquat, but they were still appreciable. Unlike paraquat, effects on legumes from glyphosate were much more severe than on grasses. There was not a good correlation between effects on germination and effects on seedling growth. In several cases, seedling growth was reduced much more severely from glyphosate application than was germination.

Some of these results agree with those reported by Segura et al. (22), who found significant reductions in seedling numbers when glyphosate was applied directly over the seeds of red clover and Italian ryegrass (Lolium multiflorum Lam.) at rates of 3.0 and 4.0 kg/ha. However, these findings disagree with those of Moshier et al. (15) and Klingman and Murray (11) who reported that glyphosate sprayed at 4.5 kg/ha did not inhibit germination of Kentucky bluegrass, red fescue, tall fescue, and creeping bentgrass when applied to the soil before seeding or when applied directly over the seeds.

Because of the activity of glyphosate on seedling growth beyond its effect on germination, the effects from direct seed exposure and from subsequent growth in treated soil were separated out by moving treated seed onto clean soil (Method 1) and untreated seeds onto treated soil (Method 2). Glyphosate consistently inhibited both germination and seedling growth of alfalfa and red clover when applied directly to the seeds, but it was much less damaging when untreated seeds were moved onto treated soil. These data suggest that the major toxic effect of glyphosate to legume seeds and seedlings occurs following direct contact of the herbicide with the seeds. Even so, a minor effect was detected through soil application which indicates that glyphosate was not inactivated on contact with the soil as fast as paraquat, and over a short period of time the herbicide may be available for uptake by the emerging radicle of the seeds even though glyphosate is reported to have no residual soil activity (20, 25).

These results indicate that the use of glyphosate as a tool in chemical seedbed preparation may prove damaging to new crops if the herbicide is applied directly to exposed seeds. The legumes in this study seem to be especially sensitive and may even be damaged when seeding is done after glyphosate application. Results would also suggest that some seeds of grass and legume weed species which are exposed to glyphosate, might be at least partially controlled. The rates of glyphosate used in these studies are commomly used in the field by growers, so the results could well have practical implications.

SECTION II

Residual Effect of Glyphosate in the Soil

INTRODUCTION

Adsorption of Glyphosate by Soils

Several workers have suggested that the apparent lack of glyphosate soil activity is largely due to adsorption. Sprankle et al. (20, 21) reported that glyphosate was inactivated rapidly in organic and mineral soils, but not by washed quartz sand. They indicated that glyphosate and phosphate may be competing for the same binding or adsorption sites, and that initial inactivation of glyphosate in soil is by reversible adsorption to clay and organic matter, probably through the phosphonic acid moiety of glyphosate and not by microbial or chemical degradation. Following the initial inactivation of glyphosate by binding to the soil, the pattern of degradation suggested co-metabolism by the constitutive microbial population (21). Torstensson and Aamisepp (23) also found the initial rapid inactivation of glyphosate to be by adsorption and the results indicated that further disappearance of soil activity depended primarily on microbial degradation. Because glyphosate did not seem to sustain microbial growth, degradation was probably an example of co-metabolism.

Hance (8) concluded that inorganic phosphate excludes glyphosate from sorption sites, so that the glyphosate adsorption is correlated with unoccupied phosphate sorption capacity. But he further emphasized that the low phytotoxicity of glyphosate when applied to the soil is not due simply to high adsorption. Rather, it is the result of a combination of moderate adsorption and the low intrinsic activity of this herbicide when made available to the root system.

Moshier et al. (14) postulated that formation of colloidal Fe and Al precipitates in modified soils with concomitant adsorption of glyphosate is responsible for decreased availability of glyphosate to microorganisms. Along the same line, Hanson and Rieck (9) feel that glyphosate adsorption to mineral colloids and organic matter is due primarily to formation of Fe^{+++} and Al^{+++} complexes with glyphosate. They found no significant reduction in the yield of soybeans (*Glycine max* L.) following foliar application of glyphosate + $FeCl_3$. Hensley et al. (10) also reported that glyphosate may be inactivated in the soil by iron and aluminum and that organic matter and cation exchange capacity of the soil appear to have less influence on the inactivation process than do these two metal constituents.

Soil Activity of Glyphosate

Several reports have been made in relation to soil activity of glyphosate. Most of these indicate that glyphosate is rapidly inactivated in the soil, thus having very little or no apparent soil residual activity when applied at rates required for control of annual and perennial weeds. Crops planted after normal applications of glyphosate in the field would be unlikely to suffer from the residual effect of this herbicides (2, 3, 5, 7, 12, 17, 20, 21, 24).

Baird et al. (2) observed glyphosate to be non-herbicidal when applied and incorporated into mineral soils at above normal use rates. Sprankle et al. (20) indicated that clay loam and muck soil rapidly inactivated 56.0 kg/ha of glyphosate. Moshier et al. (15, 16) reported that preplant incorporation application of 17.9 kg/ha of glyphosate caused no significant reduction in plant height of Kentucky bluegrass, creeping bentgrass, and red fescue, and 9.0 kg/ha did not affect alfalfa.

Rodrigues et al. (18) found that ^{14}C-glyphosate applied to wheat plants was exuded into soil and caused root inhibition and foliar injury symptoms in corn seedlings growing in the same soil. These results showed that glyphosate can, indeed, be herbicidally active in the soil, at least under certain conditions.

Other research workers (4, 5) have reported that glyphosate has some soil activity at extremely high rates, but this action would be expected to be negligible at normal field rates. However, Brewster and Appleby (4) reported that preemergence application of glyphosate to moist soil made 0, 1, 2, or 4 days after planting wheat, caused injury to a substantial number of plants from rates as low as 1.68 kg/ha, especially for the applications nearest to emergence. They suggested that glyphosate is not inactivated instantaneously, particularly in moist soil.

Because of its apparent lack of soil residual activity, glyphosate sometimes is applied shortly prior to emergence of the crop. If the soil is wet, occasionally glyphosate does not seem to be readily adsorbed. Consequently, it might persist in the soil long enough to produce some injury. A few reports from growers have indicated some concern about glyphosate injury to newly-seeded crops from soil activity but this has not been studied closely under Oregon conditions.

In preliminary trials in the greenhouse, we found that 3.37 kg a.e./ha of glyphosate applied to moist soil 1, 2, 3, 4, or 5 days before bentgrass emergence resulted in considerable damage to plants, causing symptoms on the leaves and growth retardation.

The objectives of this study were to: (a) determine whether or not glyphosate could have herbicidal activity when applied directly to soil, and (b) examine some soil factors which might influence the soil activity of glyphosate.

MATERIALS AND METHODS

Greenhouse studies were conducted between May 1980 and May 1981 at Oregon State University. Greenhouse temperatures ranged from 18 to 24 C with no supplemental lighting. Mineral soils and high organic soils were used. The latter were well decomposed soils of the Semiahmoo series (a member of the Euic, mesic family of Typic Medisaprists). The semiahmoo series is a deep, very poorly drained muck soil on old lakebeds in the Willamette Valley of Oregon. The characteristics of the soils are given in Table 6.

Table 6. Characteristics of soils used.

Type of soil	pH	% O.M.	P	Fe	Al
			(ppm)		
Mineral soils					
Sandy loam soil (greenhouse soil)	6.2	3.7			
Chehalis sandy loam soil (East Farm)	6.1	2.1	20	63	4
Organic soils					
Organic soil No. 2	5.5	21	155	201	4
Organic soil No. 3	5.4	64	66	411	5
Organic soil No. 4	5.4	28	59	303	5

In most of the experiments, 'Highland' bentgrass was utilized as a bio-indicator plant to test soil activity of a single glyphosate rate of 3.37 kg a.e./ha, except for two trials in which alfalfa and red clover were used. In certain experiments, other rates of glyphosate were included, as well as a single rate of paraquat used as a standard. Plastic pots (10 by 10 by 10 cm) were partially filled with screened greenhouse soil to serve as a base. A 3.5-cm layer of the soil to be studied was placed upon the base soil. We assumed that all soil-herbicide interactions would occur in this top layer, so this technique was used in order to conserve the limited amounts of soil available. A uniform volume of bentgrass seed was planted evenly in two rows in each pot, approximately 1.3 cm deep.

The pots were subirrigated throughout the experiment. Pots were harvested at a uniform time after treatment in each experiment and dry weights of topgrowth were determined. Each experiment was designed as a randomized complete block with four replications.

Experiment III. Effect of glyphosate on bentgrass growth when applied before and after emergence. A bentgrass seed volume of 0.25 ml/pot was planted in two rows in organic soil No. 4. Seedings were made on May 4, 5, 6, 7, and 8. On May 8, glyphosate at 3.37 kg a.e./ha was applied. Bentgrass seedlings emerged 5 days after seeding, so that on May 9, bentgrass seeded on May 4 was beginning to emerge. Additional pots that had been seeded to bentgrass on May 4, 5, and 6, were sprayed with glyphosate on May 11, at which time seedlings were visible in all pots.

Dry weight of shoot growth was determined 5 weeks following each seeding date.

Experiment IV. Influence of soil type on preemergence activity of glyphosate. Three soils were used, a Chehalis sandy loam soil (East Farm), and organic soils No. 2 and 3. The soils were moist but not wet. Dry weights were determined 6 weeks following treatment. Bentgrass seeding procedure and herbicide application were as described for Experiment III.

Experiment V. Influence of organic matter content on soil activity of glyphosate. Several ratios of a mineral soil (East Farm) and organic soil No. 3 were used to obtain various percentages of organic matter. The various proportions of soils were mixed in a soil blender for 5 min to assure a uniform mix. The organic matter percentages of the resulting mixtures are given in Table 7.

Table 7. Percentages of organic matter for different soil combinations.

Soil Proportions		
Organic	Mineral	% O.M.
1	0	64
2	1	37
1.5	1	36
1	1	36
0.5	1	27
0.25	1	16
0	1	2

Three of the resultant mixtures were unexpectedly similar in organic matter content, as determined by the Soil Testing Laboratory at Oregon State University. The reason for this apparent anomaly is not known.

One bentgrass seeding was done in the manner previously described. Glyphosate was applied 2 days before plant emergence. Dry weights were determined 8 weeks following seeding.

Experiment VI. Influence of soil pH on preemergence activity of glyphosate. In order to determine the effect of soil pH on glyphosate activity in the various soils, either sulfuric acid (H_2SO_4) or calcium hydroxide [Ca(OH)2] were added to the soils and allowed to equilibrate in order to lower or raise pH, respectively.

To reduce soil pH, a certain number of milliequivalents of sulfuric acid were added per 200 g of soil. The H_2SO_4 was diluted in water sufficiently to moisten the soils. The soils were then thoroughly mixed and placed in perforated plastic bags, thus allowing air to reach the soil. After 2 days, the soils were stirred again and replaced in the bags for 2.5 weeks. Soils were removed from the bags, placed in plastic dishpans, and allowed to dry for 3.5 additional weeks, at which time soil pH determinations were made.

To raise soil pH, a certain number of milliequivalents of calcium per 200 g of soil were added. Soils were kept in plastic bags for just 2 days and placed in dishpans for 6 weeks. The original and adjusted pH values are given in Table 8.

Pots were prepared with the various soils and bentgrass was seeded in the manner previously described. All pots were sprayed with glyphosate 2 days before bentgrass emergence. Dry weights were determined 8.5 weeks after seeding.

This experiment was repeated with minor changes. One pH level was deleted from organic soil No. 3 and an additional level was

Table 8. Original and adjusted soil pH's after incubation with H_2SO_4 and $Ca(OH)_2$.

Soil type	Original pH	Meq/200 g soil H_2SO_4	Ca^{++}	Adjusted pH Trial 1	Trial 2
Mineral soil (East Farm)	6.1				
		5		4.8	4.6
		10		4.4	4.1
			35	-	9.0
Organic soil No.2	5.5				
		10		4.9	4.6
		20		4.3	4.0
			70	7.9	8.4
Organic soil No.3	5.4				
		10		5.0	-
		20		4.7	4.6
			70	6.9	7.2
Organic soil No.4	5.4				
		20		4.6	4.5
			70	6.9	7.3

added to the mineral soil. Glyphosate was applied 3 days before plant emergence. Dry weights were determined 6 weeks following seeding.

Experiment VII. Influence of phosphorus on preemergence activity of glyphosate. Sprankle et al. (21) found that glyphosate was adsorbed to soil in a manner similar to that of phosphorus. They speculated that the levels of phosphorus in the soil may influence the relative availability of glyphosate. Five levels of phosphorus were added to each of three soils, the East Farm mineral soil and organic soils No. 2 and 3. Phosphorus levels used were 0, 28, 56, 84, and 112 kg/ha of $K_2HPO_4.3H_2O$ (dibasic potassium phosphate hydrated). All applications were calculated based upon kgs of P per 2,245,454 kg soil (assuming that a layer of soil 15 cm deep over 1 ha weighs 2,245,454 kg for all three soils used).

The potassium phosphate was dissolved in water before it was added to the soil and mixed in a soil blender for about 5 min. The soils were placed in plastic bags for 2 days before being placed in pots and seeded with bentgrass. Glyphosate was applied 2 days before plant emergence. Dry weights were determined 8 weeks following seeding.

Experiment VIII. Residual soil activity of glyphosate on two legume species. Pots were filled with greenhouse soil and moistened thoroughly by subirrigation. Water was removed from the irrigation pans, allowing the water to drain from the soil for 13.5 h before applying 1.0 and 3.0 kg a.e./ha of glyphosate and 0.56 kg/ha of paraquat. At 3, 6, 9, and 24 h after herbicide application, 100 alfalfa or red clover seeds were distributed on the sprayed soil surface. Immediately after seeding, all pots were subirrigated. Dry weights and germination percentage were determined after 6.5 weeks.

This experiment was repeated using the same procedures described above. Dry weights and germination percentage were determined 7.5 weeks following seeding.

RESULTS

Experiment III. Effect of glyphosate on bentgrass growth when applied before and after emergence. Growth of bentgrass seedlings was significantly reduced when glyphosate was applied before plant emergence (Table 9, Figure 1, Appendix Table 17). In addition to growth reduction, injury symptoms also appeared on the bentgrass seedlings. Applications 1 and 2 days before emergence caused necrosis on the leaves which was still visible at least 8 days after emergence. The symptoms were somewhat similar to those from applications to emerged seedlings. Plants from pots sprayed more than 2 days prior to emergence were not necrotic, although plant growth was reduced significantly.

Emergence was poor in pots treated 5 days before seedling emergence, even in the untreated check plots. The reason for this poor emergence is not know, but even in this case, glyphosate caused a significant reduction in growth when harvested 5 weeks following seeding. However, at the time the foliage was harvested, many ungerminated seeds in those pots appeared to be healthy. The soil was not discarded immediately after harvesting and after 1 week, many seeds had germinated and the new plants were growing very well, even though the pots did not receive additional water. The poor germination and emergence during the treatment period may have been caused by poor aeration from excessive soil moisture.

Some seedlings sprayed after emergence survived, although damage was severe. Damage was greatest in plants sprayed 2 days

Table 9. Influence of 3.37 kg a.e./ha of glyphosate applied before and after bentgrass emergence.

Time from treatments to emergence	Dry foliage weight		
	Treated[a]	Check	% of check
(days)	(mg)		
1	715**	2923	24
2	1092**	2740	40
3	1194**	2474	48
4	1165**	2397	49
5	24**	511	5
Days after emergence			
0	1140*	2115	54
1	864**	2507	34
2	341**	2884	12

[a]Means significantly different from appropriate check at 5%(*) and 1% (**) levels as determined by the unpaired *t* test.

Figure 1A. Effect of glyphosate on bentgrass when applied 1 day before plant emergence.

Figure 1B. Effect of glyphosate on bentgrass when applied 4 days before plant emergence.

after emergence, compared to those sprayed on the same day of emergence. This is as expected, since more leaf surface was exposed to the spray in the older plants.

The results of this experiment clearly show that glyphosate was not inactivated immediately upon contact with the soil. Sufficient herbicide was available for plant uptake to cause severe reduction in seedling growth.

Experiment IV. Influence of soil type on preemergence activity of glyphosate. Preemergence activity of glyphosate differed considerably among the three soils tested (Table 10, Appendix Table 18). No effect from glyphosate was seen in the mineral soil. In organic soil No. 2, only those plants which emerged 5 days following treatment were significantly reduced, although no visual symptoms were noted on those plants. In organic soil No. 3, plant growth was significantly reduced in four of the five timings. These differences probably would have been much more drastic had the plants been harvested 3 weeks earlier. Large differences were obvious at that time, but in the ensuing 3 weeks to harvest, many of the surviving bentgrass plants in the treated pots began to grow more vigorously and the large differences between treated and untreated plants had partially disappeared by harvest time.

With most herbicides there is an inverse correlation between herbicide availability in the soil solution and organic matter content. This was not the case in this experiment because the only soil in which glyphosate was available was at the highest organic matter

Table 10. Influence of 3.37 kg a.e./ha of glyphosate applied before bentgrass emergence on three different soils

Time from treatment to emergence	Dry foliage weight		
	Treated[a]	Check	% of check
(days)	(mg)		
Mineral soil (East Farm)			
1	726	801	91
2	395	384	103
3	481	451	107
4	481	451	107
5	462	452	102
Organic soil 2			
1	1077	1230	88
2	1080	890	121
3	1204	1062	113
4	1220	1236	99
5	1029*	1215	85
Organic soil 3			
1	532*	1109	48
2	585*	825	71
3	687**	998	69
4	877	905	97
5	555*	842	66

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the unpaired *t* test.

content (63.6%). Apparently, glyphosate is more tightly adsorbed by clay than it is by organic matter.

Experiment V. Influence of organic matter content on soil activity of glyphosate. Because an apparent direct relationship was noted between organic matter content and glyphosate activity in the preceding experiment, a range of soil organic matter percentages were prepared by mixing a mineral soil and organic soil No. 3 in various ratios. Very little soil activity of glyphosate was seen in this experiment (Table 11), and clear conclusions were hampered by a relatively high degree of variability (Appendix Table 19). Although the highest organic matter mixture (64%) reduced foliage growth the most, high variability prevented this difference from being statistically significant. Only in the mixture containing 27% organic matter was the plant growth significantly reduced. The reason for this relatively low level of activity compared to previous trials is not known.

Experiment VI. Influence of soil pH on preemergence activity of glyphosate. As seen in previous experiments, preemergence activity of glyphosate differed markedly from one soil to another. In the first trial of this experiment, there was a trend toward increased toxicity with increasing pH in the mineral soil and in organic soil No. 2 (Table 12, Appendix Table 20). This trend was also obvious in the mineral soil in the second trial (Table 13, Figure 2, Appendix Table 21), but the activity in organic soil No. 2 was much less and damage to the bentgrass resulted only at the high pH.

Table 11. Influence of 3.37 kg a.e./ha of glyphosate when applied 2 days before bentgrass emergence on soils of different organic matter content.

% O.M.	Dry foliage weight		
	Treated[a]	Check	% of check
	(mg)	(mg)	
64	458	661	69
37	442	490	90
36	440	462	95
36	597	644	93
27	597*	743	80
16	487	473	103
2	420	466	90

[a]Means significantly different from appropriate check at 5% (*) level as determined by the unpaired t test.

Table 12. Influence of soil pH on activity of 3.37 kg a.e./ha of glyphosate applied 2 days before bentgrass emergence. First trial.

Soil type	Original pH	Adjusted pH	Dry foliage weight		
			Treated[a]	Check	% of check
			—— (mg) ——		
Mineral soil (East Farm)	6.1		69**	504	14
		4.8	163**	600	27
		4.4	214**	554	39
Organic soil 2		7.9	14*	969	1
	5.5		203**	938	22
		4.9	174**	518	34
		4.3	332**	679	49
Organic soil 3		6.9	86**	595	14
	5.4		20**	945	2
		5.0	4**	505	1
		4.7	1**	429	0
Organic soil 4		6.9	9**	415	2
	5.4		4**	814	0
		4.6	1**	481	0

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the unpaired *t* test.

Table 13. Influence of soil pH on activity of 3.37 kg a.e./ha of glyphosate applied 3 days before bentgrass emergence. Second trial.

Soil type	Original pH	Adjusted pH	Dry foliage weight Treated[a]	Check	% of check
			(mg)	(mg)	
Mineral soil (East Farm)		9.0	0**	521	0
	6.1		252**	480	53
		4.6	425	483	88
		4.1	461	427	108
Organic soil 2		8.4	101**	697	14
	5.5		1281	1098	117
		4.6	592	636	93
		4.0	956	901	106
Organic soil 3		7.2	39**	286	14
	5.4		27**	1009	3
		4.6	1**	223	0
Organic soil 4		7.3	52**	470	11
	5.4		18**	567	3
		4.5	0**	614	0

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the unpaired t test.

Figure 2. Influence of soil pH on the soil activity of glyphosate (3.37 kg a.e./ha) when the herbicide was applied 3 days before bentgrass emergence.

The level of activity against bentgrass seedlings was very high in organic soils No. 3 and 4 in both trials. This high activity tended to mask differences which might be due to differences in pH levels, although in both trials there seemed to be a trend toward greater toxicity as pH was reduced.

Experiment VII. Influence of phosphorus on preemergence activity of glyphosate. Unlike most of the previous experiments, glyphosate showed considerable activity against bentgrass when applied preemergence on the mineral soil from the East Farm (Table 14, Appendix Table 22). Although there was a slight trend toward more herbicidal activity as the amount of phosphorus increased, this was not statistically significant.

Glyphosate did not cause a significant reduction in foliage growth in organic soil No. 2 at any level of phosphorus. As in previous experiments, there was a high degree of glyphosate activity in organic soil No. 3. Damage to the bentgrass was so severe that any possible effects from phosphorus rate would have been masked.

Sprankle et al. (21) found that additions of 98 or 196 kg/ha of phosphate in the soil surface of a sandy loam soil reduced glyphosate adsorption (making the herbicide more available for seedling uptake). The levels of phosphorus used in this experiment may have been too low for these soil types or the phosphate adsorption capacity of the soils was relatively high.

Experiment VIII. Residual soil activity of glyphosate on two legume species. When glyphosate was applied to a soil surface and

Table 14. Influence of phosphorus on activity of 3.37 kg a.e./ha of glyphosate applied 3 days before bentgrass emergence.

Soil type	kg/ha of P	Dry foliage weight		
		Treated[a]	Check	% of check
		(mg)		
Mineral soil (East Farm)	0	262**	505	52
	28	259**	489	53
	56	192**	463	41
	84	241**	495	49
	112	191**	577	33
Organic soil 2	0	856	980	87
	28	872	885	98
	56	801	820	98
	84	701	864	81
	112	696	939	74
Organic soil 3	0	37**	936	4
	28	62**	607	10
	56	7**	582	1
	84	8**	509	2
	112	23**	650	4

[a]Means significantly different from appropriate check at 1% (**) level as determined by the unpaired t test.

untreated alfalfa and clover seeds were added at intervals, both germination and subsequent shoot growth was inhibited severely in both species (Tables 15, 16; Figure 3; Appendix Tables 23, 24, 27, 28). Alfalfa was somewhat more sensitive to glyphosate residues than was red clover, and more damage resulted from applications of 3.0 kg/ha than from 1.0 kg/ha. The length of time that had elapsed from treatment to seeding seemed to have no correlation with the amount of damage to the legumes.

Table 15. Effect of glyphosate and paraquat on the germination of alfalfa and red clover when a moist soil was treated and untreated seeds were placed on the soil surface at intervals.

Time from treatment to seeding	hours	Germination[a] Glyphosate (kg a.e./ha) 1.0	3.0	Paraquat (a.i./ha) 0.56	Check
		(%)			
First trial					
Alfalfa	3	20	5**	40	38
	6	16**	3**	41	47
	9	13**	1**	32	34
	24	22*	1**	41	43
Red clover	3	45	32	54	46
	6	57	25**	56	60
	9	44**	23**	45**	59
	24	39	48	54	49
Second trial					
Alfalfa	3	35*	3**	64	57
	6	29	4**	51	48
	9	7**	5**	62	64
	24	34*	6**	43	55
Red clover	3	59	38*	62	55
	6	52*	45**	65	69
	9	49	45	62	66
	24	53	45	60	57

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the LSD.

Table 16. Effect of glyphosate and paraquat on the growth of alfalfa and red clover when a moist soil was treated and untreated seeds were placed on the soil surface at intervals.

Time from treatment to seeding	hours	Dry foliage weight[a] Glyphosate (kg a.e./ha) 1.0	3.0	Paraquat (a.i./ha) 0.56	Check
		(mg)			
First trial					
Alfalfa	3	72	10	169	201
	6	58**	11**	173	236
	9	46	3*	178	137
	24	76*	2**	184	245
Red clover	3	240	116*	453	350
	6	371	85*	521	533
	9	273**	79**	346*	483
	24	312	183*	408	368
Second trial					
Alfalfa	3	203*	16**	412	391
	6	142	19*	291	288
	9	32**	18**	362*	453
	24	141**	20**	278	319
Red clover	3	354	147**	450	428
	6	348*	205**	553	574
	9	312**	196**	636	548
	24	386	250	415	460

[a]Means significantly different from appropriate check at 5% (*) and 1% (**) levels as determined by the LSD.

Figure 3. Effect of glyphosate (3.0 kg a.e./ha) when sprayed on moist soil and untreated alfalfa seeds were placed on the soil surface at 9-h and 24-h intervals.

DISCUSSION

Results from this series of experiments indicate that glyphosate can definitely injure plants by uptake from soil. The herbicide remained available for a sufficient period of time to cause significant growth reduction in bentgrass, alfalfa, and red clover.

Attempts to determine soil characteristics related to glyphosate activity were not entirely successful. Glyphosate activity differed considerably among the soil types used in these studies. Relationship to organic matter content was not clear, but the most active soil was organic soil No. 4. There was a general, but not entirely consistent, trend toward less activity as organic matter decreased. Possibly, glyphosate is not adsorbed strongly to organic matter and tends to be bound more strongly by clay.

In the mineral soil and organic soil No. 2, in which soil activity often was not evident, increasing pH levels increased the level of activity considerably. This is not an uncommon observation with many herbicides. As pH is increased, the herbicide becomes more ionized and is, therefore, less "cationic." This results in less adsorption on the negative clay surface. Also, at high pH levels, competition for adsorption sites from calcium and other ions may be more extensive, thereby making the glyphosate more available for plant uptake. The levels of activity in organic soils No. 3 and 4 were sufficiently high that any influence of pH was masked.

There was a slight trend toward more glyphosate activity as phosphorus levels increased, but differences were not always statistically significant. If, as speculated by Sprankle et al. (21), initial adsorption of glyphosate is through the phosphorus moieties, then increased phosphorus levels could be expected to influence glyphosate adsorption. Phosphorus levels seemed to have only a minor influence on glyphosate activity on these studies, and there was little or no correlation between unamended phosphorus levels in the various soils and their ability to tie up glyphosate.

Contrary to reports by Hanson and Rieck (9) and Hensley et al. (10), there was no evidence that glyphosate formed an inactive complex with Fe or Al. The two soils in which glyphosate was most active, organic soils No. 3 and 4, contained the highest levels of Fe and at least equal levels of Al.

When applied to moist soil, glyphosate was able to cause injury to alfalfa and clover, even when the seeds were placed on the soil 24 h later. This was somewhat surprising, since we had assumed that even on moist soils the glyphosate would be adsorbed by that period of time.

These findings are somewhat contradictory to reports in the literature that glyphosate has little or no soil activity (2, 3, 5, 7, 8, 17, 20, 21, 24). On the other hand, Rodrigues et al. (18) found that glyphosate was exuded into the soil from wheat plants and caused root inhibition and foliar injuries to corn seedlings, thus pointing out that glyphosate could be herbicidally active in the soil under given conditions. Hance (8) has reported that adsorption of glyphosate is in the same general range of a soil-active herbicide, diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea].

Brewster and Appleby (4) reported that applications of glyphosate prior to emergence of wheat shoots caused considerable damage. They further suggested that wheat injury occurred under moist soil conditions (sandy loam soil) and that soil moisture could be the key factor for such injury. Preliminary experiments in our studies on the effect of soil moisture were inconclusive. Further research should be conducted to clarify the influence of this factor. Quite possibly, glyphosate activity would be seen only under continuously moist conditions in which water molecules compete with glyphosate molecules for adsorption sites, thus allowing glyphosate molecules to be available in soil solution for plant uptake.

At the present time, research results indicate that glyphosate can be soil-active, that maximum opportunity should be afforded for adsorption to soil to occur before planting desirable crops, and that a tendency for a soil to allow activity from soil-applied glyphosate is still unpredictable. A waiting period of several days should elapse from glyphosate treatment to emergence of a crop, particularly if the soil remains moist and the pH of the soil tends to be high.

LITERATURE CITED

1. Appleby, A.P. and R.G. Brenchley. 1968. Influence of paraquat on seed germination. Weed Sci. 16:484-485.

2. Baird, D.D., R.P. Upchurch, W.B. Homesley, and J.E. Franz. 1971. Introduction of a new broad-spectrum postemergence herbicide class with utility for herbaceous perennial weed control. Proc. North Cent. Weed Contr. Conf. 26:64-68.

3. Baird, D.D., R.P. Upchurch, and G.W. Selleck. 1972. Phosphonomethylglycine, a new broad-spectrum postemergence herbicide. Proc. Calif. Weed Conf. 24:94-102.

4. Brewster, B.D. and A.P. Appleby. 1972. Preemergence soil activity of N-(phosphonomethyl) glycine on winter wheat. Res. Prog. Rep. West. Weed Sci. Soc. 90.

5. Burt, E.O. and A.E. Dudeck. 1975. Glyphosate -4 years results. Proc. South. Weed Soc. 28:152-153.

6. Egley, G.H. and R.D. William. 1978. Glyphosate and paraquat effects on weed seed germination and seedling emergence. Weed Sci. 26:249-251.

7. Fischer, B.B., F.H. Swanson, D.M. May, and A.H. Lange. 1976. Roundup Review. Agrichem. Age 19:16, 17, 21.

8. Hance, R.J. 1976. Adsorption of glyphosate by soils. Pestic. Sci. 7:363-366.

9. Hanson, C.L. and C.E. Rieck. 1976. The effect of iron and aluminum on glyphosate toxicity. (Abstr.) Proc. South. Weed Sci. Soc. 26:49.

10. Hensley, D.L., D.S.N. Beuerman, and P.L. Carpenter. 1978. The inactivation of glyphosate by various soils and metal salts. Weed Res. 18:287-291.

11. Klingman, D.L. and J.J. Murray. 1976. Germination of seeds of turfgrasses as affected by glyphosate. Weed Sci. 24:191-193.

12. Lange, A., H. Kempen, W. McHenry, and O. Leonard. 1973. Roundup, a new perennial weed killer. Calif. Agric. 27:6-7.

13. Lee, W.O. 1965. Herbicides in seedbed preparation for the establishment of grass seed fields. Weeds 13:293-297.

14. Moshier, L. and D. Penner. 1978. Factors influencing microbial degradation of ^{14}C-glyphosate to $^{14}CO_2$ in soil. Abstr. Weed Sci. Soc. Am., Abstr. No. 183.

15. Moshier, L., A.J. Turgeon, and D. Penner. 1976. Effects of glyphosate and siduron on turfgrass establishment. Weed Sci. 24:445-448.

16. Moshier, L., A.J. Turgeon, and D. Penner. 1978. Use of glyphosate in sod seeding alfalfa (Medicago sativa) establishment. Weed Sci. 26:163-166.

17. Richardson, W.G. and M.L. Dean. 1973. The postemergence selectivity of some recently developed herbicides: bentazon, EMD-IT 6412, cyprazine, metribuzin, chlornitrofen, glyphosate, MC 4379 and chlorfenprop-methyl. Tech. Rep. Agric. Res. Coun. Weed Res. Ore. 1973, 26:79.

18. Rodrigues, J.J. and A.D. Worsham. 1980. Exudation of glyphosate from treated vegetation and its implication in increasing yields of no-till corn and soybeans. Abstr. Weed Sci. Soc. Am., Abstr. No. 199.

19. Rueppel, M.L., B.B. Brightwell, J. Schaefer, and J.T. Marvel. 1977. Metabolism and degradation of glyphosate in soil and water. J. Agric. Food Chem. 25:517-528.

20. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Rapid inactivation of glyphosate in the soil. Weed Sci. 23:224-228.

21. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Adsorption mobility and microbial degradation of glyphosate in the soil. Weed Sci. 23:229-234.

22. Segura, J., S.W. Bingham, and C.L. Foy. 1978. Phytotoxicity of glyphosate to Italian ryegrass (Lolium multiflorum) and red clover (Trifolium pratense). Weed Sci. 26:32-36.

23. Tortenson, N.T.L. and A. Aamisepp. 1977. Detoxification of glyphosate in soil. Weed Res. 17:209-212.

24. Upchurch, R.P. and D.D. Baird. 1972. Herbicidal action of MON-0573 as influenced by light and soil. Proc. West. Weed Sci. Soc. 25:41-44.

25. Weed Science Society of America. 1979. Herbicide Handbook, 4th ed., Weed Sci.Soc. of Amer.

26. Wiedman, S.J. and A.P. Appleby. 1972. Plant growth stimulation by sublethal concentrations of herbicides. Weed Res. 12:65-74.

A P P E N D I X

Appendix Table 1. Germination from experiment I, first trial (July 16, 1980), to determine the effect of glyphosate and paraquat on the germination of six grass and two legume species when seeds were exposed to the spray.

Rate (kg/ha)	Species	Blocks I	II	III	IV	Mean
		(%)				
0	Kentucky bluegrass	24	34	43	41	35
	Perennial ryegrass	71	66	70	77	71
	Bentgrass	47	46	60	48	50
	Tall fescue	45	56	63	52	54
	Fine fescue	66	69	76	71	70
	Orchardgrass	39	98	44	55	59
	Alfalfa	32	38	58	49	44
	Red clover	43	29	32	35	35
1.0 glyphosate	Kentucky bluegrass	35	50	29	36	37
	Perennial ryegrass	79	65	72	77	73
	Bentgrass	52	69	54	66	60
	Tall fescue	75	71	52	54	63
	Fine fescue	68	81	88	73	77
	Orchardgrass	67	66	33	70	59
	Alfalfa	50	45	43	11	37
	Red clover	50	22	32	16	30
3.0 glyphosate	Kentucky bluegrass	28	25	52	33	34
	Perennial ryegrass	51	49	60	49	52
	Bentgrass	53	57	49	58	54
	Tall fescue	70	61	54	43	57
	Fine fescue	57	64	69	64	63
	Orchardgrass	66	71	53	42	58
	Alfalfa	48	48	26	26	37
	Red clover	47	34	32	17	32
0.56 paraquat	Kentucky bluegrass	19	14	9	14	14
	Perennial ryegrass	43	33	31	55	40
	Bentgrass	49	63	58	62	58
	Tall fescue	26	43	35	64	42
	Fine fescue	24	16	24	25	22
	Orchardgrass	21	16	17	19	18
	Alfalfa	35	44	23	29	33
	Red clover	24	54	75	52	51

Appendix Table 2. Dry weight of shoots from experiment I, first trial (July 16, 1980), to determine the effect of glyphosate and paraquat on the growth of six grass and two legume species when seeds were exposed to the spray.

Rate (kg/ha)	Species	Blocks I	II	III	IV	Total	Mean
		(mg)					
0	Kentucky bluegrass	94	159	153	83	489	122
	Perennial ryegrass	1336	1344	1140	648	4468	1117
	Bentgrass	622	841	765	700	2928	732
	Tall fescue	1006	790	1067	459	3322	830
	Fine fescue	473	565	994	399	2431	608
	Orchardgrass	601	889	404	620	2514	628
	Alfalfa	433	106	688	326	1553	388
	Red clover	650	40	249	703	1642	410
1.0 glyphosate	Kentucky bluegrass	66	136	73	52	327	82
	Perennial ryegrass	557	471	589	436	2053	513
	Bentgrass	446	258	42	98	844	211
	Tall fescue	665	606	509	420	2200	550
	Fine fescue	412	415	420	331	1578	394
	Orchardgrass	329	253	114	266	962	240
	Alfalfa	162	310	235	91	798	199
	Red clover	115	64	71	86	336	84
3.0 glyphosate	Kentucky bluegrass	16	77	103	45	241	60
	Perennial ryegrass	362	345	603	173	1483	371
	Bentgrass	200	85	271	145	701	175
	Tall fescue	375	192	285	260	1112	278
	Fine fescue	225	137	407	203	972	243
	Orchardgrass	154	243	180	149	726	181
	Alfalfa	65	98	50	25	238	59
	Red clover	14	19	43	47	123	31
0.56 paraquat	Kentucky bluegrass	99	29	8	107	243	61
	Perennial ryegrass	349	491	387	477	1704	426
	Bentgrass	291	437	444	454	1626	406
	Tall fescue	307	519	502	280	1608	402
	Fine fescue	300	153	172	213	838	209
	Orchardgrass	350	106	185	152	793	198
	Alfalfa	348	483	272	316	1419	355
	Red clover	148	736	1070	512	2466	616

Appendix Table 3. Analysis of variance for data in Appendix Table 1.

Kentucky Bluegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	95.2	31.7	0.33
Treatments	3	1448.7	482.9	5.09*
Error	9	853.8	94.9	
Total	14	2397.7		

$LSD_{.05}$ = 15.6% C.V. = 32.1%

Perennial Ryegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	270.5	90.2	2.29
Treatments	3	2938.5	979.5	24.92**
Error	9	354.0	39.3	
Total	14	3563.0		

$LSD_{.05}$ = 10.0% C.V. = 10.6%

$LSD_{.01}$ = 14.4%

Bentgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	385.6	128.5	4.40
Treatments	3	88.6	29.5	1.01 n.s.
Error	9	262.7	29.2	
Total	14	736.9		

C.V. = 9.5%

Appendix Table 3 (continued)

Tall Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	94.5	31.5	0.17
Treatments	3	936.0	312.0	1.68 n.s.
Error	9	1665.5	185.1	
Total	14	2696.0		

C.V. = 25.2%

Fine Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	226.6	75.5	3.66
Treatments	3	7376.2	2458.7	119.35**
Error	9	185.1	20.6	
Total	14	7787.9		

$LSD_{.05}$ = 7.2%

$LSD_{.01}$ = 10.4%

C.V. = 7.8%

Orchardgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	1380.6	460.2	1.86
Treatments	3	4903.2	1634.4	6.62*
Error	9	2220.0	246.7	
Total	14	8503.9		

$LSD_{.05}$ = 25.1%

$LSD_{.01}$ = 36.1%

C.V. = 32.3%

Appendix Table 3 (continued)

Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	517.2	172.4	0.99
Treatments	3	272.2	90.7	0.52 n.s.
Error	9	1553.0	172.5	
Total	14	2342.4		

C.V. = 34.7%

Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	412.3	137.4	0.58
Treatments	3	1109.3	369.8	1.56 n.s.
Error	9	2127.6	236.4	
Total	14	3649.2		

C.V. = 41.4%

Appendix Table 4. Analysis of variance for data in Appendix Table 2.

Kentucky Bluegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	2466.0	822.0	0.41
Treatments	3	10170.0	3390.0	1.69 n.s.
Error	9	18013.0	2001.4	
Total	14	30649.0		

C.V. = 55.1%

Perennial Ryegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	161750.5	53916.8	1.72
Treatments	3	1429871.5	476623.8	15.23**
Error	9	281679.0	31297.7	
Total	14	1873301.0		

$LSD_{.05}$ = 283.0

$LSD_{.01}$ = 406.5

C.V. = 29.1%

Bentgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	6691.2	2230.4	15.11**
Treatments	3	780336.7	260112.2	0.13
Error	9	154940.6	17215.6	
Total	14	941968.5		

$LSD_{.05}$ = 209.9

$LSD_{.01}$ = 301.5

C.V. = 34.4%

Appendix Table 4 (continued)

Tall Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	147682.7	49227.6	2.48
Treatments	3	678809.0	626269.7	11.41**
Error	9	178424.3	19824.9	
Total	14	1004916.0		

$LSD_{.05}$ = 225.2 C.V. = 27.3%

$LSD_{.01}$ = 323.6

Fine Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	105289.7	35096.6	1.90
Treatments	3	395416.7	131805.6	7.16**
Error	9	165731.0	18414.5	
Total	14	666437.4		

$LSD_{.05}$ = 217.0 C.V. = 37.3%

$LSD_{.01}$ = 311.8

Orchardgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	57643.2	19214.4	1.38
Treatments	3	541010.7	180336.9	12.93**
Error	9	125540.5	13948.9	
Total	14	724194.4		

$LSD_{.05}$ = 188.9 C.V. = 37.8%

$LSD_{.01}$ = 271.4

Appendix Table 4 (continued)

Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	29661.5	9887.2	0.44
Treatments	3	275700.5	91900.2	4.13*
Error	9	200016.0	22224.0	
Total	14	505378.0		

$LSD_{.05} = 238.4$ C.V. = 59.5%

Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	63357.7	21119.2	0.27
Treatments	3	922743.2	307581.1	3.98*
Error	9	695633.1	77292.6	
Total	14	1681734.0		

$LSD_{.05} = 444.7$ C.V. = 97.4%

Appendix Table 5. Germination from experiment I, second trial (November 29, 1980), to determine the effect of glyphosate and paraquat on the germination of six grass and two legume species when seeds were exposed to the spray.

Rate (kg/ha)	Species	Blocks I	II	III	IV	Mean
		(%)				
0	Kentucky bluegrass	65	74	50	66	64
	Perennial ryegrass	93	92	99	98	95
	Bentgrass	71	69	83	72	74
	Tall fescue	85	82	93	85	86
	Fine fescue	91	90	81	87	87
	Orchardgrass	41	54	39	44	44
	Alfalfa	56	43	68	56	56
	Red clover	87	54	82	89	78
1.0 glyphosate	Kentucky bluegrass	67	55	65	58	61
	Perennial ryegrass	61	63	56	60	60
	Bentgrass	79	70	66	76	73
	Tall fescue	76	61	64	50	63
	Fine fescue	68	74	79	62	71
	Orchardgrass	35	46	33	38	38
	Alfalfa	29	14	6	5	13
	Red clover	46	32	32	14	31
3.0 glyphosate	Kentucky bluegrass	41	37	50	60	47
	Perennial ryegrass	53	43	33	40	42
	Bentgrass	63	53	52	62	57
	Tall fescue	37	41	16	35	32
	Fine fescue	42	49	46	45	45
	Orchardgrass	23	26	33	23	26
	Alfalfa	8	11	0	15	8
	Red clover	33	40	19	44	34
0.56 paraquat	Kentucky bluegrass	6	5	2	6	5
	Perennial ryegrass	8	8	4	4	6
	Bentgrass	34	35	44	30	36
	Tall fescue	22	17	10	17	16
	Fine fescue	8	1	6	3	4
	Orchardgrass	2	1	2	1	1
	Alfalfa	45	41	77	54	54
	Red clover	67	79	83	93	80

Appendix Table 6. Dry weight of shoots from experiment I, second trial (November 29, 1980), to determine the effect of glyphosate and paraquat on the growth of six grass and two legume species when seeds were exposed to the spray.

Rate (kg/ha)	Species	Blocks I	II	III	IV	Total	Mean
		(mg)					
0	Kentucky bluegrass	213	305	220	159	897	224
	Perennial ryegrass	557	578	635	641	2411	603
	Bentgrass	254	216	217	246	933	233
	Tall fescue	772	851	470	571	2664	666
	Fine fescue	450	432	443	508	1833	458
	Orchardgrass	642	514	319	371	1846	461
	Alfalfa	383	253	254	360	1250	312
	Red clover	721	431	650	786	2588	647
1.0 glyphosate	Kentucky bluegrass	103	96	155	195	549	137
	Perennial ryegrass	306	406	184	409	1305	326
	Bentgrass	355	214	237	218	1024	256
	Tall fescue	496	295	246	183	1220	305
	Fine fescue	253	284	280	154	971	243
	Orchardgrass	208	130	171	148	657	164
	Alfalfa	72	26	18	20	136	34
	Red clover	155	84	118	47	404	101
3.0 glyphosate	Kentucky bluegrass	78	118	69	120	385	96
	Perennial ryegrass	255	130	60	75	520	130
	Bentgrass	134	31	51	95	311	78
	Tall fescue	132	183	30	60	405	101
	Fine fescue	66	52	91	63	272	68
	Orchardgrass	100	60	69	104	333	83
	Alfalfa	21	19	0	34	74	18
	Red clover	92	105	71	138	406	101
0.56 paraquat	Kentucky bluegrass	7	8	3	6	24	6
	Perennial ryegrass	40	25	8	3	76	19
	Bentgrass	125	154	101	99	479	120
	Tall fescue	99	135	65	100	399	100
	Fine fescue	33	6	16	8	63	16
	Orchardgrass	8	1	3	9	21	5
	Alfalfa	178	240	419	271	1108	277
	Red clover	690	973	1075	761	3499	875

Appendix Table 7. Analysis of variance for data in Appendix Table 5.

Kentucky Bluegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	77.2	25.7	0.36
Treatments	3	8948.2	2982.7	41.60**
Error	9	645.0	71.7	
Total	14	9670.4		

$LSD_{.05}$ = 13.5% C.V. = 19.2%

$LSD_{.01}$ = 19.5%

Perennial Ryegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	68.2	22.7	0.94
Treatments	3	16651.2	5550.4	229.64**
Error	9	217.5	24.2	
Total	14	16936.9		

$LSD_{.05}$ = 7.7% C.V. = 9.6%

$LSD_{.01}$ = 11.3%

Bentgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	60.6	20.2	0.50
Treatments	3	3783.6	1261.2	30.99**
Error	9	366.7	40.7	
Total	14	4210.9		

$LSD_{.05}$ = 10.2% C.V. = 10.7%

$LSD_{.01}$ = 14.6%

Appendix Table 7 (continued)

Tall Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	209.6	69.9	0.98
Treatments	3	11650.6	3883.5	54.31**
Error	9	643.7	71.5	
Total	14	12503.9		

$LSD_{.05}$ = 13.5%   C.V. = 17.1%

$LSD_{.01}$ = 19.4%

Fine Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	43.5	14.5	0.56
Treatments	3	15570.5	5190.2	199.62**
Error	9	234.0	26.0	
Total	14	15848.0		

$LSD_{.05}$ = 8.1%   C.V. = 9.8%

$LSD_{.01}$ = 11.7%

Orchardgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	98.6	32.9	1.48
Treatments	3	4307.2	1435.7	64.67**
Error	9	200.1	22.2	
Total	14	4605.9		

$LSD_{.05}$ = 7.5%   C.V. = 17.1%

$LSD_{.01}$ = 10.7%

Appendix Table 7 (continued)

Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	232.5	77.5	0.52
Treatments	3	7798.5	2599.5	17.34**
Error	9	1349.0	149.9	
Total	14	9380.0		

$LSD_{.05}$ = 19.6% C.V. = 37.1%

$LSD_{.01}$ = 28.1%

Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	190.3	63.4	0.31
Treatments	3	8772.8	2924.3	14.39**
Error	9	1828.7	203.2	
Total	14	10791.8		

$LSD_{.05}$ = 22.8% C.V. = 25.5%

$LSD_{.01}$ = 32.8%

Appendix Table 8. Analysis of variance for data in Appendix Table 6.

Kentucky Bluegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	2120.7	706.9	0.36
Treatments	3	98638.7	32879.6	16.95**
Error	9	17453.5	1939.3	
Total	14	118212.9		

$LSD_{.05} = 70.4$ C.V. 38.0%

$LSD_{.01} = 101.2$

Perennial Ryegrass

Source of Variation	d.f.	SS	MS	F
Reps	3	12275.5	4091.8	0.72
Treatments	3	785946.5	261982.2	46.06**
Error	9	51190.0	5687.8	
Total	14	849412.0		

$LSD_{.05} = 120.6$ C.V. = 28.0%

$LSD_{.01} = 173.3$

Bentgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	11336.7	3778.9	2.95
Treatments	3	89681.2	29893.7	23.33**
Error	9	11533.5	1281.5	
Total	14	112551.4		

$LSD_{.05} = 57.2$ C.V. = 20.8%

$LSD_{.01} = 82.2$

Appendix Table 8 (continued)

Tall Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	97269.5	32423.2	4.33
Treatments	3	853546.5	284515.5	37.97**
Error	9	67436.0	7492.9	
Total	14	1018252.0		

$LSD_{.05}$ = 138.4 C.V. = 29.5%

$LSD_{.01}$ = 198.9

Fine Fescue

Source of Variation	d.f.	SS	MS	F
Reps	3	1284.7	428.2	0.26
Treatments	3	479338.2	159779.4	99.06**
Error	9	14517.5	1613.0	
Total	14	495140.4		

$LSD_{.05}$ = 64.2 C.V. = 20.1%

$LSD_{.01}$ = 92.3

Orchardgrass

Source of Variation	d.f.	SS	MS	F
Reps	3	22361.2	7453.7	1.45
Treatments	3	477520.7	159173.6	30.89**
Error	9	46368.0	5152.0	
Total	14	546249.9		

$LSD_{.05}$ = 114.8 C.V. = 40.2%

$LSD_{.01}$ = 164.9

Appendix Table 8 (continued)

Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	3798.5	1266.2	0.26
Treatments	3	291366.0	97122.0	19.72**
Error	9	44313.5	4923.7	
Total	14	339478.0		

$LSD_{.05}$ = 122.2 C.V. = 43.7%

$LSD_{.01}$ = 161.3

Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	14416.2	4805.4	0.26
Treatments	3	1844157.2	614719.1	34.01**
Error	9	162649.5	18072.2	
Total	14	2021222.9		

$LSD_{.05}$ = 215.0 C.V. = 31.2%

$LSD_{.01}$ = 308.9

Appendix Table 9. Germination from experiment II, first trial (August 28, 1980), to determine the effect of glyphosate and paraquat on the germination of two legume species evaluated under three different methods.

Rate (kg/ha)		Blocks I	II	III	IV	Mean
		(%)				
	Method 1[a]					
0	A*	59	56	65	81	65
	RC*	92	84	76	84	84
1.0 G*	A	29	62	56	36	46
	RC	29	34	65	65	48
3.0 G	A	12	40	66	19	34
	RC	52	41	57	41	48
0.56 P*	A	61	58	68	74	65
	RC	77	79	61	69	71
	Method 2[b]					
0	A	87	65	69	81	75
	RC	62	63	58	52	59
1.0 G	A	71	45	66	61	61
	RC	80	72	59	52	66
3.0 G	A	59	42	42	62	51
	RC	79	67	57	50	63
0.56 P	A	86	59	71	57	68
	RC	79	63	82	44	67
	Method 3[c]					
0	A	58	89	33	56	59
	RC	96	95	89	78	89
1.0 G	A	52	21	43	29	36
	RC	66	56	61	53	59
3.0 G	A	9	12	43	11	19
	RC	34	32	53	73	48
0.56 P	A	68	91	53	76	72
	RC	84	91	71	88	83

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

[a]Method 1: Seeds sprayed directly with herbicides, dried for 3 h, and placed on clean soil.

[b]Method 2: Wet soil sprayed with herbicides; after 3 h, untreated seeds were placed on treated soil surface.

[c]Method 3: Seeds were placed on soil surface and sprayed directly with herbicides.

Appendix Table 10. Dry weight of shoots from experiment II, first trial (August 28, 1980), to determine the effect of glyphosate and paraquat on the growth of two legume species evaluated under three different methods.

Rate (kg/ha)		Blocks I	II	III	IV	Total	Mean
		(mg)					
	Method 1[a]						
0	A*	313	248	249	627	1437	359
	RC*	764	776	564	784	2888	722
1.0 G*	A	116	263	137	135	651	163
	RC	93	108	228	149	578	144
3.0 G	A	43	125	112	31	311	78
	RC	130	152	116	126	524	131
0.56 P	A	292	368	240	488	1388	347
	RC	660	795	553	615	2623	656
	Method 2[b]						
0	A	736	719	448	667	2570	642
	RC	777	802	388	417	2384	596
1.0 G	A	401	178	434	483	1496	374
	RC	770	691	419	506	2386	596
3.0 G	A	296	218	104	215	833	208
	RC	619	509	359	270	1757	439
0.56 P	A	684	463	446	445	2038	509
	RC	853	717	397	343	2310	577
	Method 3[c]						
0	A	263	912	241	349	1765	441
	RC	1214	877	817	548	3456	864
1.0 G	A	146	47	102	44	339	85
	RC	205	179	168	157	709	177
3.0 G	A	45	32	142	15	234	58
	RC	98	83	169	191	541	135
0.56	A	391	764	185	537	1877	469
	RC	872	1214	454	671	3211	802

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

[a]Method 1: Seeds sprayed directly with herbicides, dried for 3 h and placed on clean soil.

[b]Method 2: Wet soil sprayed with herbicides; after 3 h, untreated seeds were placed on treated soil surface.

[c]Method 3: Seeds were placed on soil surface and sprayed directly with herbicides.

Appendix Table 11. Analysis of variance for data in Appendix Table 9.

Method 1 — Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	1115.2	371.7	1.74
Treatments	3	2814.7	938.2	4.38*
Error	9	1925.7	214.0	
Total	15	5855.7		

$LSD_{.05}$ = 23.4%   C.V. = 27.8%

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	1080.7	360.2	6.54
Treatments	3	1293.7	431.2	7.82**
Error	9	496.5	55.1	
Total	15	2870.9		

$LSD_{.05}$ = 11.9%   C.V. = 11.6%

$LSD_{.01}$ = 17.1%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	280.5	93.5	0.24
Treatments	3	6726.5	2242.2	5.89*
Error	9	3427.0	380.8	
Total	15	10434.0		

$LSD_{.05}$ = 31.2%   C.V. = 42.0%

Appendix Table 11 (continued)

Method 1 Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	74.2	24.7	0.14
Treatments	3	3853.2	1284.4	7.30**
Error	9	1586.3	176.2	
Total	15	5513.7		

$LSD_{.05}$ = 21.2% C.V. = 21.1%

$LSD_{.01}$ = 30.5%

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	1343.7	447.9	6.73
Treatments	3	159.2	53.1	0.80 n.s.
Error	9	598.5	66.5	
Total	15	2101.4		

C.V. = 12.8%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	54.0	18.0	0.10
Treatments	3	4670.0	1556.7	8.84**
Error	9	1584.0	176.0	
Total	15	6308.0		

$LSD_{.05}$ = 21.2% C.V. = 18.9%

$LSD_{.01}$ = 30.5%

Appendix Table 12. Analysis of variance for data in Appendix Table 10.

Method 1 Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	47993.7	15997.9	1.36
Treatments	3	231673.1	77224.4	6.58*
Error	9	105630.6	11736.7	
Total	15	385297.4		

$LSD_{.05}$ = 173.3 C.V. = 45.8%

$LSD_{.01}$ = 248.9

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	67001.2	22333.7	2.01
Treatments	3	414939.2	138313.1	12.43**
Error	9	100163.6	11129.3	
Total	15	582104.0		

$LSD_{.05}$ = 168.7 C.V. = 24.3%

$LSD_{.01}$ = 242.4

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	173604.7	57868.2	1.61
Treatments	3	591618.7	197206.2	5.48*
Error	9	323656.6	35961.8	
Total	15	1088880.0		

$LSD_{.05}$ = 303.3 C.V. = 72.0%

Appendix Table 12 (continued)

Method 1 — Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	17256.2	5752.1	0.87
Treatments	3	1224097.7	408032.6	61.69**
Error	9	59527.6	6614.2	
Total	15	1300881.5		

$LSD_{.05}$ = 130.1 C.V. = 19.7%

$LSD_{.01}$ = 186.9

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	446611.2	148870.4	35.43
Treatments	3	69114.7	23038.2	5.48*
Error	9	37812.1	4201.3	
Total	15	553538.0		

$LSD_{.05}$ = 103.7 C.V. = 11.7%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	153840.2	51280.1	1.17
Treatments	3	1845024.2	615008.1	14.07**
Error	9	393434.1	43714.9	
Total	15	2392298.5		

$LSD_{.05}$ = 334.4 C.V. = 42.2%

$LSD_{.01}$ = 480.5

Appendix Table 13. Germination from experiment II, second trial (October 11, 1980), to determine the effect of glyphosate and paraquat on the germination of two legume species evaluated under three different methods.

Rate (kg/ha)		Blocks I	II	III	IV	Mean
		(%)				
	Method 1[a]					
0	A*	42	26	53	51	43
	RC*	37	44	41	41	41
1.0 G*	A	8	18	41	41	27
	RC	31	33	37	30	33
3.0 G	A	1	14	2	18	9
	RC	15	20	42	11	22
0.56 P*	A	58	38	51	50	49
	RC	41	40	28	43	38
	Method 2[b]					
0	A	43	32	54	55	46
	RC	21	42	40	48	38
1.0 G	A	46	52	27	47	43
	RC	25	29	45	30	32
3.0 G	A	26	56	39	28	37
	RC	18	40	37	20	29
0.56 P	A	33	37	44	30	36
	RC	26	30	21	30	28
	Method 3[c]					
0	A	47	50	41	60	49
	RC	52	50	45	63	52
1.0 G	A	22	30	5	49	26
	RC	26	6	44	25	25
3.0 G	A	15	1	0	0	4
	RC	5	23	19	0	12
0.56 P	A	54	27	54	23	39
	RC	45	49	59	45	49

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

[a]Method 1: Seeds sprayed directly with herbicides, dried for 3 h, and placed on clean soil.

[b]Method 2: Wet soil sprayed with herbicides; after 3 h, untreated seeds were placed on treated soil surface.

[c]Method 3: Seeds were placed on soil surface and sprayed directly with herbicides.

Appendix Table 14. Dry weight of shoots from experiment II, second trial (October 11, 1980), to determine the effect of glyphosate and paraquat on the growth of two legume species evaluated under these different methods.

Rate (kg/ha)		Blocks I	II	III	IV	Total	Mean
		(mg)					
	Method 1[a]						
0	A*	202	112	368	329	1011	253
	RC*	176	240	191	178	785	196
1.0 G*	A	32	53	105	127	317	79
	RC	109	78	101	89	377	94
3.0 G	A	22	27	7	42	98	24
	RC	37	47	59	45	188	47
0.56 P*	A	361	220	297	349	1227	307
	RC	297	199	117	293	906	226
	Method 2[b]						
0	A	314	231	300	383	1228	307
	RC	62	185	126	111	484	121
1.0 G	A	295	306	161	209	971	243
	RC	120	80	156	188	544	136
3.0 G	A	133	327	282	217	959	240
	RC	64	154	102	99	419	105
0.56 P	A	197	230	299	185	911	228
	RC	90	124	91	110	415	104
	Method 3[c]						
0	A	209	367	306	478	1360	340
	RC	211	261	229	257	958	239
1.0 G	A	53	118	6	205	382	95
	RC	105	20	205	81	411	103
3.0 G	A	47	8	0	0	55	14
	RC	14	41	41	0	96	24
0.56 P	A	452	117	369	163	1101	275
	RC	355	359	347	322	1383	346

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

[a]Method 1: Seeds sprayed directly with herbicides, dried for 3 h, and placed on clean soil.

[b]Method 2: Wet soil sprayed with herbicides; after 3 h, untreated seeds were placed on treated soil surface.

[c]Method 3: Seeds were placed on soil surface and sprayed directly with herbicides.

Appendix Table 15. Analysis of variance for data in Appendix Table 13.

Method 1 — Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	692.5	230.8	2.03
Treatments	3	3936.5	1312.2	11.61**
Error	9	1021.0	113.4	
Total	15	5650.0		

$LSD_{.05}$ = 17.0% C.V. = 33.3%

$LSD_{.01}$ = 25.7%

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	107.2	35.7	0.25
Treatments	3	269.2	89.7	0.63 n.s.
Error	9	1281.5	142.4	
Total	15	1657.9		

C.V. = 29.4%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	252.7	84.2	0.38
Treatments	3	4634.7	1544.9	7.13**
Error	9	1948.3	216.5	
Total	15	6835.7		

$LSD_{.05}$ = 23.5% C.V. = 49.2%

$LSD_{.01}$ = 33.8%

Appendix Table 15 (continued)

Method 1 Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	96.2	32.1	0.43
Treatments	3	822.2	274.1	3.68 n.s.
Error	9	669.3	74.4	
Total	15	1587.7		

C.V. = 25.8%

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	453.2	151.1	2.17
Treatments	3	278.7	92.9	1.33 n.s.
Error	9	627.8	69.7	
Total	15	1359.7		

C.V. = 26.6%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	265.5	88.5	0.70
Treatments	3	4607.5	1535.8	12.30**
Error	9	1124.0	124.9	
Total	15	5997.0		

$LSD_{.05}$ = 17.9%

$LSD_{.01}$ = 25.7%

C.V. = 32.2%

Appendix Table 16. Analysis of variance for data in Appendix Table 14.

Method 1 — Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	27992.2	9330.7	2.60
Treatments	3	219535.2	73178.4	20.37**
Error	9	32328.6	3592.1	
Total	15	279856.4		

$LSD_{.05}$ = 95.9 C.V. = 36.1%

$LSD_{.01}$ = 137.7

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	3291.7	1097.2	0.19
Treatments	3	15309.2	5103.1	0.88 n.s.
Error	9	52076.6	5786.3	
Total	15	70677.5		

C.V. = 29.9%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	7774.2	2591.4	0.18
Treatments	3	277787.2	92595.7	6.32*
Error	9	131818.3	14646.5	
Total	15	417379.7		

$LSD_{.05}$ = 193.6 C.V. = 66.8%

$LSD_{.01}$ = 278.1

Appendix Table 16 (continued)

Method 1 — Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	3480.5	1160.2	0.47
Treatments	3	85537.5	28512.5	11.59**
Error	9	22146.0	2460.7	
Total	15	111164.0		

$LSD_{.05}$ = 79.3

$LSD_{.01}$ = 114.0

C.V. = 35.2%

Method 2

Source of Variation	d.f.	SS	MS	F
Reps	3	6168.2	2056.1	1.43
Treatments	3	2804.2	934.7	0.65 n.s.
Error	9	12957.3	1439.7	
Total	15	21929.7		

C.V. = 32.6%

Method 3

Source of Variation	d.f.	SS	MS	F
Reps	3	4123.5	1374.5	0.71
Treatments	3	245203.5	81734.5	42.21**
Error	9	17429.0	1936.5	
Total	15	266756.0		

$LSD_{.05}$ = 70.4

$LSD_{.01}$ = 101.1

C.V. = 24.7%

Appendix Table 17. Dry weight of shoots from experiment III to determine the influence of 3.37 kg a.e./ha of glyphosate on bentgrass growth when applied before and after emergence.

Time from treatment to emergence (days)	Blocks I	II	III	IV	Total	Mean
	(mg)					
Treated						
1	634	1418	440	368	2860	715
2	1134	896	1056	1284	4370	1092
3	1046	1654	661	1416	4777	1194
4	1066	1786	1059	750	4661	1165
5	11	45	8	33	97	24
After emergence						
0	473	1448	1722	918	4561	1140
1	764	1234	358	1100	3456	864
2	141	411	297	514	1363	341
Checks						
1	2518	3286	3004	2885	11693	2923
2	3164	2814	1918	3066	10962	2740
3	2864	1760	2792	2481	9897	2474
4	2250	2444	2570	2326	9590	2397
5	550	490	480	523	2043	511
After emergence						
0	2647	2136	1921	1757	8461	2115
1	2855	2400	2072	2702	10029	2507
2	3387	2952	2573	2623	11535	2884

Appendix Table 18. Dry weight of shoots from experiment IV to determine the influence of soil type on preemergence activity of glyphosate (3.37 kg a.e./ha).

Time from treatment to emergence (days)	Blocks I	II	III	IV	Total	Mean
	(mg)					
Mineral soil						
1	685	687	908	623	2903	726
2	431	354	383	414	1582	395
3	417	474	455	577	1923	481
4	442	450	433	601	1926	481
5	545	462	449	391	1847	462
Checks						
1	780	725	808	892	3205	801
2	343	413	378	404	1538	384
3	379	554	439	433	1805	451
4	543	367	447	448	1805	451
5	476	407	454	473	1810	452
Organic soil No. 2						
1	1061	936	1319	991	4307	1077
2	1266	1049	884	1121	4320	1080
3	1405	1032	1079	1301	4817	1204
4	1223	1121	1334	1203	4881	1220
5	1047	983	946	1140	4116	1029
Checks						
1	1385	915	1147	1474	4921	1230
2	1107	906	576	970	3559	890
3	1100	907	1168	1075	4250	1062
4	1331	1223	1050	1342	4946	1236
5	1142	1121	1281	1317	4861	1215
Organic soil No. 3						
1	438	523	504	664	2129	532
2	638	474	641	588	2341	585
3	690	553	635	870	2748	687
4	998	788	1040	684	3510	877
5	323	711	557	631	2222	555
Checks						
1	1190	900	868	1480	4438	1109
2	1011	685	693	911	3300	825
3	998	1072	965	956	3991	998
4	1002	845	837	936	3620	905
5	704	860	901	905	3370	842

Appendix Table 19. Dry weight of shoots from experiment V to determine the influence of 3.37 kg a.e./ha of glyphosate when applied 2 days before bentgrass emergence on soils of different organic matter content.

% O.M.	Blocks I	II	III	IV	Total	Mean
	(mg)					
Treated						
63.60	339	397	512	583	1831	458
36.95	416	582	383	386	1767	442
36.15	420	335	563	443	1761	440
36.18	552	554	535	748	2389	597
26.94	657	548	607	578	2390	597
16.15	549	539	493	368	1949	487
2.07	418	396	454	413	1681	420
Checks						
63.60	659	419	600	967	2645	661
36.95	329	838	380	413	1960	490
36.15	634	462	413	341	1850	462
36.18	745	453	812	568	2578	644
26.94	782	737	825	630	2974	743
16.15	482	418	581	413	1894	473
2.07	402	516	467	479	1864	466

Appendix Table 20. Dry weight of shoots from experiment VI, first trial (December 22, 1980), to determine the influence of soil pH on the soil activity of glyphosate (3.37 kg a.e./ha) when applied 2 days before bentgrass emergence.

Soil type	Soil pH	Blocks I	II	III	IV	Total	Mean
		(mg)					
Mineral							
Treated							
	6.1	35	83	112	47	277	69
	4.8	120	100	199	232	651	163
	4.4	170	246	147	292	855	214
Checks							
	6.1	383	588	432	613	2016	504
	4.8	546	621	503	732	2402	600
	4.4	517	475	513	712	2217	554
Organic No. 2							
Treated	7.9	8	7	27	15	57	14
	5.5	231	172	224	185	812	203
	4.9	182	248	72	195	697	174
	4.3	268	255	393	414	1330	332
Checks	7.9	655	374	1578	1271	3878	969
	5.5	824	902	935	1091	3752	938
	4.9	568	561	340	603	2072	518
	4.3	710	609	656	742	2717	679
Organic No. 3							
Treated	6.9	60	76	79	131	346	86
	5.4	35	1	13	33	82	20
	5.0	3	12	0	0	15	4
	4.7	2	0	0	2	4	1
Checks	6.9	591	518	374	898	2381	595
	5.4	726	912	1463	680	3781	945
	5.0	450	377	464	731	2022	505
	4.7	558	401	350	406	1715	429
Organic No. 4							
Treated	6.9	12	5	6	14	37	9
	5.4	3	1	1	13	18	4
	4.6	0	1	1	3	5	1
Checks	6.9	336	350	373	601	1660	415
	5.4	986	621	1040	611	3258	814
	4.6	381	610	398	537	1926	481

Appendix Table 21. Dry weight of shoots from experiment VI, second trial (March 22, 1981), to determine the influence of soil pH on the soil activity of glyphosate (3.37 kg a.e./ha) when applied 3 days before bentgrass emergence.

Soil type	Soil pH	Blocks I	II	III	IV	Total	Mean
		(mg)					
Mineral							
Treated	9.0	0	0	0	0	0	0
	6.1	310	279	251	169	1009	252
	4.6	470	407	407	415	1699	425
	4.1	513	399	460	472	1844	461
Checks	9.0	545	588	459	492	2084	521
	6.1	604	473	407	435	1919	480
	4.6	511	444	456	520	1931	483
	4.1	456	415	375	464	1710	427
Organic No. 2							
Treated	8.4	199	13	47	144	403	101
	5.5	1170	1388	1374	1191	5123	1281
	4.6	661	561	614	533	2369	592
	4.0	995	965	884	980	3824	956
Checks	8.4	706	736	637	711	2790	697
	5.5	1156	1082	897	1256	4391	1098
	4.6	714	632	638	561	2545	636
	4.0	896	896	862	950	3604	901
Organic No. 3							
Treated	7.2	56	13	80	6	155	39
	5.4	2	16	2	87	107	27
	4.6	0	0	2	0	2	1
Checks	7.2	292	272	268	313	1145	286
	5.4	1105	1182	850	901	4038	1009
	4.6	230	184	236	242	892	223
Organic No. 4							
Treated	7.3	79	12	94	22	207	52
	5.4	7	5	54	7	73	18
	4.5	0	0	0	0	0	0
Checks	7.3	423	328	668	461	1880	470
	5.4	481	699	529	561	2270	567
	4.5	640	659	567	590	2456	614

Appendix Table 22. Dry weight of shoots from experiment VII to determine the influence of phosphorus on 3.37 kg a.e./ha of glyphosate when the herbicide was applied 3 days before bentgrass emergence.

Soil type	P (kg/ha)	Blocks I	II	III	IV	Total	Mean
		(mg)					
Mineral soil							
Treated	0	186	259	323	279	1047	262
	28	318	173	279	267	1037	259
	56	82	150	211	327	770	192
	84	280	160	275	248	963	241
	112	256	176	77	255	764	191
Checks	0	480	492	532	515	2019	505
	28	422	506	423	606	1957	489
	56	462	428	530	431	1851	463
	84	516	495	431	539	1981	495
	112	512	619	541	638	2310	577
Organic soil 2							
Treated	0	898	640	1152	734	3424	856
	28	803	706	993	986	3488	872
	56	882	854	488	979	3203	801
	84	525	722	729	829	2805	701
	112	594	556	769	864	2783	696
Checks	0	752	992	1052	1126	3922	980
	28	839	744	701	1255	3539	885
	56	705	1007	851	719	3282	820
	84	807	841	956	852	3456	864
	112	742	977	1240	799	3758	939
Organic soil 3							
Treated	0	46	77	16	11	150	37
	28	35	51	65	99	250	62
	56	17	2	7	4	30	7
	84	0	31	0	0	31	8
	112	20	33	32	9	94	23
Checks	0	758	977	882	1129	3746	936
	28	646	425	740	616	2427	607
	56	386	539	852	550	2327	582
	84	438	649	692	259	2038	509
	112	416	654	726	804	2600	650

Appendix Table 23. Germination from experiment VIII, first trial (November 15, 1980), to determine the effect of glyphosate and paraquat on the germination of alfalfa and red clover when a moist soil was treated and untreated seeds were placed on the soil surface at intervals.

Rate (kg/ha)	Timing (h)		Blocks I	II	III	IV	Mean
			(%)				
0	3	A*	35	31	31	56	38
		RC*	48	42	56	37	46
1.0 G*		A	27	13	20	19	20
		RC	52	40	49	40	45
3.0 G		A	0	8	12	0	5
		RC	29	48	19	34	32
0.56 P*		A	30	58	44	27	40
		RC	58	59	35	65	54
0	6	A	53	50	39	48	47
		RC	58	75	54	52	60
1.0 G		A	14	12	23	16	16
		RC	72	55	53	49	57
3.0 G		A	0	4	9	0	3
		RC	11	29	27	33	25
0.56 P		A	45	40	48	31	41
		RC	55	64	50	54	56
0	9	A	27	47	31	31	34
		RC	59	64	51	62	59
1.0 G		A	12	10	6	23	13
		RC	43	42	47	44	44
3.0 G		A	0	0	3	3	1
		RC	19	29	24	22	23
0.56 P		A	19	29	40	40	32
		RC	44	43	45	50	45
0	24	A	65	42	28	36	43
		RC	38	60	52	47	49
1.0 G		A	17	11	48	12	22
		RC	29	30	45	53	39
3.0 G		A	0	0	4	2	1
		RC	44	34	55	58	48
0.56 P		A	43	35	41	45	41
		RC	58	53	55	50	54

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

Appendix Table 24. Dry weight of shoots from experiment VIII, first trial (November 15, 1980), to determine the effect of glyphosate and paraquat on the growth of alfalfa and red clover when a moist soil was treated and untreated seeds were placed on the soil surface at intervals.

Rate (kg/ha)	Timing (h)		Blocks I	II	III	IV	Total	Mean
			(mg)					
0	3	A*	79	131	166	429	805	201
		RC*	367	267	417	350	1401	350
1.0 G*		A	140	28	65	56	289	72
		RC	156	279	327	199	961	240
3.0 G		A	0	18	23	0	41	10
		RC	78	222	48	118	466	116
0.56 P		A	110	285	177	104	676	169
		RC	419	452	251	689	1811	453
0	6	A	349	226	153	215	943	236
		RC	414	636	423	661	2134	533
1.0 G		A	36	39	93	65	233	58
		RC	530	219	366	368	1483	371
3.0 G		A	0	24	20	0	44	11
		RC	17	91	97	134	339	85
0.56 P		A	177	170	195	149	691	173
		RC	465	570	471	579	2085	521
0	9	A	98	192	126	133	549	137
		RC	458	529	413	532	1932	483
1.0 G		A	37	30	18	101	186	46
		RC	183	244	311	355	1093	273
3.0 G		A	0	0	5	9	14	3
		RC	63	102	65	87	317	79
0.56 P		A	46	122	150	396	714	178
		RC	286	300	341	457	1384	346
0	24	A	451	136	111	284	982	245
		RC	242	489	377	364	1472	368
1.0 G		A	47	30	189	39	305	76
		RC	223	282	291	454	1250	312
3.0 G		A	0	0	6	2	8	2
		RC	140	104	168	322	734	183
0.56 P		A	192	160	179	204	735	184
		RC	377	417	454	386	1634	408

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

Appendix Table 25. Analysis of variance for data in Appendix Table 23.

T1 (3 h) Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	46.5	15.6	0.12
Treatments	3	3275.2	1091.7	8.19**
Error	9	1199.5	133.3	
Total	15	4521.4		

$LSD_{.05}$ = 18.5% C.V. = 44.9%

$LSD_{.01}$ = 26.5%

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	77.5	25.8	0.72
Treatments	3	5183.5	1727.8	48.40**
Error	9	321.0	35.7	
Total	15	5582.0		

$LSD_{.05}$ = 9.5% C.V. = 22.1%

$LSD_{.01}$ = 13.7%

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	202.2	67.4	1.19
Treatments	3	2939.2	979.7	17.37**
Error	9	507.5	56.4	
Total	15	3648.9		

$LSD_{.05}$ = 12.0% C.V. = 37.4%

$LSD_{.01}$ = 17.2%

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	256.2	85.4	0.51
Treatments	3	4476.7	1492.2	9.00**
Error	9	1491.5	165.7	
Total	15	6224.4		

$LSD_{.05}$ = 20.6% C.V. = 48.0%

$LSD_{.01}$ = 29.6%

Appendix Table 25 (continued)

T1 (3 h) Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	141.7	47.2	0.37
Treatments	3	964.7	321.6	2.55 n.s.
Error	9	1133.5	125.9	
Total	15	2239.9		

C.V. = 25.2%

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	231.2	77.1	0.88
Treatments	3	3217.7	1072.6	12.20**
Error	9	791.0	87.9	
Total	15	4239.9		

$LSD_{.05}$ = 15.0% C.V. = 19.0%

$LSD_{.01}$ = 21.5%

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	36.5	12.2	0.69
Treatments	3	2574.0	858.0	49.03**
Error	9	157.5	17.5	
Total	15	2768.0		

$LSD_{.05}$ = 6.7% C.V. = 9.7%

$LSD_{.01}$ = 9.6%

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	305.7	101.9	1.21
Treatments	3	453.7	151.2	1.80 n.s.
Error	9	756.5	84.0	
Total	15	1515.9		

C.V. = 19.3%

Appendix Table 26. Analysis of variance for data in Appendix Table 24.

T1 (3 h) Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	8609.2	2869.7	0.28
Treatments	3	92568.2	30856.1	2.99 n.s.
Error	9	92907.0	10323.0	
Total	15	194084.4		

C.V. = 89.8%

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	2526.7	842.2	0.35
Treatments	3	127493.7	42497.9	17.90**
Error	9	21367.5	2374.2	
Total	15	151387.9		

$LSD_{.05}$ = 77.9 C.V. = 40.8%

$LSD_{.01}$ = 112.0

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	28431.7	9477.2	1.73
Treatments	3	77724.2	25908.1	4.73*
Error	9	49320.0	5480.0	
Total	15	155475.9		

$LSD_{.05}$ = 118.4 C.V. = 80.9%

$LSD_{.01}$ = 170.1

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	16804.2	5601.4	0.67
Treatments	3	141853.2	47284.4	5.66*
Error	9	75172.3	8352.5	
Total	15	233829.7		

$LSD_{.05}$ = 146.2 C.V. = 72.0%

$LSD_{.01}$ = 210.0

Appendix Table 26 (continued)

T1 (3 h) Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	18826.2	6275.4	0.45
Treatments	3	250779.7	83593.2	5.99*
Error	9	125631.1	13959.0	
Total	15	395237.0		

$LSD_{.05}$ = 189.0 C.V. = 40.7%

$LSD_{.01}$ = 271.5

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	21081.2	7027.1	0.64
Treatments	3	522992.7	174330.9	15.82**
Error	9	99196.1	11021.8	
Total	15	643270.0		

$LSD_{.05}$ = 167.9 C.V. = 27.8%

$LSD_{.01}$ = 241.3

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	25404.3	8468.1	3.65
Treatments	3	339862.3	113287.4	48.89**
Error	9	20853.2	2317.0	
Total	15	386119.8		

$LSD_{.05}$ = 77.0 C.V. = 16.3%

$LSD_{.01}$ = 110.6

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	37334.8	12444.9	2.07
Treatments	3	115242.8	38414.3	6.40*
Error	9	53980.2	5997.8	
Total	15	206557.8		

$LSD_{.05}$ = 123.9 C.V. = 24.3%

$LSD_{.01}$ = 178.0

Appendix Table 27. Germination from experiment VIII, second trial (November 30, 1980), to determine the effect of glyphosate and paraquat on the germination of alfalfa and red clover when a moist soil was treated and untreated seeds were placed on the soil surface at intervals.

Rate (kg/ha)	Timing (h)		Blocks I	II	III	IV	Mean
			(%)				
0	3	A*	50	61	45	71	57
		RC*	47	60	69	45	55
1.0 G*		A	50	32	33	24	35
		RC	62	60	49	64	59
3.0 G		A	3	5	2	2	3
		RC	29	38	36	51	38
0.56 P*		A	67	65	71	53	64
		RC	52	69	67	62	62
0	6	A	66	32	68	25	48
		RC	69	70	70	66	69
1.0 G		A	16	36	53	13	29
		RC	58	50	52	48	52
3.0 G		A	6	11	1	0	4
		RC	64	33	32	50	45
0.56 P		A	80	31	37	57	51
		RC	65	63	64	67	65
0	9	A	59	72	64	63	64
		RC	70	60	68	65	66
1.0 G		A	7	11	4	8	7
		RC	52	41	49	53	49
3.0 G		A	6	4	5	6	5
		RC	51	53	58	19	45
0.56 P		A	55	60	58	75	62
		RC	59	53	65	71	62
0	24	A	66	47	71	37	55
		RC	61	54	65	50	57
1.0 G		A	59	30	32	15	34
		RC	62	46	42	62	53
3.0 G		A	4	7	3	10	6
		RC	54	38	40	47	45
0.56 P		A	49	55	36	32	43
		RC	52	57	65	68	60

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

Appendix Table 28. Dry weight of shoots from experiment VIII, second trial (November 30, 1980), to determine the effect of glyphosate and paraquat on the growth of alfalfa and red clover when a moist soil was treated and untreated seeds were placed on the soil surface at intervals.

Rate (kg/ha)	Timing (h)		Blocks I	II	III	IV	Total	Mean
			(mg)					
0	3	A*	405	343	274	544	1566	391
		RC*	427	426	602	257	1712	428
1.0 G*		A	371	159	157	124	811	203
		RC	307	316	278	514	1415	354
3.0 G		A	19	22	13	12	66	16
		RC	79	121	168	219	587	147
0.56 P*		A	379	465	454	352	1650	412
		RC	361	438	491	509	1799	450
0	6	A	455	143	403	150	1151	288
		RC	481	680	513	623	2297	574
1.0 G		A	45	184	291	47	567	142
		RC	406	300	426	261	1393	348
3.0 G		A	18	50	7	0	75	19
		RC	268	134	118	300	820	205
0.56 P		A	476	117	227	345	1165	291
		RC	530	565	653	465	2213	553
0	9	A	450	384	514	464	1812	453
		RC	531	609	463	588	2191	548
1.0 G		A	24	46	12	47	129	32
		RC	314	264	244	426	1248	312
3.0 G		A	14	20	15	23	72	18
		RC	217	233	234	102	786	196
0.56 P		A	340	299	352	457	1448	362
		RC	433	446	636	607	2122	530
0	24	A	356	318	397	207	1278	319
		RC	449	382	627	381	1839	460
1.0 G		A	249	121	148	48	566	141
		RC	356	423	243	524	1546	386
3.0 G		A	13	25	10	32	80	20
		RC	300	124	248	328	1000	250
0.56 P		A	275	363	280	195	1113	278
		RC	355	267	595	442	1659	415

*G = glyphosate; P = paraquat; A = alfalfa; RC = red clover.

Appendix Table 29. Analysis of variance for data in Appendix Table 27.

T1 (3 h) Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	70.2	23.4	0.24
Treatments	3	9010.2	3003.4	30.74**
Error	9	879.3	97.7	
Total	15	9959.7		

$LSD_{.05}$ = 15.8% C.V. = 24.9%

$LSD_{.01}$ = 22.7%

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	968.5	322.8	0.92
Treatments	3	5499.5	1833.2	5.25*
Error	9	3139.0	348.8	
Total	15	9607.0		

$LSD_{.05}$ = 29.9% C.V. = 56.2%

$LSD_{.01}$ = 42.9%

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	110.2	36.7	1.35
Treatments	3	12961.7	4320.6	158.80**
Error	9	244.5	27.2	
Total	15	13316.4		

$LSD_{.05}$ = 8.3% C.V. = 15.0%

$LSD_{.01}$ = 12.0%

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	888.2	296.1	2.11
Treatments	3	5261.2	1753.7	12.50**
Error	9	1262.5	140.3	
Total	15	7411.9		

$LSD_{.05}$ = 18.9% C.V. = 34.3%

$LSD_{.01}$ = 27.2%

Appendix Table 29 (continued)

T1 (3 h) Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	213.5	71.2	0.87
Treatments	3	1345.5	448.5	5.52*
Error	9	732.0	81.3	
Total	15	2291.0		

$LSD_{.05}$ = 14.4% C.V. = 16.8%

$LSD_{.01}$ = 20.7%

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	254.1	84.7	1.46
Treatments	3	1487.6	495.9	8.58**
Error	9	520.2	57.8	
Total	15	2261.9		

$LSD_{.05}$ = 12.2% C.V. = 13.2%

$LSD_{.01}$ = 17.5%

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	211.1	70.4	0.60
Treatments	3	1191.6	397.2	3.37 n.s.
Error	9	1059.2	117.7	
Total	15	2461.9		

C.V. = 19.6%

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	186.6	62.2	0.93
Treatments	3	564.1	188.0	2.81 n.s.
Error	9	602.2	66.9	
Total	15	1352.9		

C.V. = 15.2%

Appendix Table 30. Analysis of variance for data in Appendix Table 28.

T1 (3 h) Alfalfa

Source of Variation	d.f.	SS	MS	F
Reps	3	9915.7	3305.2	0.38
Treatments	3	412192.7	137397.6	15.95**
Error	9	77528.8	8614.3	
Total	15	499636.5		

$LSD_{.05}$ = 148.4 C.V. = 36.3%

$LSD_{.01}$ = 213.3

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	51388.0	17129.3	1.06
Treatments	3	205424.7	68474.9	4.24*
Error	9	145173.0	16130.3	
Total	15	401985.7		

$LSD_{.05}$ = 203.1 C.V. = 68.7%

$LSD_{.01}$ = 291.9

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	7871.1	2623.7	1.55
Treatments	3	601810.6	200603.5	118.33**
Error	9	15257.7	1695.3	
Total	15	624939.4		

$LSD_{.05}$ = 65.8 C.V. = 19.0%

$LSD_{.01}$ = 94.6

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	26271.1	8757.0	2.72
Treatments	3	223241.6	74413.9	23.15**
Error	9	28931.7	3214.6	
Total	15	278444.4		

$LSD_{.05}$ = 90.7 C.V. = 29.9%

$LSD_{.01}$ = 130.3

Appendix Table 30 (continued)

T1 (3 h) Red Clover

Source of Variation	d.f.	SS	MS	F
Reps	3	22026.7	7342.2	0.68
Treatments	3	228961.7	76320.6	7.10**
Error	9	96675.6	10741.7	
Total	15	347664.0		

$LSD_{.05}$ = 165.8 C.V. = 30.1%

$LSD_{.01}$ = 238.2

T2 (6 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	532.7	177.6	0.02
Treatments	3	368323.7	122774.6	11.75**
Error	9	94055.6	10450.6	
Total	15	462912.0		

$LSD_{.05}$ = 163.5 C.V. = 24.3%

$LSD_{.01}$ = 234.9

T3 (9 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	7071.2	2357.1	0.30
Treatments	3	351890.7	117296.9	14.78**
Error	9	71409.6	7934.4	
Total	15	430371.5		

$LSD_{.05}$ = 142.5 C.V. = 22.4%

$LSD_{.01}$ = 204.7

T4 (24 h)

Source of Variation	d.f.	SS	MS	F
Reps	3	42381.5	14127.2	1.03
Treatments	3	97958.5	32652.8	2.39 n.s.
Error	9	122811.0	13645.7	
Total	15	263151.0		

C.V. = 30.9%