AN ABSTRACT OF THE THESIS OF

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(Name of student)

in AGRONOMIC CROP SCIENCE presented on Aug. 23, 1974
(Major Department) (Date)

Title: INTERACTION BETWEEN GLYPHOSATE AND CERTAIN s-TRIAZINE HERBICIDES

Abstract approved: Redacted for Privacy
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Investigations were made in the field, greenhouse, growth chamber, and laboratory to: (a) observe the general activity of N-(phosphonomethyl)glycine (glyphosate); (b) determine the extent of its interaction with certain s-triazine herbicides; and (c) find an explanation for such an interaction.

Greenhouse and growth chamber studies substantiated other observations that glyphosate is very active as a foliarly-applied herbicide. It had very little crop selectivity in these studies. Glyphosate stimulated the transpiration rate of wheat plants shortly after treatment. The stimulation disappeared as visible plant injury appeared. Glyphosate did not affect root-shoot ratios in wheat, measured on a dry weight basis over time. It did not seem to cause direct damage to cell membranes, since no significant early leakage of electrolytes from leaf sections floating in glyphosate solutions

was observed. No significant differences were found in injury ratings or growth of wheat plants treated with different available formulations of glyphosate in the greenhouse.

When glyphosate was applied to quackgrass in the field in combination with 2-chloro-4, 6-bis(ethylamino)-s-triazine (simazine), no clear interaction was observed, but simazine reduced glyphosate activity on quackgrass in the greenhouse. Antagonistic interactions were observed between glyphosate and simazine on quackgrass, corn, and beans, and between glyphosate and 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine (atrazine) on corn in greenhouse studies. Antagonism also was observed when glyphosate was applied to corn in combination with 2-chloro-2', 6'-diethyl-N-(methoxymethyl)-acetanilide (alachlor) and (2, 4-dichlorophenoxy)acetic acid (2, 4-D) which were not formulated with clay materials. The interaction of glyphosate with alachlor was similar to that provided by simazine or atrazine, while the interaction with 2, 4-D was temporary, disappearing after 1 week. In all cases, the interaction was overcome by an increase in application rate of glyphosate.

When glyphosate and simazine were applied to corn and beans, reduction in glyphosate activity was observed only when the two herbicides were applied together as a mixture. Simultaneous application of simazine on different leaves of the same plants or to the soil while glyphosate was applied on the foliage did not produce any visible interaction. In subsequent experiments, an equal rate of the inert ingredients used in a commercial formulation of simazine also reduced the activity of glyphosate to a similar extent as when mixed with the commercial product containing the active ingredient. This finding tends to exclude the possibility of major physiological involvement in the interaction, and suggests a physical and/or chemical interaction between glyphosate molecules and those of simazine and the inert ingredients as a primary cause.

In further laboratory studies, about 10% of the glyphosate was removed from solution by mixing with the simazine formulation or inert ingredients and centrifuging. Significantly more glyphosate was adsorbed by the suspended materials when the spray mixtures became more concentrated. Less glyphosate was recovered by washing dried pellets derived from the centrifugation of the spray mixtures in comparison with the amounts of glyphosate recovered by washing wet pellets.

Supernatants of the spray mixtures applied to beans caused less plant injury than glyphosate alone. Addition of extra surfactant to these supernatants did not improve their activity on bean plants.

Results of these studies are consistent with the hypothesis that physical and/or chemical interaction between glyphosate and other herbicide products in the spray tank and on the leaf surface is the primary cause of the observed reduction of glyphosate activity on test plants. Other possible explanations were not disproved and should be investigated further.

Interaction Between Glyphosate and Certain s-Triazine Herbicides

by

Montien Somabhi

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1975

APPROVED:

Redacted for Privacy

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Date thesis is presented August 23, 1974

Typed by Opal Grossnicklaus for Montien Somabhi

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following individuals:

To Dr. Arnold P. Appleby for his helpful counseling and constant encouragement during my graduate program and during the preparation of this manuscript.

To Dr. Ronald J. Burr, Dr. Thomas C. Moore, Dr. Roy O. Morris, and Dr. Richard Astro for serving on my graduate committee.

To Dr. Roy O. Morris and Dr. Te May Ching for their advice and for permission to use their laboratory facilities.

To Dr. William Furtick, Dr. Lyall F. Taylor, and Dr. Juan Cardenas for their counseling during the early part of my graduate program.

Appreciation is extended to the following organizations:

To the Thai Government for a generous grant of leave from civil duty during my graduate program.

To the Rockefeller Foundation for financial support for the entire program at Oregon State University.

Acknowledgement is extended to Monsanto Company for providing technical and experimental samples of glyphosate and to Ciba-Geigy Corporation for the supply of the inert ingredients used in the formulation of simazine.

IN APPRECIATION

For her great love and ambition in her children's education, I dedicate this thesis to my mother.

To my wife, Varunee, and our son, Manas, for their love, patience, and understanding during the long years of study, I also dedicate this thesis.

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INTERACTION BETWEEN GLYPHOSATE AND CERTAIN *s*-TRIAZINE HERBICIDES

I. INTRODUCTION

A new compound, N-(phosphonomethyl) glycine or glyphosate, has been shown to have activity as a good postemergence herbicide on a wide spectrum of plant species, grasses as well as broadleaf weeds. According to a preliminary report (Baird *et al.*, 1971), glyphosate lacks crop selectivity. It readily translocates to the root system as indicated by good control of some perennial weeds. The material, however, appears to translocate most efficiently in broadleaf perennial weeds when the "sink" site shifts to the root system shortly after flowering (Lee, 1973). It is practically inactive when applied to dry soil even at an unusually high rate (Brewster and Appleby, 1972).

Because of its unique properties and activity, this compound has potential uses in a wide variety of crop as well as non-crop areas. Its use in minimum tillage crop production and chemical seedbed preparation is anticipated in addition to use in tree crops. However, tank mixing with many other herbicides has been found to reduce its activity considerably, especially at low rates of glyphosate. Increasing the rate of application usually overcomes this effect. The interaction has been observed to occur with several herbicides studied (Baird *et al.*, 1971).

The primary objectives of this research were to: (a) observe the general activity of glyphosate and to determine its dose responses on test plants in the greenhouse and growth chamber; (b) study its possible interaction with certain herbicides to confirm earlier reports from primary evaluations; and (c) explain the interaction between this herbicide and others with emphasis on s-triazine herbicides.

II. GENERAL ACTIVITY OF GLYPHOSATE AS A HERBICIDE

Introduction

A large amount of effort has been spent to evaluate and develop glyphosate both by Monsanto and by public research institutions around the country. Baird et al. (1971) reported that this compound was highly effective as a postemergence herbicide. Under field conditions the control of annual weeds and seedlings of perennial weeds was achieved with a rate of 1 kg/ha or lower, while established perennial weeds were controlled with 2 kg/ha or lower.

Although the compound has better activity on various weeds than some of the standard postemergence herbicides like 1, 1'-dimethyl-4, 4'-bipyridinium ion (paraquat), 2, 2-dichloropropionic acid (dalapon), and monosodium methanearsonate (MSMA), its use in row crops as topical or directed spray is questionable (Worsham and Lewis, 1973). Overton et al. (1973) reported that even the low rate of 0.56 kg/ha glyphosate as a topical or directed treatment still caused excessive injury to cotton (Gossypium hirsutum L.) and soybeans (Glycine max (L.) Merr.) at all growth stages studied. The lack of crop selectivity has also been reported for such crops as corn (Zea mays L.) (Behrens and Elakkad, 1972; and Roeth, 1972), wheat (Triticum aestivum L.) (Messersmith, 1972), and canning peas (Pisum sativum L.) (Harvey and Gritton, 1973).

This compound has almost no soil activity (Brewster and Appleby, 1972; Upchurch and Baird, 1972). This makes it particularly ideal for use in minimum tillage crop production, stale seedbed preparation, and tree crops.

When applied to the foliage, it is taken up and translocated quite readily (Baird et al., 1971). Behrens and Elakkad (1973) reported that glyphosate translocated and killed quackgrass (Agropyron repens L.) rhizomes if 10 days were allowed between treatment and a subsequent deep plowing. Tillage of the quackgrass 1 day after treatment resulted in erratic control because of incomplete translocation. Translocation of glyphosate and subsequent death of rhizomes were also reported for johnsongrass (Sorghum halepense (L.) Pers.) by Derting et al. (1973).

The research in this section was designed to study: (a) general injury symptoms typical for glyphosate on certain test plant species; (b) the level of activity of glyphosate on certain test plants in the greenhouse; (c) the effect of a foliar application of glyphosate on growth of foliage and roots of wheat; (d) the effect of different formulations of glyphosate on wheat injury symptoms and foliage growth; and (e) the effect of glyphosate on cell permeability. The information gained from studies in this section was used for planning and evaluating experiments in the following sections.

Materials and Methods

Experiment 1: Herbicidal Activity of Glyphosate on Certain Crops and Weeds

Crops and weeds listed in Table 1 were grown from seeds, except quackgrass which was grown from 2-node pieces of rhizomes planted about 2 years before. A greenhouse soil mix was used as the growing medium in 5x5-cm plastic pots for all plant species except corn and quackgrass for which 7.5x7.5-cm pots were used. After seeds germinated, the seedlings in each pot were thinned to a desirable number and fertilized with liquid fertilizer. All pots were subirrigated as necessary and kept in the greenhouse with the temperature maintained at 25±3 °C until the time of treatment. Quackgrass was maintained in the same manner as for other species, except the foliage was periodically clipped about every 3 months and the pots were fertilized with complete liquid fertilizer to maintain healthy foliar growth and to stimulate tillering.

All plant species were sprayed topically when they reached the ages and sizes shown in Table 1 with 0, 0.14, 0.28, 0.56, and 1.12 kg/ha[1] of glyphosate using 375 l/ha of spray solution at a pressure of 2.75 kg/cm^2 (40 psi). A nonionic surfactant, X-77, at 0.1% v/v

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[1] In a.e. or acid equivalent for glyphosate and 2,4-D and in a.i. or active ingredient for all other herbicides used in all experiments, unless stated otherwise.

was added to all spray solutions.

Injury symptoms were observed and the degree of injury was visually rated. Whenever possible, top growth was harvested and fresh weights were determined. The data were statistically analyzed.

Table 1. List of plant species tested in Experiment 1 and their seedling numbers per pot, size, and ages at the time of herbicidal treatment.

Plant species	Number in each pot	Age weeks	Height cm
Crops			
Corn (Zea mays L.)	1	5	40
Wheat (Triticum aestivum L.)	6	5	30
Oats (Avena sativa L.)	6	5	30
Beans (Phaseolus vulgaris L.)	1	3	25
Soybeans (Glycine max L.)	3	3	25
Weeds			
Downy brome (Bromus tectorum L.)	20	5	15
Green foxtail (Setaria viridis L.)	20	5	10
Barnyardgrass (Echinochloa crusgalli L.)	20	5	20
Quackgrass (Agropyron repens L.)	10-18[a]	3[b]	35
Pigweed (Amaranthus retroflexus L.)	2	6	15

[a]Number of shoots.

[b]Number of weeks after last clipping.

Experiment 2: Effect of Glyphosate on Growth, Transpiration Rate, and Root-shoot Ratio of Wheat

Seeds of uniform size of wheat cultivar 'Hyslop' were germinated in 2-cm plastic straw sections, each of which was closed at one end with a small piece of 20-mesh nylon screen to hold the seed. After the seeds germinated for 1 week, uniform seedlings in the straw sections were selected. Four seedlings were placed into punched holes in the cap of 220-ml plastic cups containing 200 ml of 0.25-strength Hoagland's solution. Four extra holes in each cup lid were left empty for aeration. The solution level in the cups was maintained as necessary by filling up to the original level with fresh solution. Each week the solution in the cup was discarded and replaced with fresh solution. No extra aeration was provided, since wheat seedlings in the solution grew as well as those grown for comparison in sand soaked with the same nutrient solution twice a day. The seedlings were kept in the greenhouse for 2 weeks before being moved into the growth chamber and treated.

The growth chamber was equipped with fluorescent-incandescent light source producing 19,000±1,100 lux at plant canopy. The lighting control was set to provide 12-hour days and 12-hour nights. The temperature was set at 29±2° C during the day and 18±2° C during the night. After 2 days in the growth chamber, plants were divided into three groups with each pot representing an experimental unit. The treatments were applied by submerging the leaves of wheat plants in each group into 0, 4.98×10^{-4}, 9.95×10^{-4}, and 1.97×10^{-3} M glyphosate solutions in which 0.1% v/v of X-77 surfactant was added.

Notes were taken on general symptoms of plant injury. Three, 7, and 14 days after treatment each group was harvested for plant dry weight determinations. Plants in each pot were separated into shoot and root portions at the plant crowns. The plant samples were dried at 70°C for 48 hours and weighed. The group which was harvested 14 days after treatment was also used to observe the changes in rate of transpiration. The transpiration rate measurements were made at 1, 2, 3, 4, 5, 6, 7, and 14 days after treatment by filling the nutrient solution in each cup up to a marked level, refilling the solution up to the same level after 4 hours, and recording the volume of the solution used to refill each pot. The rate of transpiration in ml/hr was obtained by dividing each recorded value by 4.

The arrangement of treatments was a completely randomized design with four replications. All data were analyzed statistically except plant injury which was not evaluated numerically.

Experiment 3: Effect of Glyphosate on Cell Membrane Permeability

Fifteen 1-cm leaf sections from the largest leaves of 5-week-old corn plants were floated in petri dishes containing 50 ml of glyphosate solution, either 50 μM or 100 μM, with 0.1% v/v of MON-0011 surfactant added. The leakage of electrolytes into the solution was used as an indication increase of cell membrane permeability. Electrical conductivity of the solution in each petri dish was monitored periodically by using a conductance bridge (Industrial Instruments, Model RC 16B2). Treatments with leaf sections floated in distilled water and in solution containing 0.1% v/v of MON-0011 surfactant alone were included as checks. Each treatment was replicated four times.

Experiment 4: Effect of Different Formulations of Glyphosate on Wheat

Wheat seeds were selected for uniformity in size and germinated in 5x5-cm plastic pots filled with greenhouse soil mix to the level of 1.5 cm from the top. Six seeds were initially planted in each pot which was kept in the greenhouse. The seedlings were thinned to four uniform plants in each pot at about 10 days after planting. After thinning, all pots were fertilized with complete liquid fertilizer.

Four weeks after planting, the seedlings in the pots were sprayed with three different formulations of glyphosate, MON-0468 (dimethylamine salt with no surfactant), MON-0139 (isopropylamine salt with no surfactant), and MON-2139 (isopropylamine salt with surfactant), at 0 and 0.28 kg/ha. In the spray solutions of MON-0468 and MON-0139, 0.1% v/v of X-77 surfactant was added. The spray volume was 375 l/ha for all treatments. The experiment was arranged in a completely randomized design with four replications.

Foliage injury to the seedling was evaluated at 2 and 3 weeks after treatment by visual rating. After the last evaluation, the top growth of seedlings in each pot was harvested at the ground level. The data were statistically analyzed.

Results

Experiment 1: Herbicidal Activity of Glyphosate on Certain Crops and Weeds

Injury Symptoms. For most plant species studied, high rates of glyphosate usually caused wilting of young leaves within 2 or 3 days. The wilting effect then spread to older leaves and the whole plants died within 1 week after treatment. There was no observed leaf chlorosis with high rates of glyphosate. At lower rates, glyphosate first caused a chlorotic area in the growing region of young leaves. Subsequently, the older leaves also turned chlorotic and the entire plants became desiccated.

In grass species, when the application rate of glyphosate was below lethal level, there was either slight injury, usually chlorosis of young leaves, or no discoloration at all, but in both cases the shoot growth was inhibited. This was followed by a prolific tillering. New tillers first appeared chlorotic and slightly deformed, but later became normal.

In broadleaf species, sublethal doses of glyphosate caused only slight chlorosis of young leaves and temporary growth inhibition. The growth resumed later.

In the case of pigweed, glyphosate applied at a rate of 0.14 kg/ha or higher resulted in rapid "leaf burn" or local necrosis on the older leaves within a few hours after treatment. The plants became desiccated within a few days.

Dose Response. Mean injury rating and fresh weights of plants treated with different rates of glyphosate are presented in Table 2 (also see data in Appendix Tables 1 and 2).

Under the conditions provided in this experiment, glyphosate was effective as a herbicide on most plant species studied at a rate of 0.28 kg/ha and higher. Green foxtail and pigweed were highly sensitive to glyphosate and were readily controlled by a rate as low as 0.14 kg/ha. Soybeans, on the other hand, were relatively resistant to this herbicide and appreciable injury was not obtained until the application rate was above 0.56 kg/ha. Quackgrass was intermediate in sensitivity to glyphosate. Although a 0.28 kg/ha rate gave a relatively high injury rating, an acceptable top kill was reached only when the rate was increased to 0.56 kg/ha or higher.

Experiment 2: Effect of Glyphosate on Growth, Transpiration Rate, and Root-shoot Ratio of Wheat

Injury Symptoms. All rates of glyphosate used in this experiment failed to kill wheat plants after 14 days. However, some injury was observed in all glyphosate-treated plants. Wheat plants with the

Table 2. Experiment 1. Plant injury and fresh weights of certain crops and weeds treated with different rates of glyphosate.

Glyphosate kg/ha	Mean injury rating[a]		Fresh weight g/pot	Fresh weight Relative
Beans	3 days	5 days		
0	0 a[b]	0 a	3.368 b	100
0.14	4 a	28 a	3.236 b	96
0.28	43 b	99 b	1.591 a	47
0.56	75 c	100 b	1.180 a	35
1.12	82 c	100 b	1.049 a	31
Corn	1 week	2 weeks		
0	0 a	0 a	22.375 b	100
0.14	13 b	28 b	20.775 b	93
0.28	46 c	86 c	4.975 a	22
0.56	79 d	99 d	1.675 a	8
1.12	90 e	100 d	1.500 a	7
Soybeans	1 week	2 weeks		
0	0 a	0 a	6.562 c	100
0.14	8 b	11 b	6.157 c	94
0.28	23 c	25 c	5.157 b	79
0.56	21 c	28 c	4.788 b	73
1.12	34 d	46 d	3.820 a	58
Oats	1 week	2 weeks		
0	0 a	0 a	13.310 d	100
0.14	5 b	30 b	8.371 c	63
0.28	79 c	93 c	1.647 b	12
0.56	98 d	100 c	0.798 ab	6
1.12	99 d	100 c	0.616 a	5
Wheat	1 week	2 weeks		
0	0 a	0 a	12.309 c	100
0.14	24 b	58 b	4.437 b	36
0.28	79 c	100 c	1.023 a	8
0.56	88 d	100 c	0.925 a	8
1.12	93 d	100 c	0.877 a	7
Downy brome	1 week	2 weeks		
0	0 a	0 a	9.758 c	100
0.14	9 a	58 b	3.963 b	41
0.28	58 b	91 c	1.027 a	11
0.56	66 b	95 c	0.939 a	11
1.12	81 c	100 c	0.854 a	9

Table 2. (Continued)

Glyphosate kg/ha	Mean injury rating		Fresh weight g/pot	Fresh weight Relative
Green foxtail	1 week	2 weeks		
0	0 a	0 a	16.547 b	100
0.14	73 b	94 b	1.255 a	8
0.28	81 c	98 c	0.857 a	5
0.56	90 d	99 c	0.845 a	5
1.12	91 d	100 c	0.845 a	5
Barnyardgrass	1 week	2 weeks		
0	0 a	0 a	22.900 d	100
0.14	5 a	25 b	13.657 c	60
0.28	50 b	75 c	3.845 b	17
0.56	69 c	93 d	1.717 ab	8
1.12	83 d	100 e	1.072 a	5
Pigweed	2 days	5 days		
0	0 a	0 a	4.465 b	100
0.14	75 b	100 b	0.402 a	9
0.28	81 b	100 b	0.467 a	11
0.56	90 b	100 b	0.491 a	11
1.12	90 b	100 b	0.552 a	12
Quackgrass	1 week	2 weeks		
0	0 a	0 a	21.179 c	100
0.14	4 a	11 a	15.351 b	73
0.28	34 b	55 b	5.740 a	27
0.56	74 c	96 c	2.613 a	12
1.12	83 cd	100 c	2.029 a	10
2.24	91 d	100 c	1.216 a	6

[a]Evaluation system for plant injury used here and in all other experiments:

0-20 .... slight growth reduction and visible chlorosis at growing point.

21-40 .... complete growth inhibition, chlorosis visible on other parts, and slight sign of wilting or necrosis on leaves.

41-60..... severe foliar chlorosis and about half of the foliage wilting or necrotic.

61-80..... more than half of the foliage wilting or necrotic and a complete loss of green color.

81-100 .... severe wilting or necrosis to complete withering.

[b]Values followed by the same letter are not significantly different at $P = 0.05$.

foliage dipped in the highest concentration, 1.97×10^{-3} M, of glyphosate solution developed first visible injury symptoms about 3 days after treatment. Yellowing of the leaf tissue began at the tips of the older leaves and gradually spread toward the leaf sheaths. At the same time young leaves stopped growing and began yellowing later.

There was no new root growth during this same period. Extension of old roots also stopped.

Toward the end of the second week, wheat plants showed some signs of recovery, producing new tillers and new roots.

Rate of Transpiration. Figure 1 shows changes in the rate of transpiration of glyphosate-treated wheat plants relative to that of the control as a function of time. About 24 hours after treatment, glyphosate slightly increased the rate of transpiration of the plants, then caused a rapid drop reaching the lowest level in about 4 days. The rate of transpiration of the treated plants remained low for the next few days and later began to rise slowly as the plants started to recover from the injury.

Dry Weight. Three days after glyphosate treatment, plant dry weights were already reduced significantly (Figure 1). Seven days after the treatment, the relative dry weight of the treated plants reached the lowest level. Unlike the morphological damage and the relative transpiration rate which gradually improved in the second

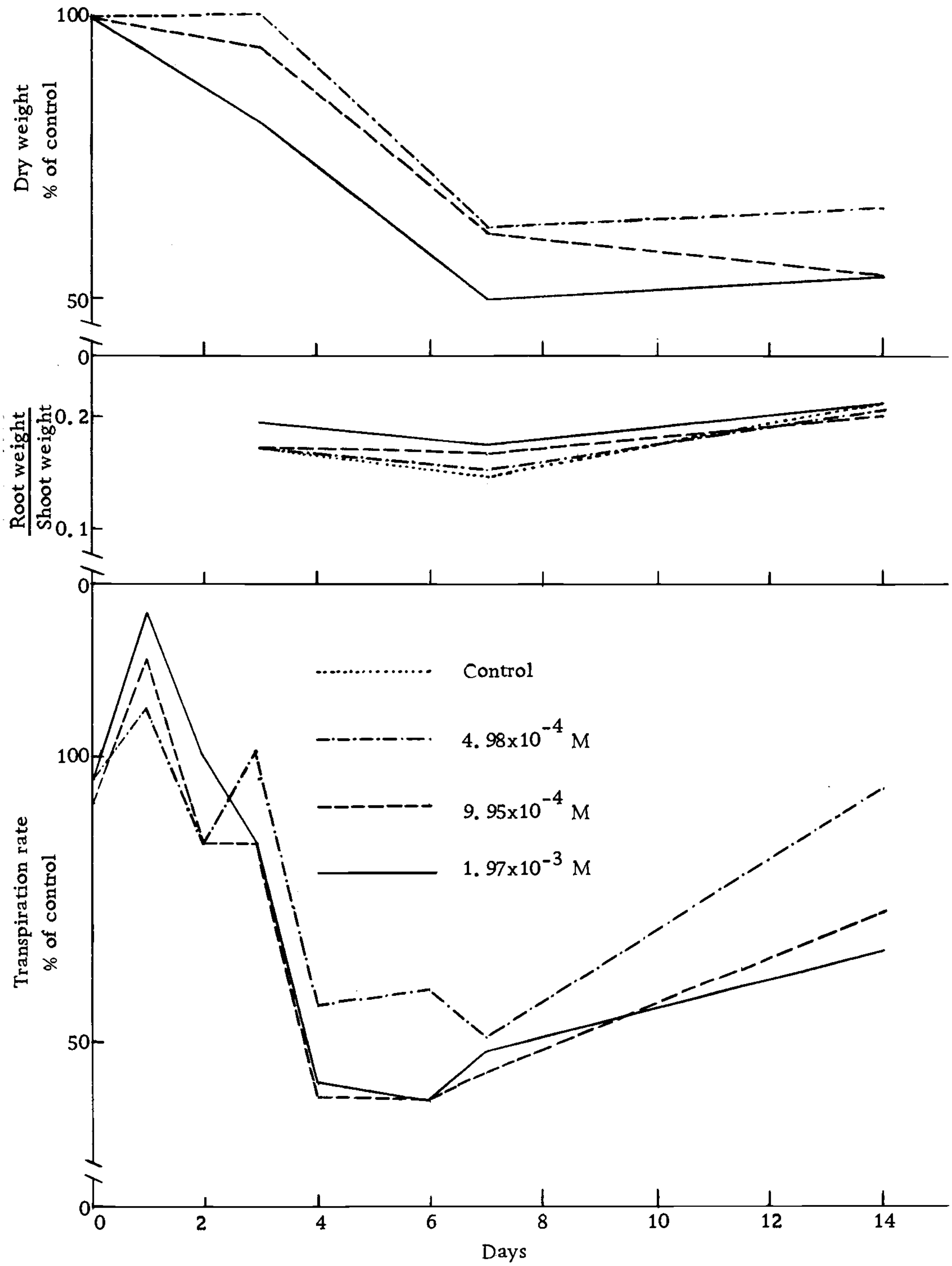

Figure 1. Experiment 2. Dry weight, root-shoot weight ratio, and transpiration rate of wheat plants treated with different rates of glyphosate.

week, the relative dry weight after 2 weeks did not change significantly from the level observed a week earlier (also see Appendix Table 4).

Root-shoot Weight Ratio. Figure 1 also shows the change in the ratio of root to shoot dry weight as affected by glyphosate treatments (also see Appendix Table 5). No significant changes in the root-shoot weight ratio were observed at any time during the 2-week period that followed the treatment. This indicated that glyphosate affected both root and shoot growth approximately to the same extent.

Experiment 3: Effect of Glyphosate on Cell Membrane Permeability

Changes in the conductivity of the solutions in which the corn leaf sections were floated were plotted as a function of time as shown in Figure 2. These changes were assumed to reflect the degree of change in cell membrane permeability of the floating leaf sections to the electrolytes. Damaged cell membranes would allow more electrolytes to leak out into the solution in the petri dish.

A rapid initial leakage of electrolytes into the solutions was observed for all treatments. This initial surge was completed in about 1 hour from the time the leaf sections were placed in the solutions. There were no significant differences between the treatments containing glyphosate and those without it. After the first hour, permeability of cells of the leaf sections floated in water did not

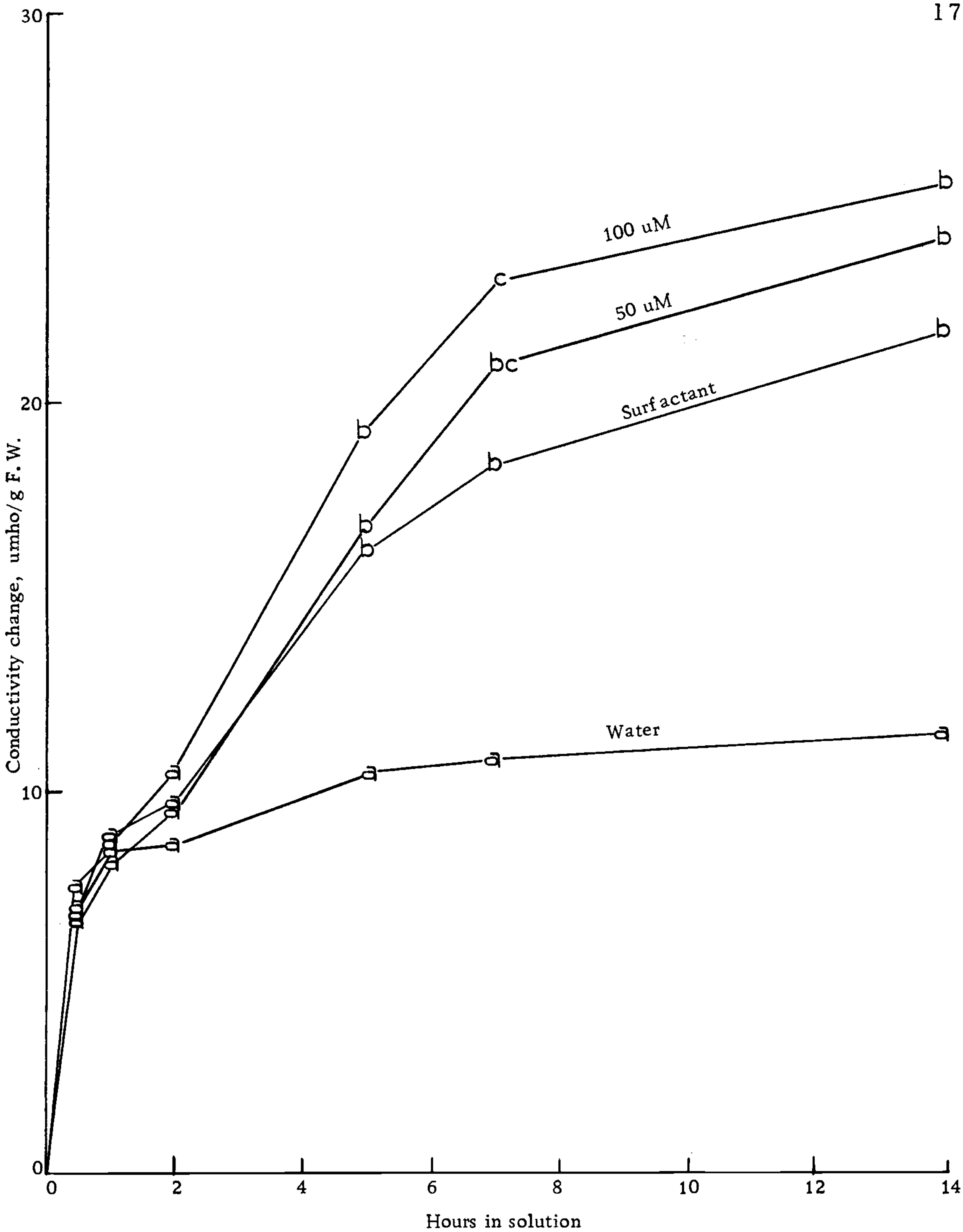

Figure 2. Experiment 3. Changes of the conductivity of the glyphosate solutions due to the leakage of electrolytes from cells of the floating leaf sections of corn. Points with the same letter are not significantly different at P = 0.05.

change significantly up to 14 hours when the experiment was terminated. Meanwhile, significant losses of electrolytes from cells of the leaf sections floated in the surfactant and glyphosate solutions continued for the entire period, although at decreasing rates. Glyphosate itself did not significantly cause higher leakage of electrolytes than the surfactant alone. A period of about 2 hours was required before any significant change in cell permeability due to the surfactant and glyphosate treatments could be observed.

Experiment 4: Effect of Different Formulations of Glyphosate on Wheat

Figure 3 (also see Appendix Table 7) shows the mean injury ratings at 2 and 3 weeks after treatment. At both evaluations, all formulations of glyphosate, with the addition of some surfactant, were equally effective on wheat plants. The data indicate that at a rate of 0.28 kg/ha any form of glyphosate would kill wheat plants in about 3 to 4 weeks when applied as a foliar spray under the conditions of this experiment.

The effect of glyphosate on growth was expressed as the shoot fresh weights relative to that of the control plants (Figure 4 and Appendix Table 8). As indicated by the plant injury ratings, all forms of glyphosate used affected the top growth of wheat to the same extent. No significant differences in degree of fresh weight reductions

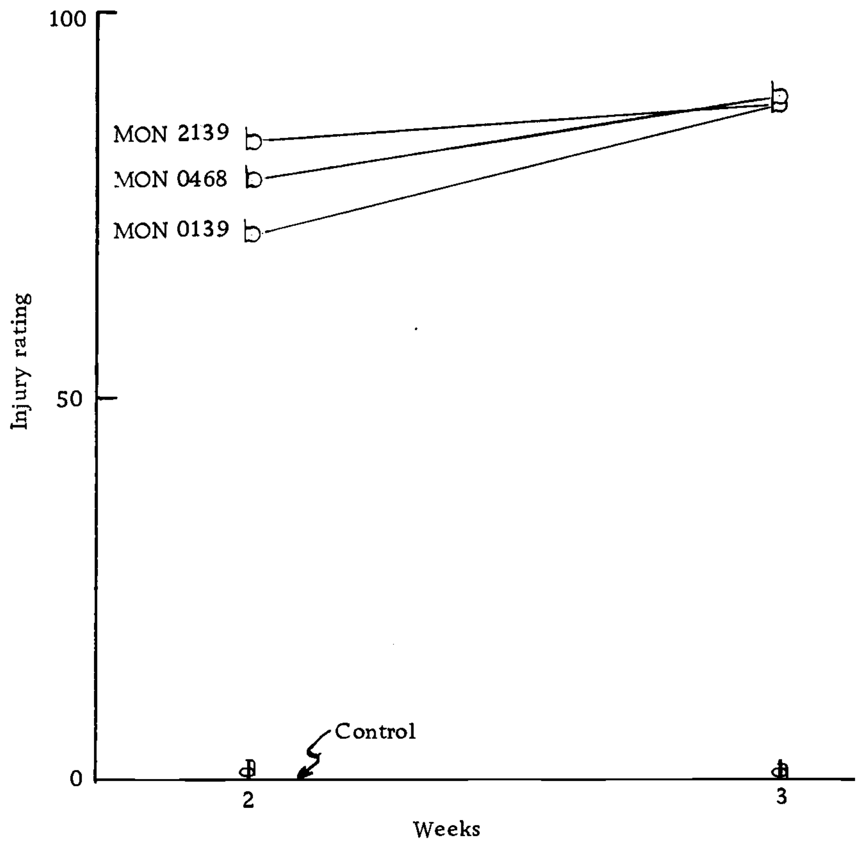

Figure 3. Experiment 4. Injury of wheat plants as affected by three different formulations of glyphosate. Points with the same letter are not significantly different at P = 0.05.

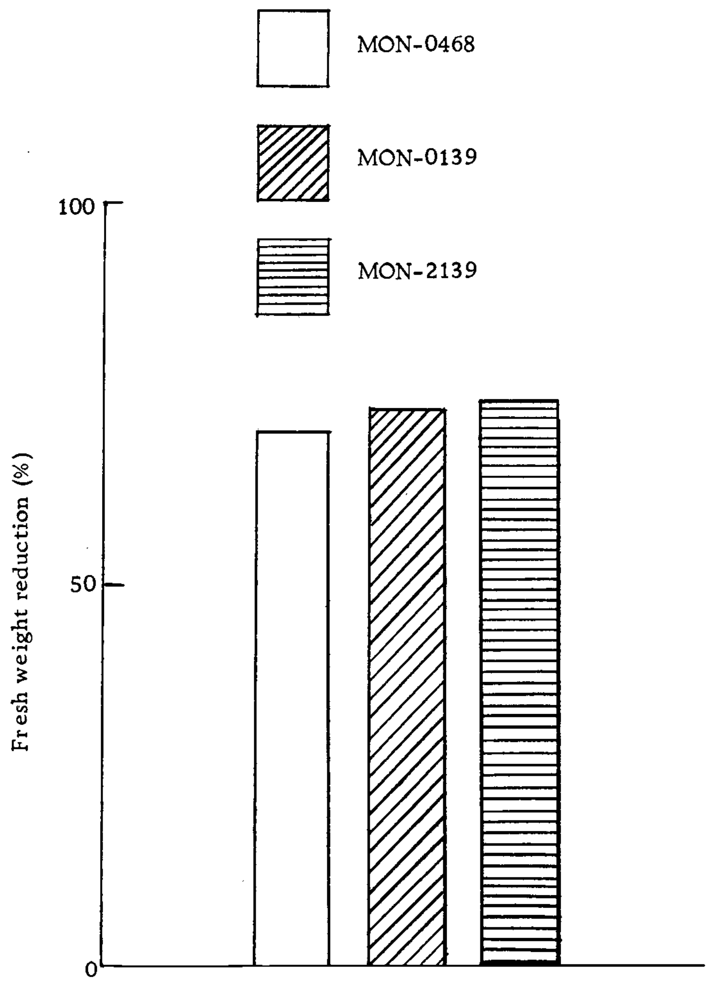

Figure 4. Experiment 4. Fresh weights of wheat plants as affected by three different formulations of glyphosate.

were observed among the three formulations.

Discussion

Glyphosate was highly effective as a foliarly-applied herbicide on certain plant species with application rates starting at 0.28 kg/ha. Of ten crop and weed species, only soybeans showed some tolerance to the treatment of glyphosate. This may suggest some practical use of glyphosate for weed control in soybeans, probably as a post-emergence and directed application as reported by Overton et al. (1973) and Worsham and Lewis (1973).

At low rates most species escaped the eventual kill by glyphosate but their growth was temporarily inhibited (Table 2). This would result in yield loss in annual crops which have a short growing season. Yield losses in annual crops were reported by Overton et al. (1973) for soybeans and cotton, by Messersmith (1972) for wheat, and by Harvey and Gritton (1973) for peas. Although fresh weight data from soybeans and corn treated with 0.14 kg/ha did not show any significant growth inhibition during the 2-week period following treatment in the greenhouse (Table 2), all higher rates caused significant growth reductions, indicating a narrow selectivity range with these two crops.

Study of root-shoot ratio of wheat revealed no differential effect of glyphosate on root growth (Figure 1). Both shoots and roots were equally affected. However, a slight early stimulation of transpiration was observed when wheat plants were treated with sublethal doses of glyphosate. This early stimulation of transpiration may become an important factor causing plant desiccation if the application rate of glyphosate is sufficiently high. The data from the wheat study (Figure 1) suggest that shoot growth can be used as a good measurement of glyphosate effect on growth of the whole plant in future studies.

In some species such as corn and beans, high rates of glyphosate caused relatively rapid wilting and desiccation without any chlorotic symptoms on the leaves. This observation may have two possible explanations. First, a high rate of glyphosate may greatly stimulate plant transpiration, the water balance in the plant is subsequently upset, and the plant finally becomes desiccated and killed. Secondly, root growth and/or water uptake processes in roots may be impaired by a high rate of glyphosate, the plant loses its water balance, and becomes desiccated.

At lower doses of glyphosate, the damage may be gradual on general metabolism of the treated plant. An inhibition of the aromatic amino acid biosynthetic pathway was suggested by Jaworski (1972) as a mode of action of glyphosate, when he found that growth inhibition of *Lemna* in the presence of glyphosate could only be partially reversed by the addition of L-phenylalanine to the nutrient medium and that of *Rhizobium* only by the addition of both L-phenylalanine and

L-tyrosine. Campbell et al. (1973) studied the chloroplast ultrastructure of quackgrass leaves treated with glyphosate and found cellular damage as early as 24 hours after treatment. The observed damage was the disruption of the chloroplast envelope and swelling of the rough endoplasmic reticulum. Later the chloroplasts and other cellular organelles were destroyed. They concluded that damage of the membrane system in cells is a major reason why plants treated with glyphosate become chlorotic and die.

Observations of rapid wilting without first becoming chlorotic in the glyphosate-treated corn and beans and of early stimulation of the transpiration in the treated wheat also suggested that glyphosate may directly react with cell membranes. Subsequently, damaged cells lose control over their own water potential and, as a result, lose excessive water due to evaporation. Early damage to the membrane system in quackgrass caused by glyphosate treatment as found by Campbell et al. (1973) seemed to support this idea. However, an experiment involving floating corn leaf sections in glyphosate solutions did not clearly show an early change in cell permeability. Although slightly greater, the changes in cell permeability due to glyphosate were not significantly different from that caused by 0.1% surfactant alone (Figure 2). Furthermore, it took at least 2 hours before any permeability change due to glyphosate treatment could be observed. This time period was too long to indicate direct damage to the cell membranes. The leakage of sugars and amino acids from Chlorella cells due to quinone compounds was clearly observed within a few minutes from the time the cells were first suspended in the solutions (Sikka et al., 1973). Glyphosate probably first acts on cellular metabolism which later affects the integrity and functions of cell membranes.

The effect of glyphosate formulation was negligible in terms of plant injury and fresh weights of the top growth of wheat (Figures 3 and 4). All formulations of glyphosate tested were equally effective on wheat plants, provided that surfactant was added to the spray solution.

III. INTERACTION BETWEEN GLYPHOSATE AND TWO s-TRIAZINE HERBICIDES

Introduction

Lacking significant soil activity as reported by Brewster and Appleby (1972) and by Upchurch and Baird (1972) makes glyphosate a very interesting compound among foliage-active and translocating herbicides. With this property and its broad-range herbicidal activity, glyphosate can fit nicely in many situations of weed control in minimum tillage crop production, stale seedbed preparation, orchard, and non-crop areas. However, residual activity in the soil is necessary to control annual weeds which subsequently germinate in the area. A combination with some soil-active herbicides appropriate for the situation can fulfill this requirement.

Early reports (Baird et al., 1971; and Baird et al., 1974) showed antagonism between glyphosate and several soil-residual herbicides in field studies. A tank mix with other herbicides usually reduced the herbicidal activity of glyphosate considerably, especially at low rates of application. When the application rate of glyphosate was increased, however, the antagonistic interaction disappeared.

Since these are the only reports on glyphosate interaction with other herbicides, and because numerous workers studying the combinations of glyphosate and other herbicides for weed control in various occasions did not report this interaction, the studies in this section were designed to confirm the results of Baird et al. (1971) and Baird et al. (1974). One field and four greenhouse experiments were conducted and carefully evaluated for any possible interaction. Corn, beans, and quackgrass in the greenhouse and quackgrass in the field were used as test plants. Simazine in the quackgrass and bean experiments, and atrazine in the corn experiment were combined with glyphosate.

Materials and Methods

Experiment 5: Interaction Between Glyphosate and Simazine on Quackgrass under Field Conditions

An established field of orchardgrass near Monroe, Oregon, which was heavily infested with quackgrass, was selected for the trial. There were no other weeds in the area at the beginning of the trial except a few patches of bentgrass (*Agrostis tenuis* Sibth.). The orchardgrass was planted in rows 30 cm apart. After the field was cut for hay in June, 1972, plots of 3 x 6 m were measured off from one corner of the field where the quackgrass stand was most uniform. On July 25, 1972, two rates of glyphosate, 2.24 and 4.48 kg/ha were applied alone, "tank mixed" with simazine at a rate of 2.80 kg/ha, or with the "follow-up" treatment of simazine at the same rate on the following day. A control and simazine alone at 2.80 kg/ha were also included for comparison. All treatments were applied with

0.1% v/v of X-77 surfactant at 2.5 kg/cm^2 (35 psi) of pressure using 375 l/ha of spray solution. The experiment was arranged in a randomized block design with four replications. Visual evaluations of the control of quackgrass were made subsequently.[2]

Experiment 6: Interaction Between Glyphosate and Atrazine on Corn in the Greenhouse

Corn plants were grown and maintained in the greenhouse as in Experiment 1. When the plants were 3 weeks old, glyphosate at rates of 0.28 and 0.56 kg/ha was appplied as a foliar spray alone and in combination with 80% wettable powder atrazine at a rate of 4.48 kg/ha. An untreated check and atrazine alone at 4.48 kg/ha applied as a foliar spray were included for comparison. All of the applications were made with 375 l/ha of spray solution. X-77, at a rate of 0.1% v/v, was added to the spray solution to ensure better wetting of the corn leaves and optimal activity of glyphosate. All treatments were replicated four times and were arranged in a completely randomized design.

Visual evaluations of the corn injury were made after the treatment. The plants were harvested after the last evaluation and

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[2]Quackgrass control rating:

0-20 . . 100-81% of the area covered by green quackgrass.
21-40 . . .80-61% of the area covered by green quackgrass.
41-60 . . .60-41% of the area covered by green quackgrass.
61-80 . . .40-21% of the area covered by green quackgrass.
81-100 . .20-0 % of the area covered by green quackgrass.

fresh weight of the top growth was determined. The data were statistically analyzed.

Experiment 7: Interaction Between Glyphosate and Simazine on Quackgrass in the Greenhouse

Quackgrass was planted and maintained in the greenhouse in the same manner as described in Experiment 1. In June, 1973, pots with uniform top growth were selected, clipped, and fertilized. The pots were divided into three groups, each to be treated 2, 4, or 6 weeks later to observe the effect of the different amounts of foliage among the groups on the activity of the herbicidal treatments.

The treatments included three rates, 0.56, 1.12, and 2.24 kg/ha of glyphosate applied to the foliage alone and each rate in combination with simazine at a rate of 2.80 kg/ha. Untreated quackgrass pots were used as standard checks. All treatments were applied as a foliar spray with a nonionic surfactant added in the same manner as described in previous experiments. The pots were subirrigated after treatment to avoid washing the herbicides from the foliage. All treatments were arranged as a completely randomized design with five replications.

Quackgrass injury was evaluated visually. The injury data were analyzed statistically.

Experiment 8: Interaction Between Glyphosate and Simazine on Beans in the Greenhouse

Bean plants were grown and maintained as described in previous experiments. One month after planting when the first trifoliate leaf was fully expanded, the plants were sprayed with glyphosate at rates of 0.56 and 1.12 kg/ha either alone or in combination with 2.80 kg/ha of simazine as an 80% wettable powder. Untreated plants and those sprayed with 2.80 kg/ha of simazine were used as checks. X-77 surfactant was added to all spray solutions. The treatments were arranged in a completely randomized design with four replications. Visual evaluation of the injury was made, top growth was harvested, and dry weights were determined.

Experiment 9: Interaction Between Glyphosate and Certain Herbicides on Corn in the Greenhouse

Corn plants were grown and maintained in the greenhouse in the same manner as in Experiment 1. When the plants were 5 weeks old, different herbicidal treatments were applied as a foliar spray. X-77 surfactant was added to all spray solutions at a rate of 0.1% v/v.

The treatments included glyphosate at 0.28 and 0.56 kg/ha, simazine at 3.36 kg/ha, 2-chloro-2', 6'-diethyl-*N*-(methoxymethyl)-acetanilide (alachlor) at 3.36 kg/ha, amine salt of 2, 4-dichloro-phenoxyacetic acid (2, 4-D) at 0.56 kg/ha, and combinations of both rates of glyphosate with all of the three herbicides. Untreated plants were used as checks.

Visual evaluations were made for plant injury. Plants were harvested after the last evaluation, and the fresh weights of top growth were determined. The data were statistically analyzed.

Results

Experiment 5: Interaction Between Glyphosate and Simazine on Quackgrass under Field Conditions

The period following treatment was unusually dry until October, 1972, when there was an appreciable amount of rainfall in the area. The quackgrass remained dormant and dry most of the summer. It was difficult to distinguish between glyphosate injury symptoms and drought injury. The control of quackgrass as visually evaluated as is summarized in Figure 5. The data on the quackgrass control for individual evaluations and their statistical analyses are presented in Appendix Table 9.

At the 2.24 kg/ha rate of glyphosate, the addition of 2.80 kg/ha of wettable powder simazine to the spray solution reduced control of the quackgrass, especially at the first evaluation (Figure 5). Simazine at the same rate applied on the following day slightly improved control of quackgrass by glyphosate, except in the first

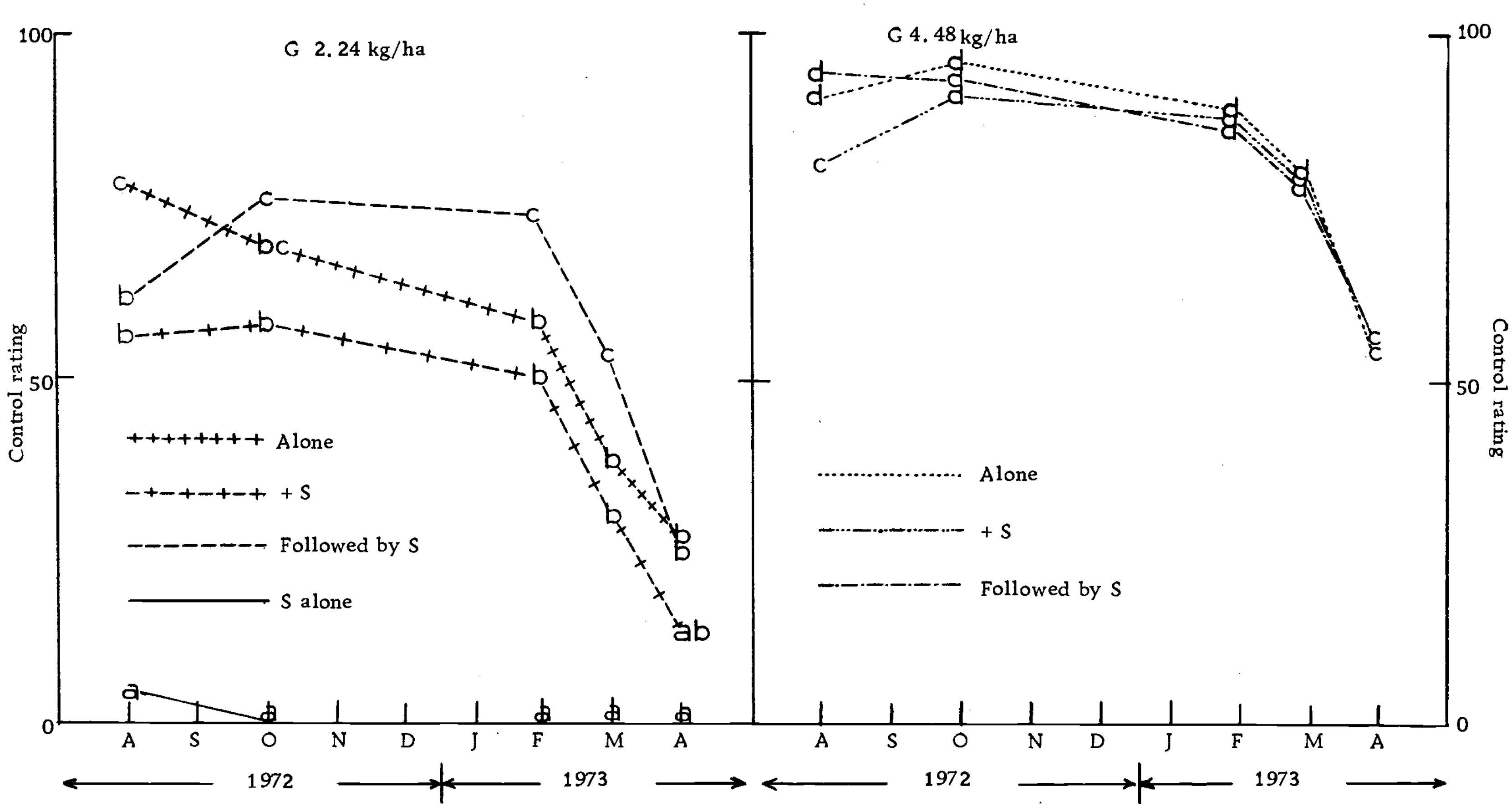

Figure 5. Control of quackgrass treated with glyphosate, simazine, and their combinations under field conditions (G = glyphosate, and S = simazine). Points with the same letter are not significantly different at P = 0.05.

evaluation where this treatment was considerably inferior.

No antagonistic effect of added simazine with 4.48 kg/ha of glyphosate was detectable, except a slight reduction in quackgrass control by the mixture in the first evaluation.

Experiment 6: Interaction Between Glyphosate and Atrazine on Corn in the Greenhouse

The effect of glyphosate and its combinations with atrazine on visual injury of corn plants and the fresh weights of their top growth are shown in Figures 6 and 7 and Appendix Tables 10 and 11.

Atrazine added to the spray solution of glyphosate significantly reduced injury to corn plants. However, this effect was less pronounced at the higher rate of glyphosate, 0.56 kg/ha. The increase in application rate of glyphosate largely overcame the antagonistic interaction with atrazine.

The same trend of interaction also was shown by the fresh weights of the corn top growth (Figure 7).

The data suggest that atrazine and simazine interact with glyphosate similarly.

Experiment 7: Interaction Between Glyphosate and Simazine on Quackgrass in the Greenhouse

The heights of quackgrass at the time of treatment were approximately 20-25, 30-35, and 50-60 cm for the groups treated

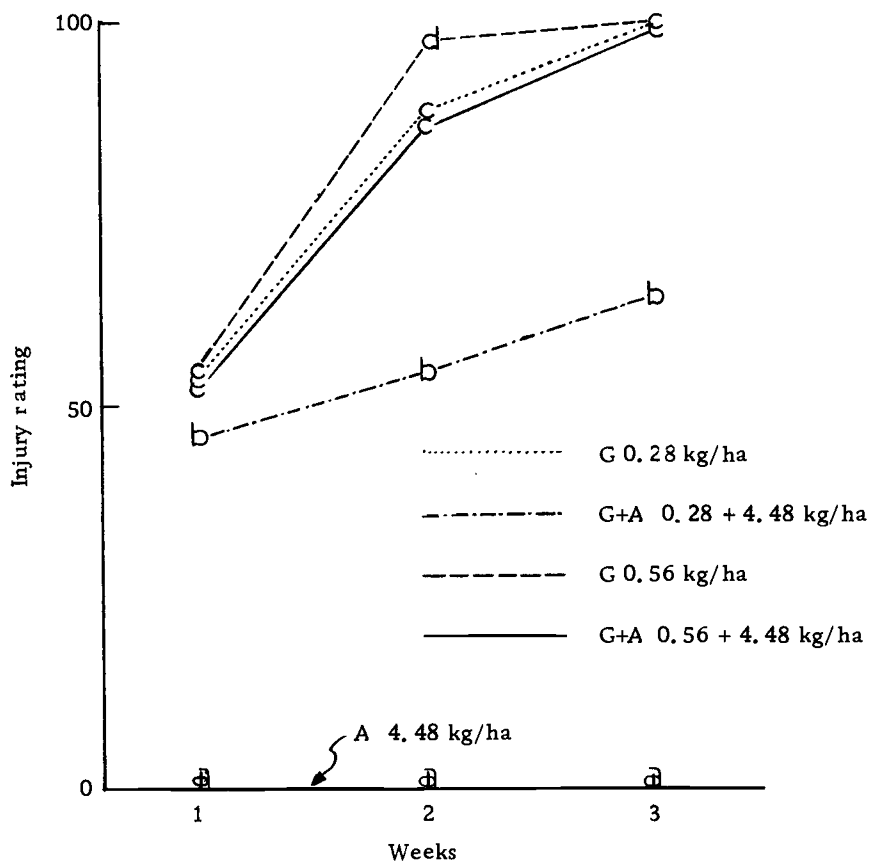

Figure 6. Experiment 6. Injury of corn plants treated with glyphosate, atrazine, and their combinations under greenhouse conditions (G = glyphosate, and A = atrazine). Points with the same letter are not significantly different at P = 0. 05.

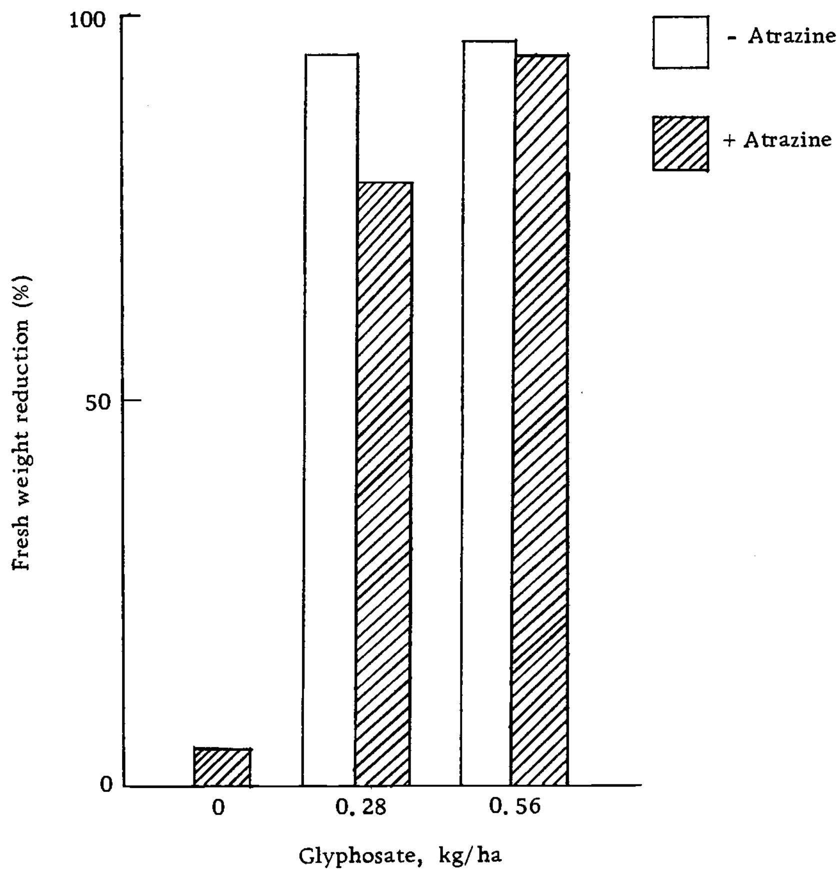

Figure 7. Experiment 6. Fresh weights of corn plants treated with glyphosate, atrazine, and their combinations under greenhouse conditions.

2, 4, and 6 weeks after clipping, respectively. The overall responses of quackgrass in the different groups to glyphosate were not drastically different (see Figures 8 through 10, and Appendix Tables 12 through 14). A pattern of response could not be established in relation to the size or the amount of top growth of the quackgrass. At a rate of 0.56 kg/ha, glyphosate caused only partial injury to the quackgrass. A complete top kill was obtained with 1.12 kg/ha or higher rates under the conditions of this experiment.

An addition of 2.80 kg/ha of simazine to the spray solution reduced the injury on the quackgrass caused by all rates of glyphosate (Figures 8, 9, and 10). The amount of reduction of injury became smaller as the rate of glyphosate was increased. In one instance, control from 2.24 kg/ha of glyphosate alone was not significantly different from that obtained in combination with 2.80 kg/ha of simazine applied 6 weeks after clipping. These data confirm the results in Experiment 6 with corn.

Experiment 8: Interaction Between Glyphosate and Simazine on Beans in the Greenhouse

Effect of the treatments on bean injury and dry weights of the top growth are shown in Figures 11 and 12, and Appendix Tables 15 and 16.

As expected, addition of the wettable powder formulation

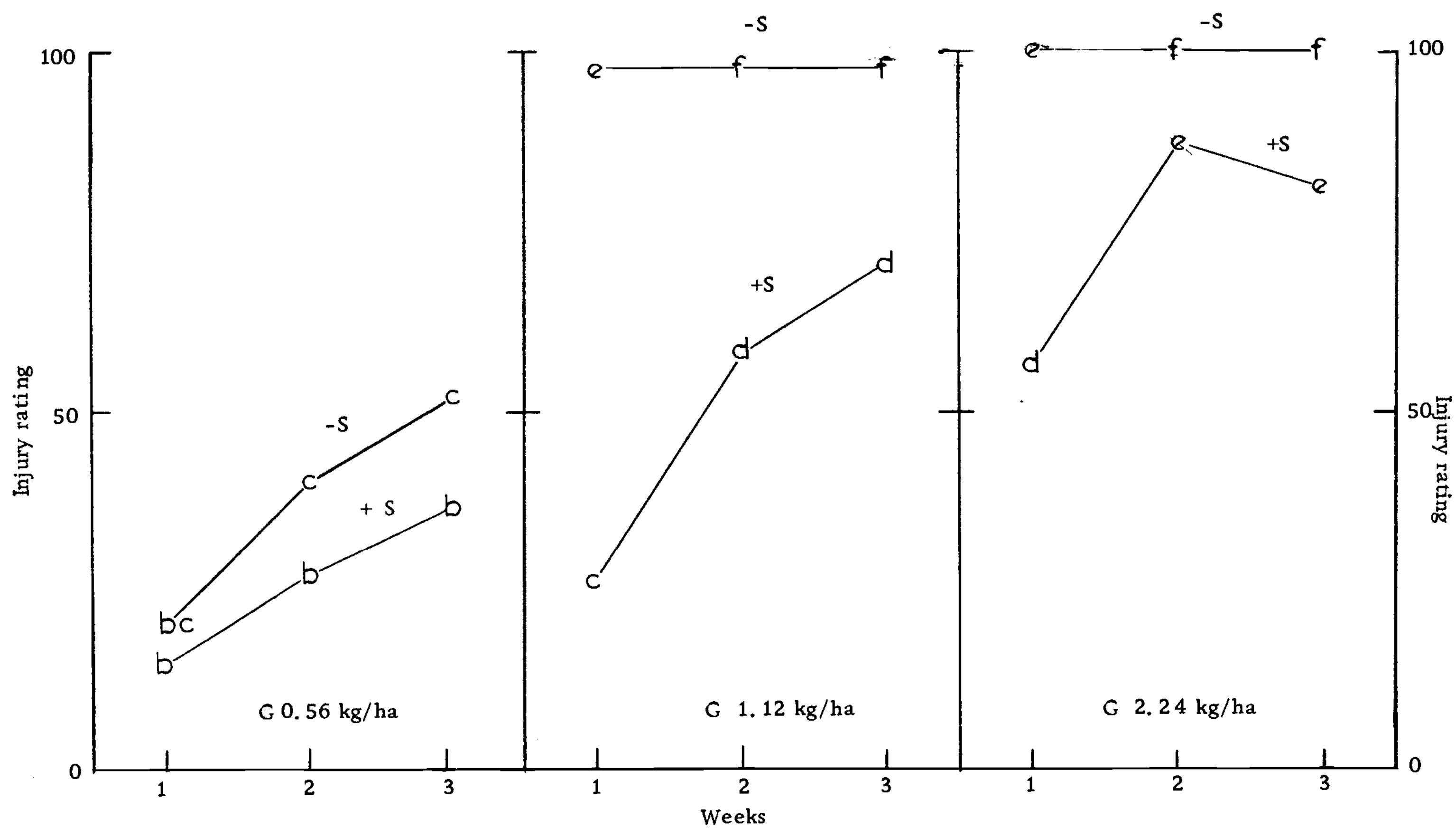

Figure 8. Experiment 7. Quackgrass injury as affected by glyphosate and its combinations with simazine under greenhouse conditions. Plants treated 2 weeks after clipping (G = glyphosate, and S = simazine). Points with the same letter are not significantly different at P = 0.05.

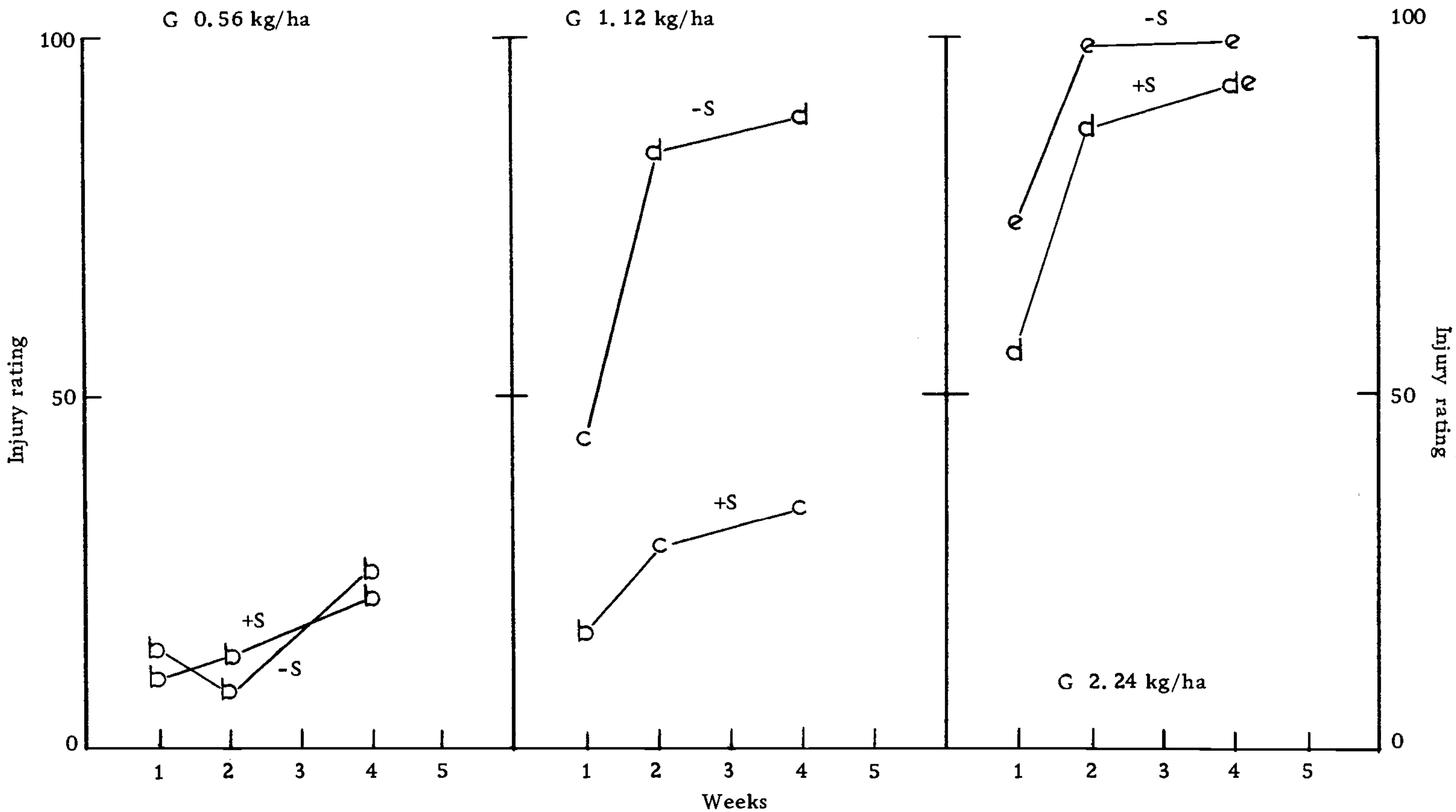

Figure 9. Experiment 7. Quackgrass injury as affected by glyphosate and its combinations with simazine under greenhouse conditions. Plants treated 4 weeks after clipping (G = glyphosate, and S = simazine). Points with the same letter are not significantly different at P = 0.05.

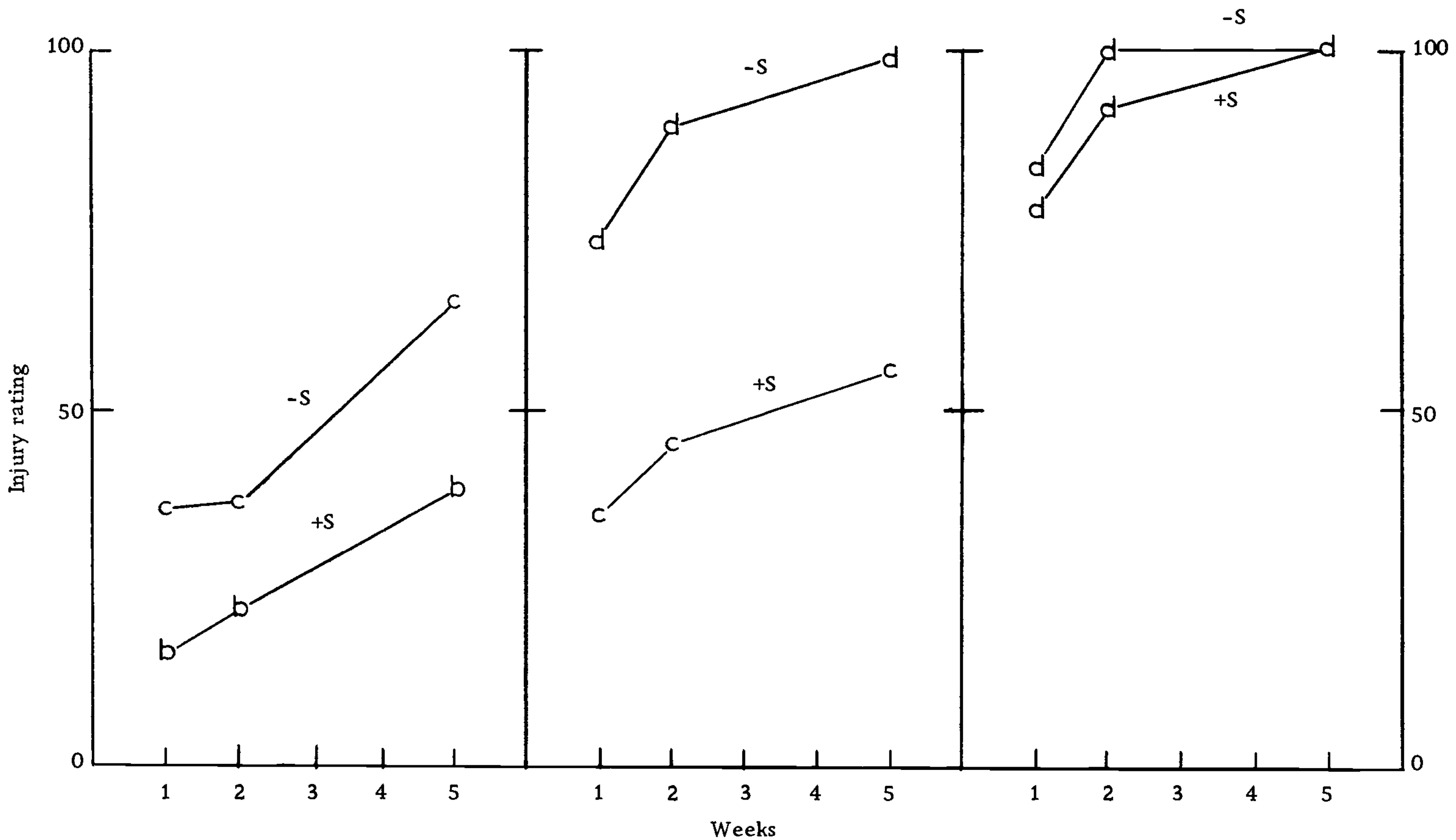

Figure 10. Experiment 7. Quackgrass injury as affected by glyphosate and its combinations with simazine under greenhouse conditions. Plants treated 6 weeks after clipping (G = glyphosate, and S = simazine). Points with the same letter are not significantly different at P = 0.05.

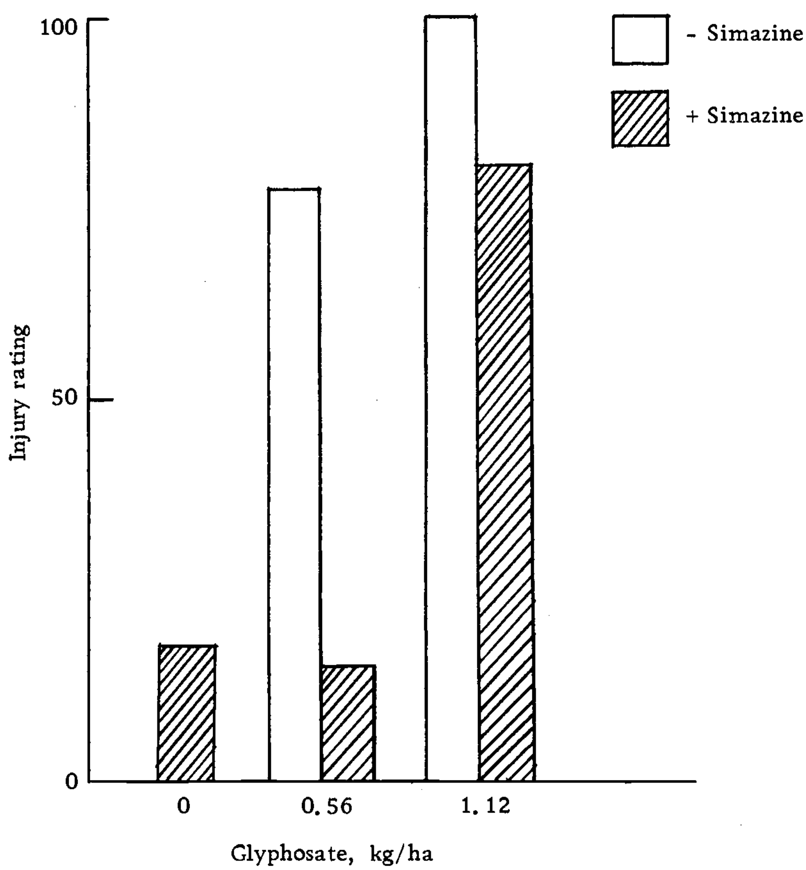

Figure 11. Experiment 8. Injury of bean plants treated with glyphosate, simazine, and their combinations under greenhouse conditions.

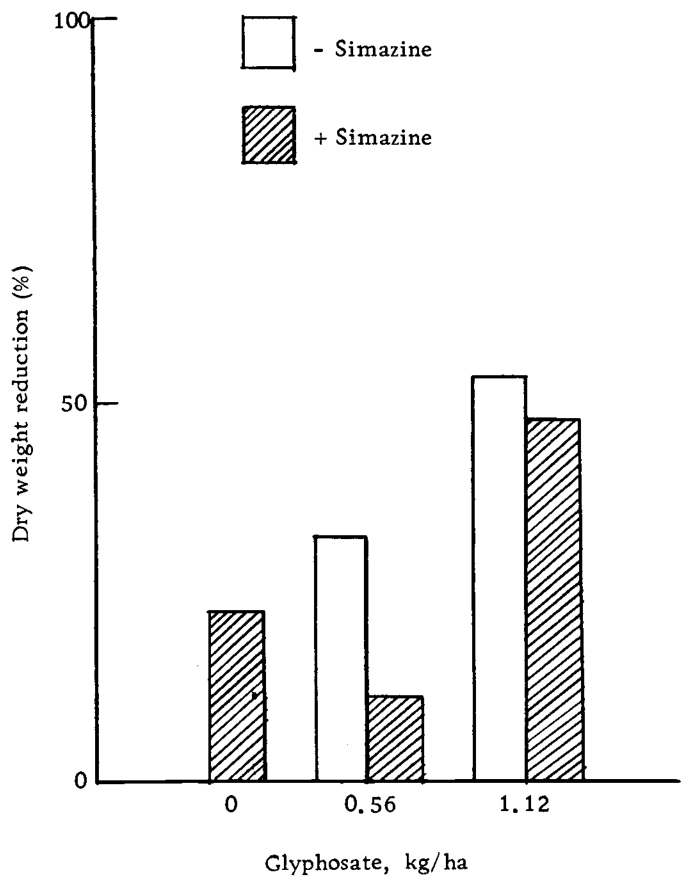

Figure 12. Experiment 8. Dry weights of top growth of bean plants treated with glyphosate, simazine, and their combinations under greenhouse conditions.

of simazine to the spray solution of glyphosate significantly reduced the injury to the bean plants. Again, as the rate of glyphosate was increased the antagonistic interaction became smaller and almost completely disappeared at a rate of 1.12 kg/ha of glyphosate. The shoot dry weights corresponded very well with the injury rating.

Experiment 9: Interaction Between Glyphosate and Certain Herbicides on Corn in the Greenhouse

The injury of corn plants evaluated 1 and 2 weeks after treatment is summarized in Figure 13 (also see Appendix Table 17).

Glyphosate alone applied at 0.28 kg/ha severely injured corn plants 2 weeks after treatment. An antagonistic interaction was clearly exhibited when glyphosate was applied together as a tank mix with simazine, alachlor, or 2,4-D amine, especially at the second evaluation. At the higher glyphosate rate, 0.56 kg/ha, the interaction was observed at the early evaluation with all the herbicides used in the combinations, but mostly disappeared later. Reduction of glyphosate injury by 2,4-D was more impressive early after treatment than by simazine or alachlor, but this effect rapidly disappeared and the injury caused by this treatment became greater than those of the combinations with simazine and alachlor.

The interaction between the low rate of glyphosate and all of the three herbicides used in the combinations was also significant

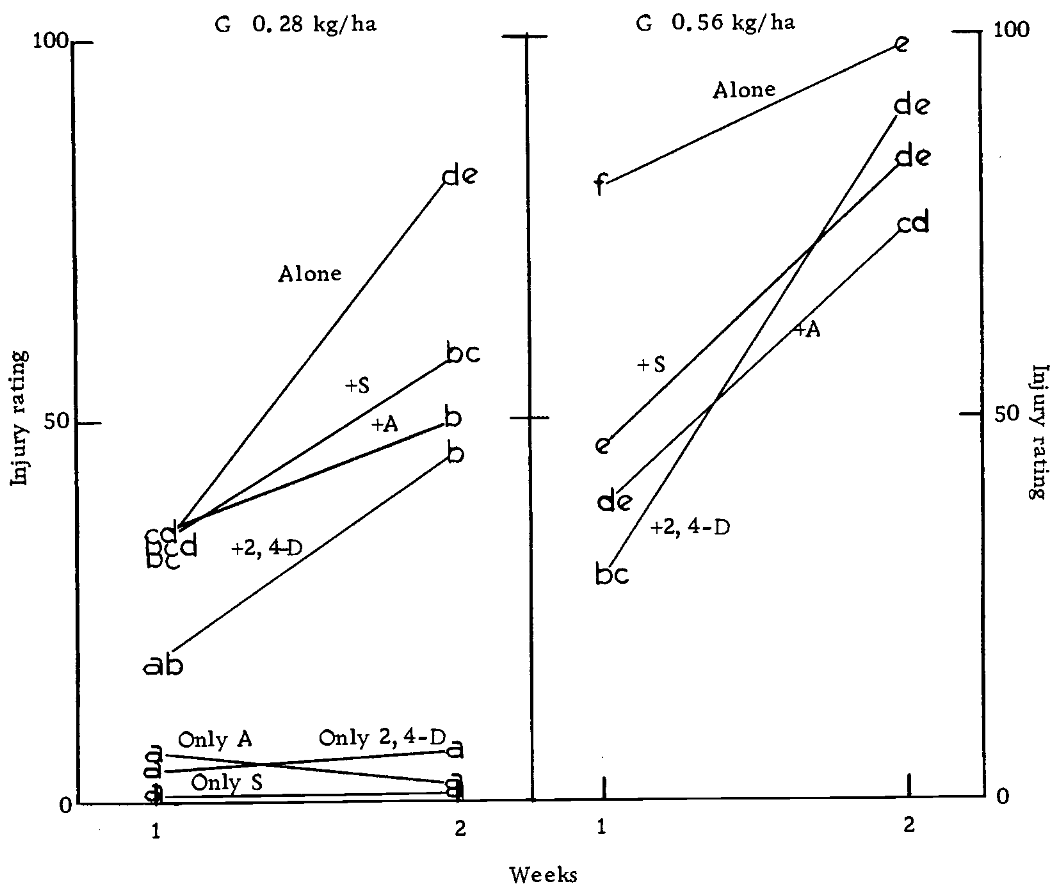

Figure 13. Experiment 9. Corn injury as affected by treatments of glyphosate, simazine, alachlor, 2, 4-D, and the combinations between glyphosate and all of the three herbicides under greenhouse conditions (G = glyphosate, S = simazine, A = alachlor, and 2, 4-D = 2, 4-D amine). Points with the same letter are not significantly different at P = 0.05.

when the fresh weight of the corn top growth was determined (Figure 14 and Appendix Table 18). However, only slight interaction was observed at the high rate of glyphosate.

Discussion

A field experiment conducted on quackgrass did not show a clear interaction between glyphosate and simazine. The lowest rate, 2.24 kg/ha, of glyphosate used in the experiment may be well above the level at which the interaction can be observed. On the other hand, the weather conditions at the time the experiment was initiated and the following few months were too dry; any interaction resulting from the treatments would have been difficult to observe because of the rather dormant and dry quackgrass in the experimental area.

However, there was clear interaction between glyphosate and simazine or atrazine in the greenhouse. In all cases, when simazine or atrazine was added to the spray solution of glyphosate, the activity of glyphosate on the test plants was lowered considerably, especially at lower application rates of glyphosate. Similar antagonistic interactions were encountered in all three plant species--quackgrass, corn, and beans. The results confirm the findings of Baird et al. (1971) and Baird et al. (1974).

The interaction affected the speed of glyphosate activity in the same manner as a reduction in application rate of glyphosate. Since

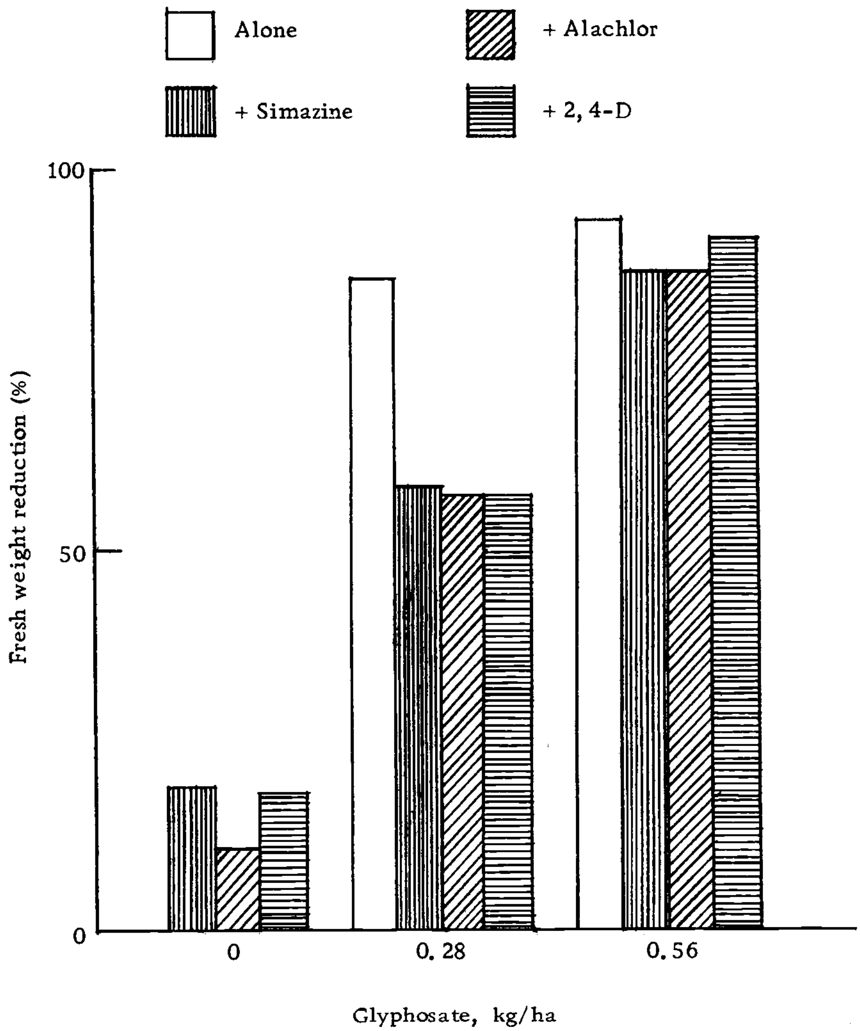

Figure 14. Experiment 9. Fresh weights of corn plants as affected by treatments of glyphosate, simazine, alachlor, 2, 4-D, and the combinations between glyphosate and all of the three herbicides under greenhouse conditions.

the same type of interaction occurred regardless of the species of the test plants, the interaction may involve physical and/or chemical interactions in the spray tank and, consequently, less free glyphosate available for plant uptake. However, antagonism involving some physiological phenomena such as interference with the absorption, movement, and metabolism of glyphosate must not be excluded from consideration at this point.

Both simazine and atrazine used in these studies contained some clay material in their formulations. The clay material has been known for its high adsorptivity. Perhaps, some glyphosate is adsorbed to the clay material, becomes unavailable for absorption by plants, and the observed decrease in activity results. Glyphosate itself also has been known for its high susceptibility to adsorption in soil (Brewster and Appleby, 1972; and Upchurch and Baird, 1972).

A study was also conducted on corn plants in the greenhluse to determine whether herbicides such as alachlor and 2, 4-D, which did not possess clay or other highly adsorptive materials in the formulations, would provide the type of interaction with glyphosate as observed with atrazine and simazine. Both alachlor and 2, 4-D reduced the activity of glyphosate when applied together as a tank mix. Alachlor gave an interaction with glyphosate similar to that provided by simazine or atrazine. However, 2, 4-D interaction with glyphosate was short-lived and disappeared rapidly after 1 week. These results do not discount the idea that physical and/or chemical interactions in the mixing tank are responsible for the antagonism. Since all herbicidal molecules possess reactive groups, physical and/or chemical interactions between these molecules and those of glyphosate are still possible. The physical interaction between molecules of glyphosate and 2, 4-D may be only temporary, the molecules of glyphosate may be released and become available to plants later. On the other hand, interaction of 2, 4-D with glyphosate may be different from that of others. Some unknown physiological processes may be a more important factor responsible for the observed interaction than the physical and/or chemical reactions outside the plants.

Results from the studies in this section clearly demonstrated that the interaction between glyphosate and simazine, atrazine, 2, 4-D, or alachlor did exist when they were applied together as a tank mix. Occasional erratic weed control may result from the use of combinations of glyphosate and some soil-residual herbicides, especially when the application rate of glyphosate is marginal.

IV. BASIS FOR THE INTERACTION BETWEEN GLYPHOSATE AND SIMAZINE IN CORN AND BEANS

Introduction

Numerous investigations have been conducted to determine the basic principles behind the interactions between pesticides which are applied simultaneously or consecutively. From the viewpoint of injury to crops or effectiveness of weed control, the interactions between different herbicides and herbicides and other pesticides are of major concern.

Some observed interactions have been found to be based on a direct effect of one pesticide on cuticle formation, altering the subsequent activity of the other. Dewey et al. (1956) demonstrated that injury to peas caused by 2-sec-butyl-4, 6-dinitorphenol (dinoseb) was increased from zero to 100% by increasing the rates of dalapon or TCA. In later studies (Dewey et al., 1962), the same workers found a reduction in cuticular wax of pea and kale leaves from TCA application. Davis and Dusbabek (1973) reported a reduction in cuticular wax in peas by a vapor treatment of diallate and a subsequent enhancement of foliar uptake of 2, 4-D, atrazine, TCA, and diquat.

Many studies have shown that some compounds interfere with or enhance the uptake of others when applied together. Parks et al. (1972) found that plant injury and the absorption of prometryne at low

(1 μM) concentration by bean plants was increased in the presence of phorate, an insecticide. The enhanced absorption disappeared when the concentration of prometryne was increased to 10 μM at which rate severe root damage was observed. The interaction did not involve the respiration of bean mitochondria. The antagonistic interaction between picloram and bromacil in oats is due to interference with bromacil uptake by picloram (Sterrett et al., 1972).

An increased uptake of alachlor by barley plants grown from seeds treated with an insecticide, carbofuran, was shown to be the factor responsible for the synergism between the two pesticides (Hamill and Penner, 1973a). Hamill and Penner (1973b) also found that increased uptake was partially responsible for the observed synergism between chlorbromuron and carbofuran in barley and corn. Carbaryl, an insecticide, enhances the uptake of linuron in carrots and subsequently increases foliar injury when both are applied as tank mixes or at 1-day intervals (DelRosario and Putnam, 1970).

An investigation of the antagonistic interaction between picloram and 2, 4-DB in beans by Hamill et al. (1972) indicated that picloram prevented the movement of 2, 4-DB, while 2, 4-DB increased both the distribution and the amount of picloram translocated.

For a herbicide which depends on the rate of metabolism in different plant species as a mechanism of selectivity, interaction with other compounds may be caused by alteration of its rate of metabolism. An excellent demonstration by Swanson and Swanson (1968) has shown that a simultaneous treatment with certain carbamate insecticides and monuron inhibited degradation of the monuron in cotton leaf discs.

The results in previous sections of this thesis indicated that an antagonistic interaction existed between glyphosate and simazine, atrazine, alachlor, and 2, 4-D. Simazine represents a large group of many important herbicides and is likely to be utilized with glyphosate in many horticultural and agronomic crops and for industrial weed control. This alone may be ample reason for further research to understand the factor responsible for the interaction between the two herbicides.

The studies in this section were conducted to find an explanation for the interaction between glyphosate and simazine in corn and beans under greenhouse conditions.

Materials and Methods

Experiment 10: Interaction Between Glyphosate and Simazine as Influenced by Different Foliar Treatments of Simazine on Corn

Seeds of field corn were germinated and the seedlings were maintained in the greenhouse as in Experiment 1. When the plants were 1 month old, plants of uniform size were selected for treatment. The treatments included a) 0.1 ml of three concentrations, 4.93×10^{-3}, 9.86×10^{-3}, and 1.97×10^{-2} M, of glyphosate and 3.96×10^{-2} M of simazine applied to the largest unfolded leaf, b) 0.1 ml of the mixtures of both herbicides at the same concentrations in a) applied to the largest leaf, and c) 0.1 ml each of both herbicides at the same concentrations in a) applied to the largest and the next largest leaves of the same plant. Untreated plants were included as checks. The applications were made by depositing the solutions on the midrib. Glyphosate solutions were prepared from the formulated MON-2139, and simazine solutions from an 80% wettable powder formulation. X-77, at a rate of 0.1% v/v, was added to all solutions to enhance leaf wetting and to ensure optimal herbicidal activity. The treatments were replicated four times and were arranged in a completely randomized design.

Injury evaluations on corn plants were made visually 2 and 3 weeks after treatment. Top growth was harvested after the second injury evaluation and fresh weights were determined. The data were analyzed statistically.

Experiment 11: Interaction Between Glyphosate and Simazine as Influenced by Different Foliar Treatments of Simazine on Beans

Seeds of beans were germinated and the plants were maintained in the greenhouse as in Experiment 1. When the seedlings were 2 weeks old, plants of uniform size were selected for the treatment. At this stage each seedling had a fully expanded pair of non-trifoliate leaves and a small trifoliate leaf.

The same set of treatments as in Experiment 10 were applied to the non-trifoliate leaves. The preparation of the herbicidal solutions and the application method were also the same as in Experiment 10. Each treatment was replicated four times and were arranged in a completely randomized design.

Visual evaluation of plant injury was made 1 week after treatment. Then the top growth was harvested and the fresh weights were determined. The data on injury rating and fresh weights were analyzed statistically.

Experiment 12: Interaction Between Glyphosate and Simazine as Influenced by Site of Simazine Placement on Corn

Corn plants were grown and maintained in the greenhouse as in Experiment 1. When the plants were 5 weeks old, they received a foliar treatment of four rates, 0, 0.28, 0.56, and 1.12 kg/ha, of glyphosate either alone, in combination with wettable powder simazine at a rate of 3.36 kg/ha, or alone on the foliage with the same rate of wettable powder simazine applied to the soil. The application of simazine to the soil was done by distributing drops of simazine solution over the surface of the soil in the pots. X-77 surfactant at a rate of 0.1% v/v was added to all herbicidal solutions. To ensure a good movement of simazine into the root zone of corn plants, all plants in the experiment were irrigated as necessary with a small amount of water applied to the top of the soil but avoiding wetting the foliage and washing off the herbicides.

Evaluations for plant injury were visually made at 1 and 2 weeks after treatment. After the last evaluation, the top growth of the plants were harvested and the fresh weights were determined. The data were analyzed statistically.

Experiment 13: Interaction Between Glyphosate and Simazine as Influenced by Site of Simazine Placement on Beans

Bean plants were grown and maintained in the greenhouse as described in Experiment 1. When the plants were 2 weeks old, they received the same set of treatments as in Experiment 11. The treatments were arranged in a completely randomized design with four replications.

Evaluations for plant injury were visually made 1 and 2 weeks after treatment. After the second evaluation, the plants were harvested at the ground level and fresh weights of top growth were determined. The data were subjected to statistical analysis.

Experiment 14: Effect of Simazine and Inert Ingredients on the Herbicidal Activity of Glyphosate on Corn

Corn plants were grown and maintained in the greenhouse as described in Experiment 1. When the plants were about 1 month old, two rates, 0.28 and 0.56 kg/ha, of glyphosate were applied to the foliage alone to compare with the same rates applied in combinations with a) 4.20 kg/ha of a commercial product containing 80% simazine, b) 0.84 kg/ha of the inert ingredients of the commercial product, and c) 4.20 kg/ha of the inert ingredients. X-77 surfactant at a rate of 0.1% v/v was added to all spray solutions. All treatments were applied in 375 l/ha of solution at 2.75 kg/cm^2 of pressure. The plants were subsequently subirrigated to avoid washing the herbicides from the leaves. All the treatments were replicated four times and arranged in a completely randomized design.

Visual evaluations for plant injury were made 1 and 2 weeks after treatment. After the second evaluation, the plants were cut at ground level and their fresh weights were determined. The data were analyzed statistically.

Experiment 15: Effect of Simazine and Inert Ingredients on the Herbicidal Activity of Glyphosate on Beans

Bean plants were grown and maintained in the greenhouse in the same manner as in Experiment 1. When the plants were 2 weeks old, they were treated with the same set of treatments as in Experiment 14. All treatments were replicated four times and arranged in a completely randomized design.

Evaluations for injury were made visually 1 and 2 weeks after treatment. Then, the top growth of the plants were harvested and the fresh weights were determined.

Experiment 16: Sorption of Glyphosate in the Spray Solutions

Adsorption Study. Spray solutions with application volumes of 94 and 375 l/ha were prepared for a 0.28 kg/ha rate of glyphosate alone and in combination with either 4.20 kg/ha of a commercial product containing 80% simazine or 4.20 kg/ha of the inert ingredients present in the commercial product. MON-0011 surfactant at a rate of 0.1% v/v was added to all solutions. Each solution was placed in conical flasks and mixed by vigorous swirling. The glyphosate-inert ingredient mixtures were adjusted to the same pH levels as the glyphosate-commercial product mixtures with the same application volume. Then all mixtures were centrifuged at 15,000 rpm for 15 minutes to separate the suspending materials out of the solutions. The supenatants were assayed for P which was used to estimate the amounts of glyphosate by using the modified Fiske-SubbaRow method for total P (Bartlett, 1959). Each sample was digested with a combination of 10N H_2SO_4 and 70% HNO_3 at 300°C for 1.5 hours before 1 ml of 30% H_2O_2 was added and the digestion was continued at the same temperature for 3.5 hours. Then the acidity of the content was adjusted to 1N by dilution before developing color. The absorbance of the mixture was read at 830 nm. Since the preliminary observations showed that the digestion of the glyphosate solution was frequently unsatisfactory compared with those of the supernatants of the combinations, an equal volume of the supernatant of the commercial product of simazine solution was added to each aliquot of the glyphosate solution before being digested with the acid combination.

A portion of the supernatant of each spray solution for the 375 l/ha application volume also was used for a bioassay in the greenhouse.

Bioassay of the Supernatant. The supernatants derived from the adsorption study were each divided into two portions. One of these was applied directly to bean plants with a calibrated sprayer, while 0.1% v/v of MON-0011 surfactant was added to the second portion before it was applied to bean plants. Bean plants were grown and maintained in the greenhouse in the same manner as described in Experiment 1. The plants were 3 weeks old and had one pair of non-trifoliate leaves and one fully expanded trifoliate leaf at the time the treatments were applied. Injury symptoms on the plants were visually rated and 1 week after treatment all plants were harvested at the ground level and their fresh weights were determined.

Elution Study. Glyphosate-commercial product and glyphosate-inert ingredient spray solutions with an application volume of 94 l/ha were prepared in 25-ml duplicates and centrifuged to separate the suspended materials as described in the adsorption study. After decanting the supernatants, one of the pellets of each combination was washed immediately with 25 ml of distilled water by stirring every 5 minutes with a glass rod and was allowed to equilibrate at room temperature (29±1° C) for 1 hour. Then, the mixture was recentrifuged at 15,000 rpm for 15 minutes and the supernatant was assayed for P as described in the adsorption study. Another pellet of the same combination was dried in the oven at 80° C for 48 hours before it was washed with 25 ml of distilled water, allowed to equilibrate at room temperature for 1 hour, recentrifuged at 15,000 rpm for 15 minutes, and the supernatant assayed for P. The relative amounts of P released from the wet and dry pellets were compared.

Another experiment with the same procedures was conducted except both wet and dry pellets were washed and allowed to equilibrate for 2 hours to observe the effect of washing time on the relative amounts of glyphosate released from the pellets.

Experiment 17: Response of Beans to Varying Doses of Glyphosate

A series of gradually decreasing rates of glyphosate between a maximum of 0.28 kg/ha and a minimum of 0.14 kg/ha was applied with 0.1% v/v of MON-0011 surfactant added to 2-week-old bean plants. The plants were grown and maintained in the greenhouse as in Experiment 1. Visual evaluations of the injury symptoms were carefully made before the plants were harvested at ground level and fresh weights were determined.

Results

Experiment 10: Interaction Between Glyphosate and Simazine as Influenced by Different Foliar Treatments of Simazine on Corn

Data from injury evaluation of corn plants are shown in Figure 15. The interaction between glyphosate and simazine occurred only when both herbicides were applied together as a mixture, not when applied at separate places on the same plant. As expected, the antagonistic effect occurred only at the lowest concentration, 4.93×10^{-3} M of glyphosate. This confirmed the results of all experiments in section III. The antagonism was clearly shown by the injury ratings. Although differences among the mean fresh weights were not significant, they consistently corresponded with the injury data (see Figure 16 and Appendix Table 20).

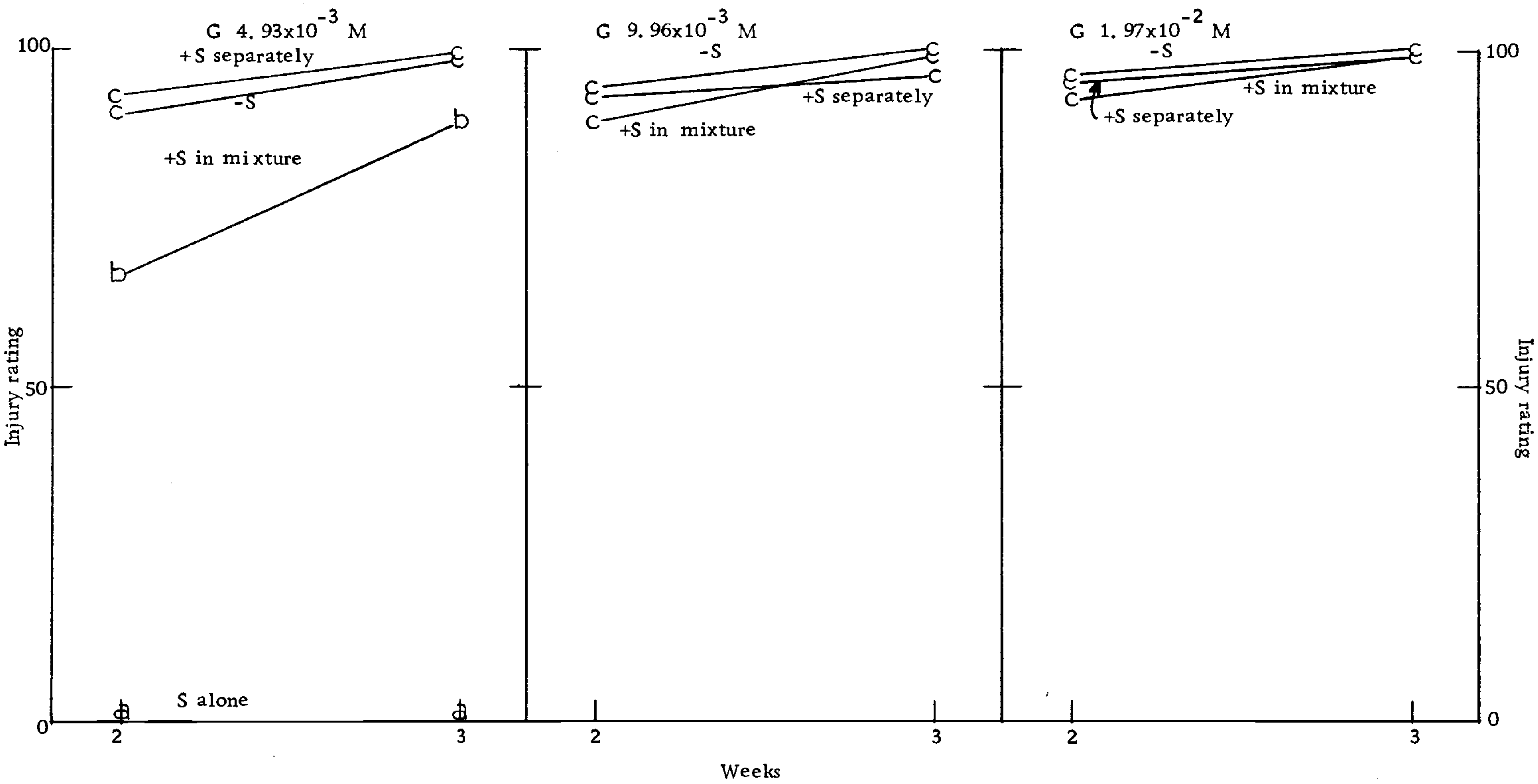

Figure 15. Experiment 10. Injury of glyphosate-treated corn plants as affected by different placements of simazine on the foliage (G = glyphosate and S = simazine). Points with the same letter are not significantly different at $P = 0.05$.

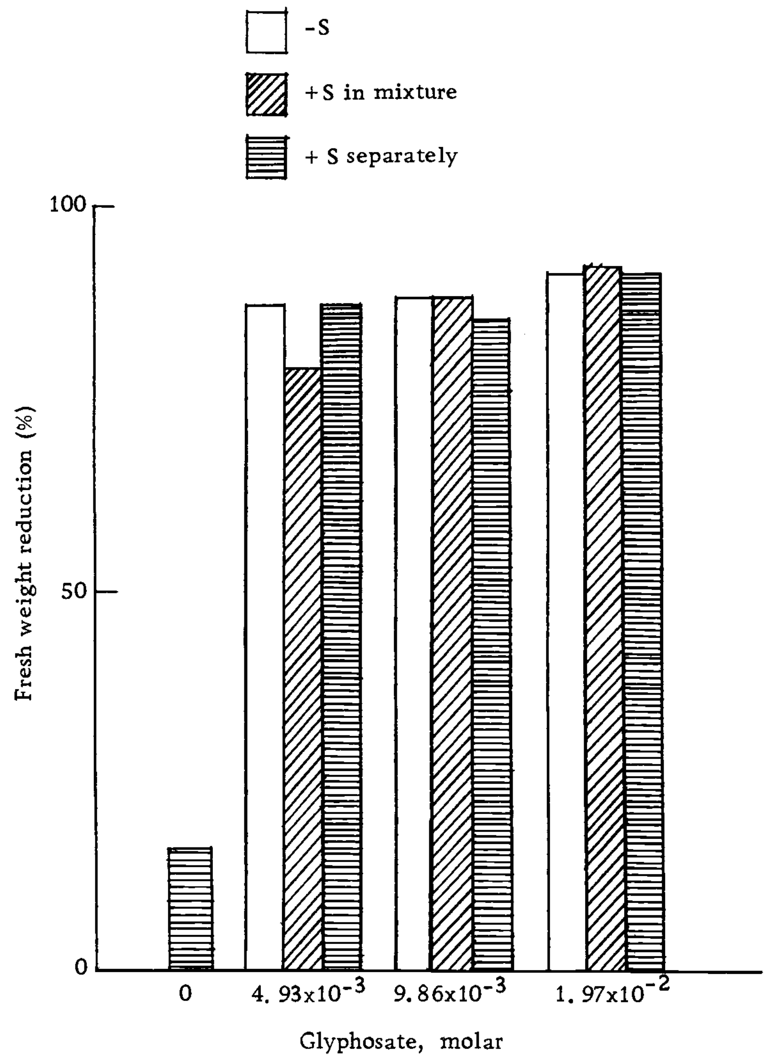

Figure 16. Experiment 10. Fresh weights of glyphosate-treated corn plants as affected by different placements of simazine on the foliage (S = simazine).

Experiment 11: Interaction Between Glyphosate and Simazine as Influenced by Different Foliar Treatments of Simazine on Beans

Plant injury and fresh weights are shown in Figures 17 and 18, respectively. For a period of 1 week following treatment, simazine alone caused no injury symptoms on bean plants and did not significantly reduce their fresh weights.

Glyphosate applied at 0.1 ml of 4.93×10^{-3} M was sufficient to kill bean plants completely in 1 week. Simazine applied together with glyphosate as a mixture reduced the injury rating significantly, but did not give the same effect when applied separately at the same rates on different leaves of the same plants. The fresh weights also clearly showed this effect. Higher rates of glyphosate killed bean plants more rapidly. Simazine applied together in the glyphosate solutions or separately did not produce the antagonistic interaction as encountered at the lower rate of glyphosate.

Experiment 12: Interaction Between Glyphosate and Simazine as Influenced by Site of Simazine Placement on Corn

Injury of corn plants is presented in Figure 19 and Appendix Table 23. Observations made 2 weeks after treatment showed that glyphosate at 0.28 kg/ha caused severe damage to corn plants in the greenhouse, while at higher rates complete kill resulted.

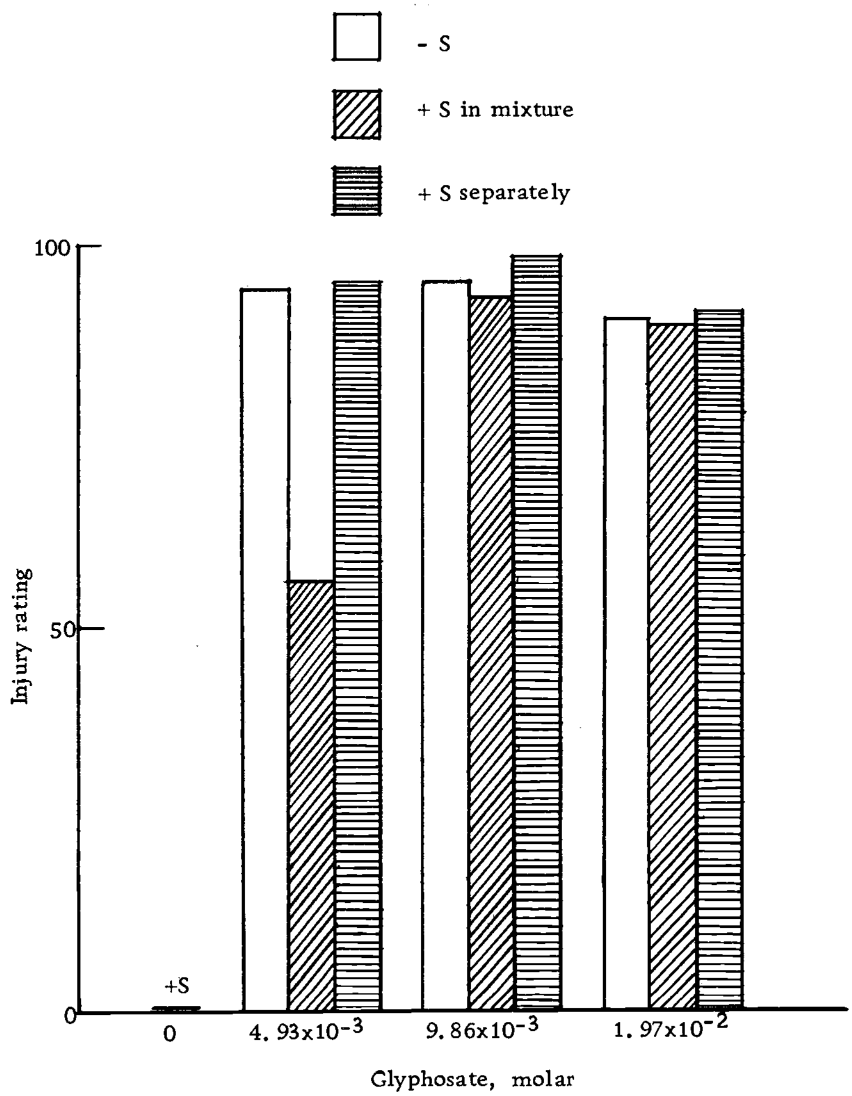

Figure 17. Experiment 11. Injury of glyphosate-treated bean plants as affected by different placements of simazine on the foliage (S = simazine).

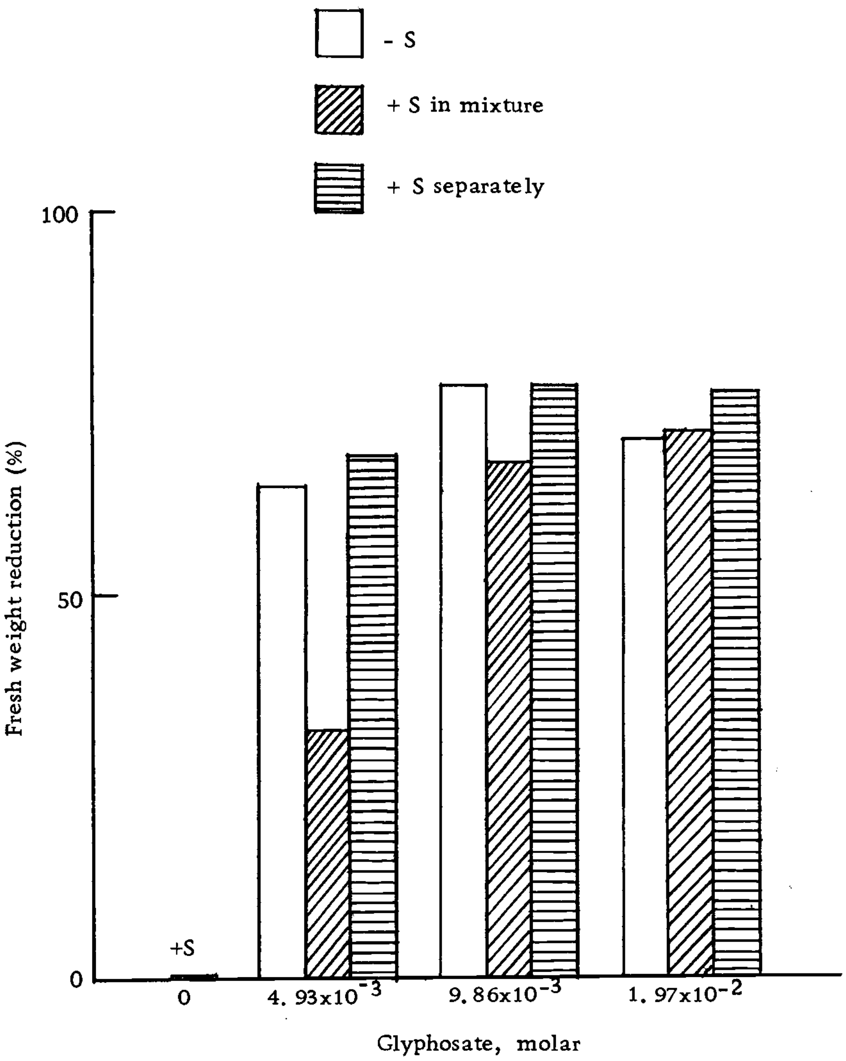

Figure 18. Experiment 11. Fresh weights of glyphosate-treated bean plants as affected by different placements of simazine on the foliage (S = simazine).

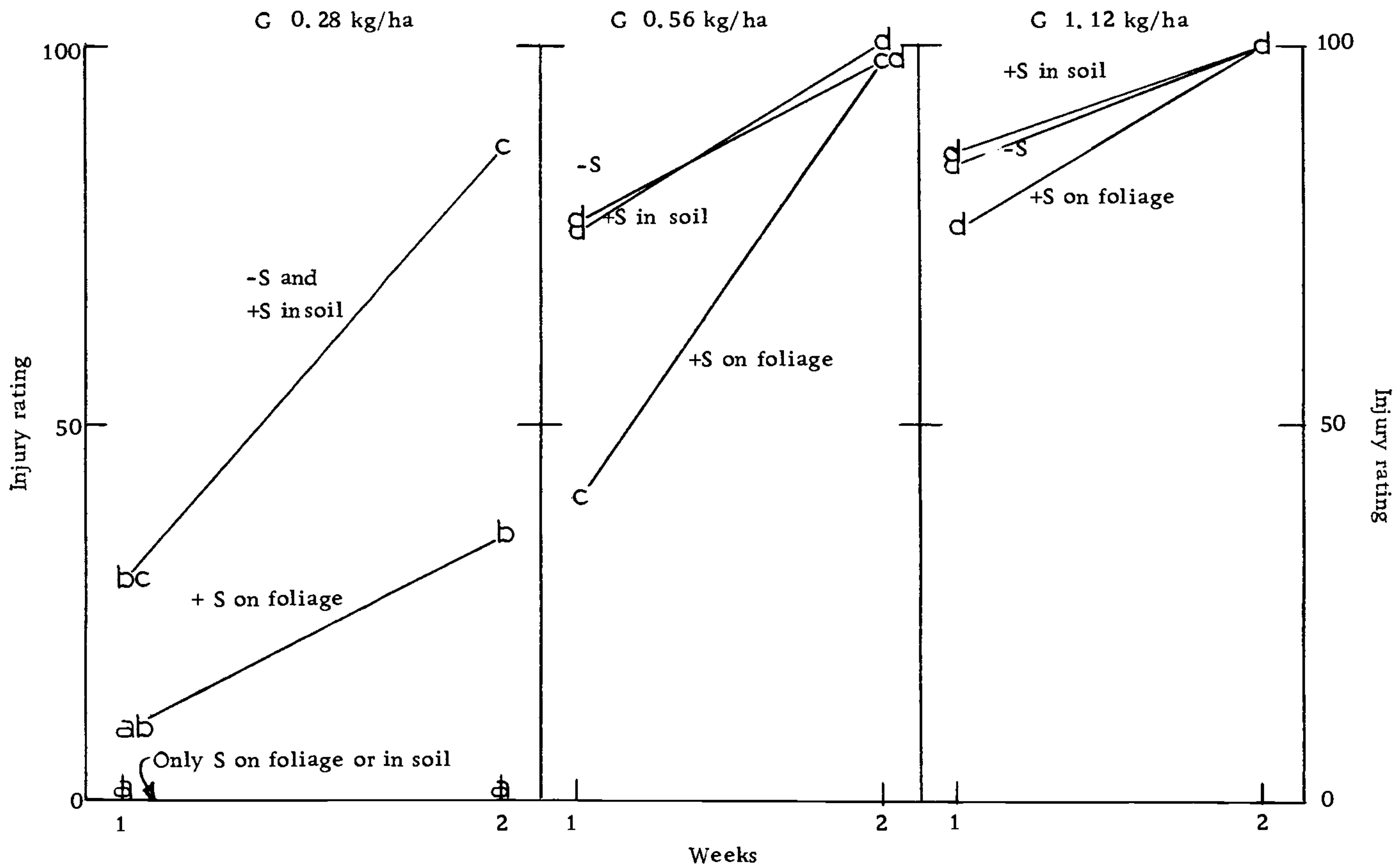

Figure 19. Experiment 12. Injury of glyphosate-treated corn plants as affected by site of simazine placement (G = glyphosate, and S = simazine). Points with the same letter are not significantly different at P = 0.05.

Wettable powder simazine at 3.36 kg/ha added to the spray solution of glyphosate significantly reduced the injury caused by 0.28 kg/ha of glyphosate at both observations made 1 and 2 weeks after treatment. With 0.56 kg/ha of glyphosate the effect was noted only at the earlier observation. When the rate of glyphosate was increased to 1.12 kg/ha, there was no significant reduction of injury by adding simazine in the spray solution. Simazine at the same rate added to the soil had virtually no effect on the activity of glyphosate, regardless of application rate.

Results on fresh weights of corn plants were similar to those on injury ratings (Figure 20 and Appendix Table 24).

Simazine alone applied either to foliage or to soil caused no injury or significant reduction in fresh weights of corn plants.

Experiment 13: Interaction Between Glyphosate and Simazine as Influenced by Site of Simazine Placement on Beans

Effect of herbicidal treatments on plant injury and fresh weights are shown in Figures 21 and 22, respectively. As expected, glyphosate at a rate as low as 0.28 kg/ha completely killed bean plants after 2 weeks. Simazine formulated as a wettable powder added to the glyphosate spray solution clearly reduced the injury to bean plants at the low rate, 0.28 kg/ha, but this effect was not observed at higher rates of glyphosate. Simazine at the same rate

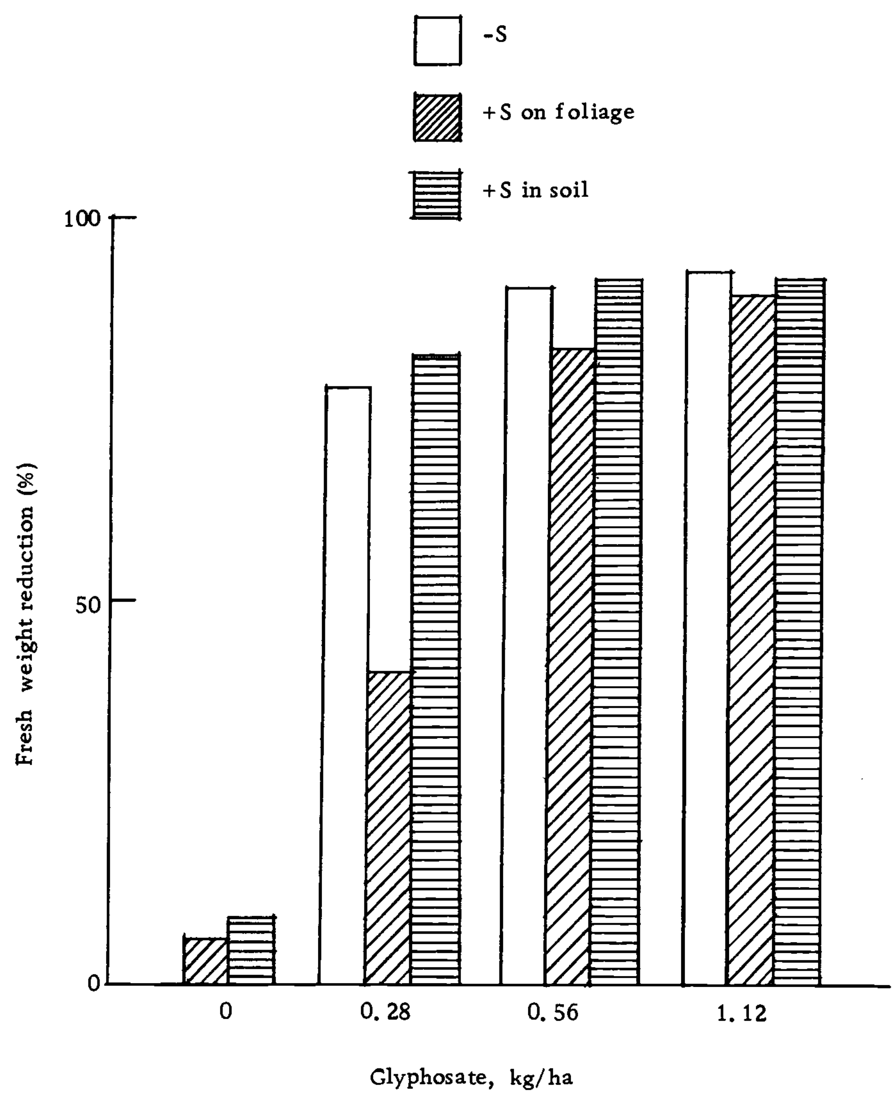

Figure 20. Experiment 12. Fresh weights of glyphosate-treated corn plants as affected by site of simazine placement (S = simazine).

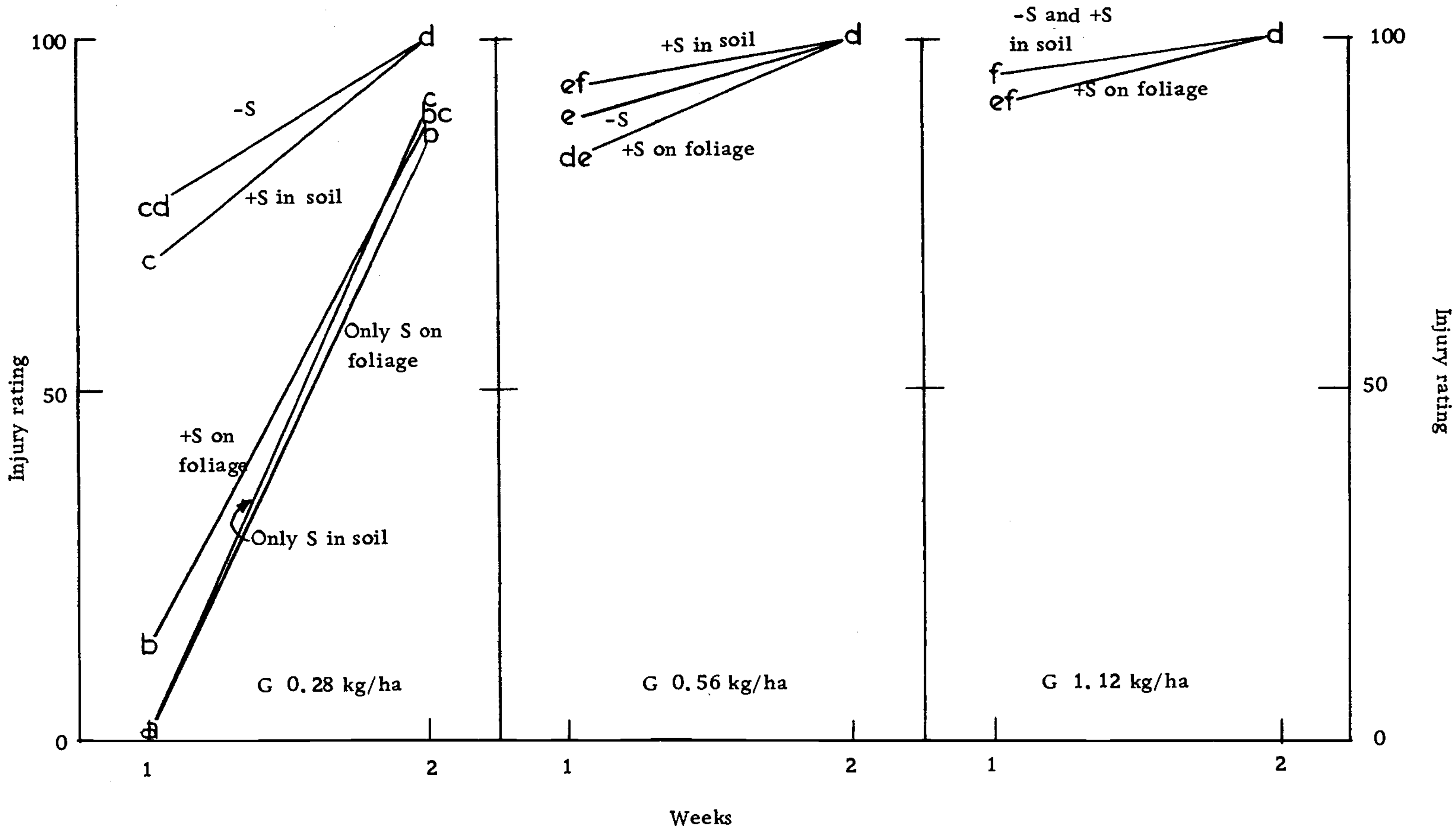

Figure 21. Experiment 13. Injury of glyphosate-treated bean plants as affected by site of simazine placement (G = glyphosate, and S = simazine). Points with the same letter are not significantly different at P = 0.05.

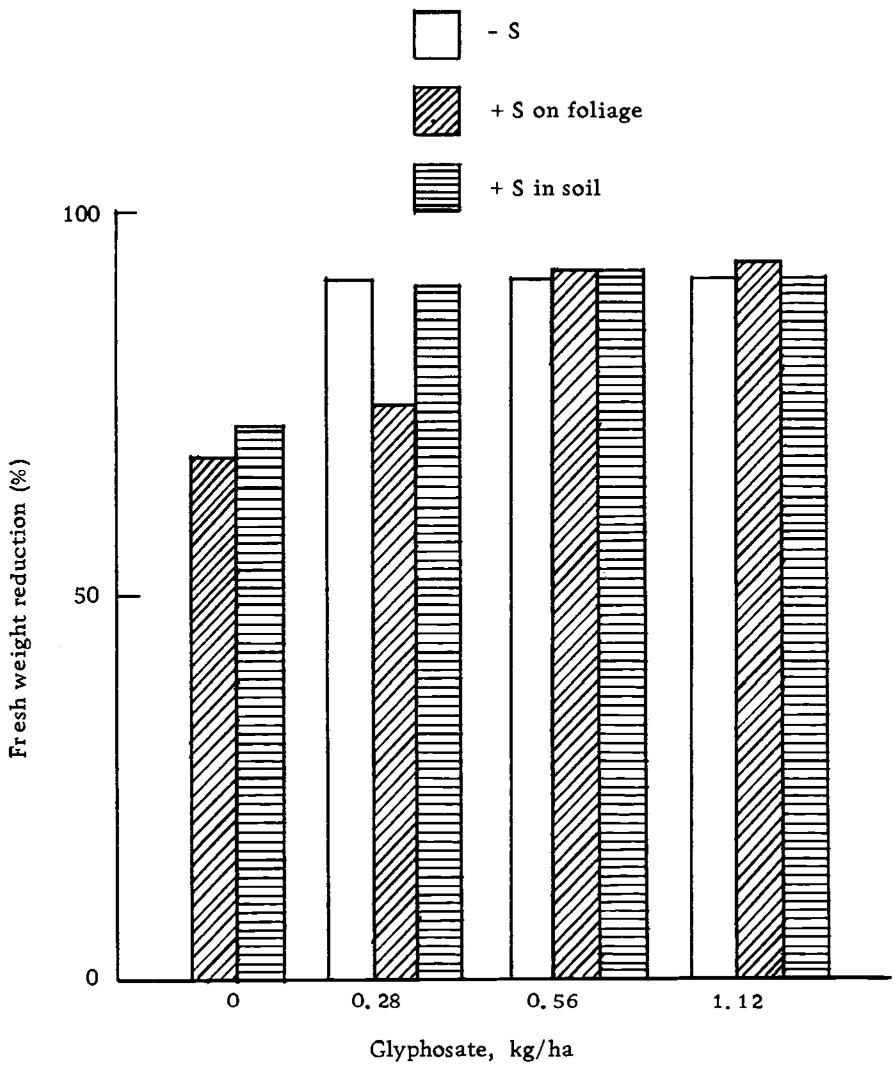

Figure 22. Experiment 13. Fresh weights of glyphosate-treated bean plants as affected by site of simazine placement (S = simazine).

applied directly to the soil did not cause any antagonism. The fresh weights of top growth showed the same trend.

Experiment 14: Effect of Simazine and Inert Ingredients on the Herbicidal Activity of Glyphosate on Corn

Mean injury ratings at 1 and 2 weeks after treatment are presented in Figure 23, and mean fresh weights of top growth are in Figure 24.

The herbicidal activity of glyphosate in this experiment was noticeably lower than was normally experienced in previous experiments. This was due to a new lot of glyphosate sample used. This lot was replaced with a new sample in later experiments.

Glyphosate, particularly the lot used here, at a rate of 0.28 kg/ha was not sufficient to kill corn plants. The killing threshold was reached when the rate was increased to 0.56 kg/ha. No clear antagonism was observed by adding the commercial product of simazine or its inert ingredients to the spray solution of glyphosate at the 0.28 kg/ha rate. However, when the rate was increased to 0.56 kg/ha, addition of the product at a rate of 4.20 kg/ha or the same rate of the inert ingredients to the glyphosate solution appreciably reduced the injury of corn plants. Adding only the inert ingredients at the amount present in 4.20 kg/ha of the product, 0.84 kg/ha, did not have any noticeable effect on reducing corn injury caused by

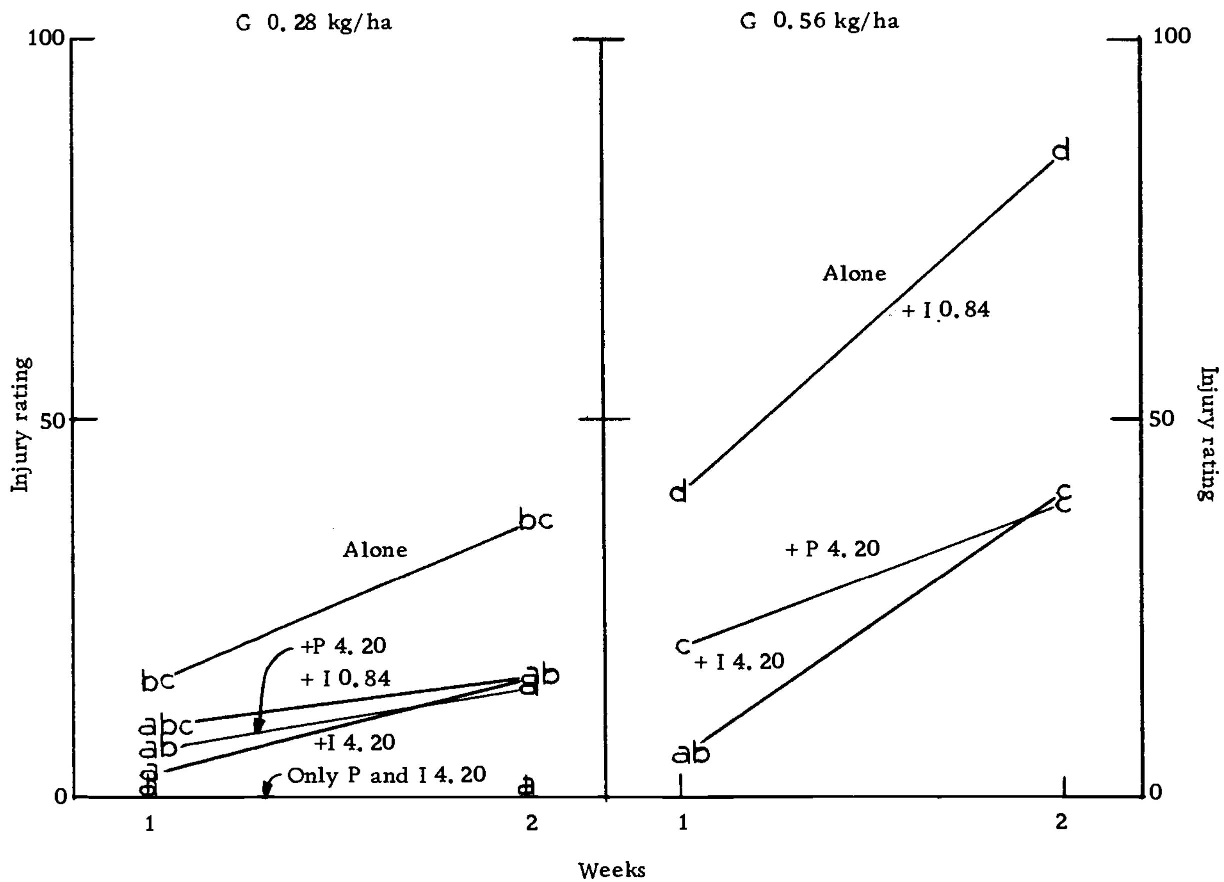

Figure 23. Experiment 14. Injury of corn plants treated with glyphosate, commercial product of simazine, inert ingredients of the product and different combinations between glyphosate and the product or inert ingredients (G = glyphosate, P = commercial product of simazine, and I = inert ingredients). Points with the same letter are not significantly different at P = 0.05.

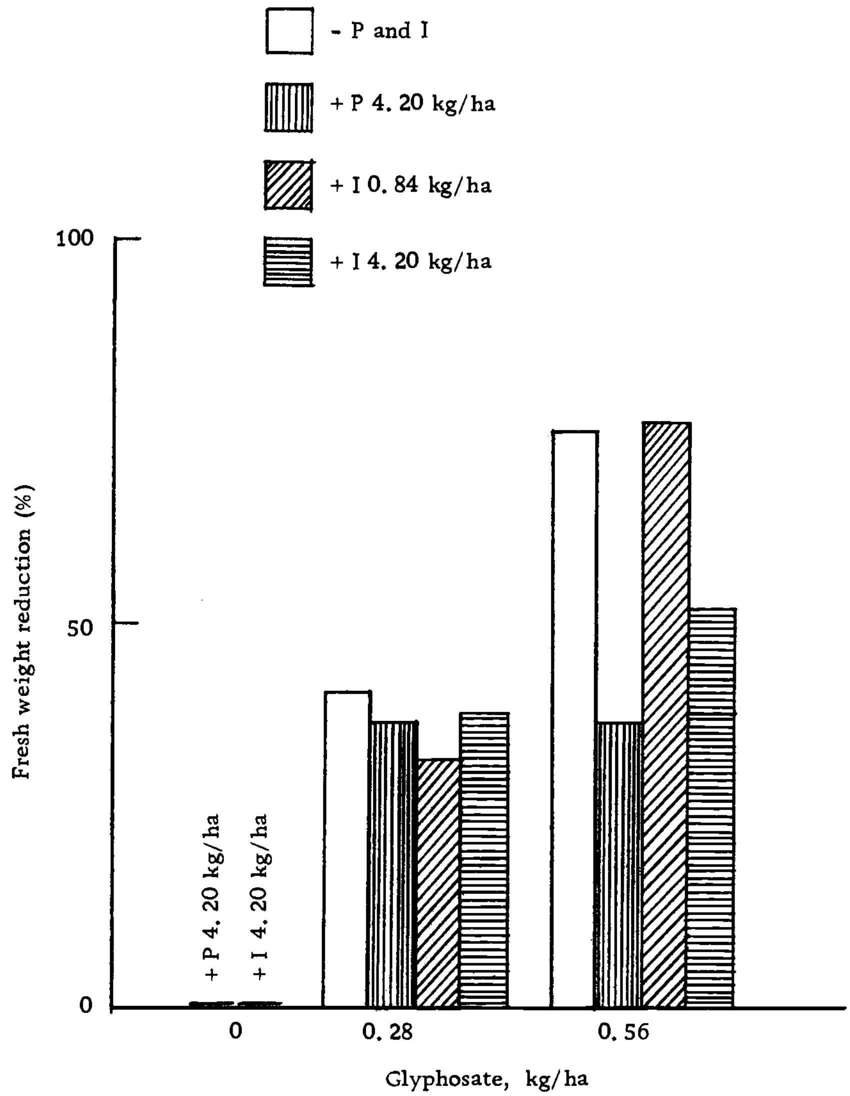

Figure 24. Experiment 14. Fresh weights of corn plants treated with glyphosate, commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product or inert ingredients (G = glyphosate, P = commercial product of simazine, and I = inert ingredients).

glyphosate. The data on mean fresh weights of corn top growth confirmed the results on injury ratings.

Experiment 15: Effect of Simazine and Inert Ingredients on the Herbicidal Activity of Glyphosate on Beans

The results on injury and fresh weights are summarized in Figures 25 and 26, respectively (also see Appendix Tables 29 and 30).

The commercial product of simazine and its inert ingredients at a rate of 4.20 kg/ha significantly reduced the injury caused by glyphosate applied at 0.28 kg/ha. The amount of the inert ingredients present in 4.20 kg/ha of the product (0.84 kg/ha) alone was not sufficient to reduce the injury appreciably. The ability to reduce glyphosate injury disappeared when the rate of glyphosate was increased to 0.56 kg/ha. The fresh weights of bean top growth showed the same trend of responses.

Experiment 16: Sorption of Glyphosate in the Spray Solutions

Adsorption Study. By using a colorimetric method of analysis for total P (Bartlett, 1959), about 10% of the glyphosate was found to adsorb to the suspended materials in the glyphosate-commercial product of simazine and glyphosate-inert ingredient solutions when the application volume was 375 l/ha. Significantly more glyphosate

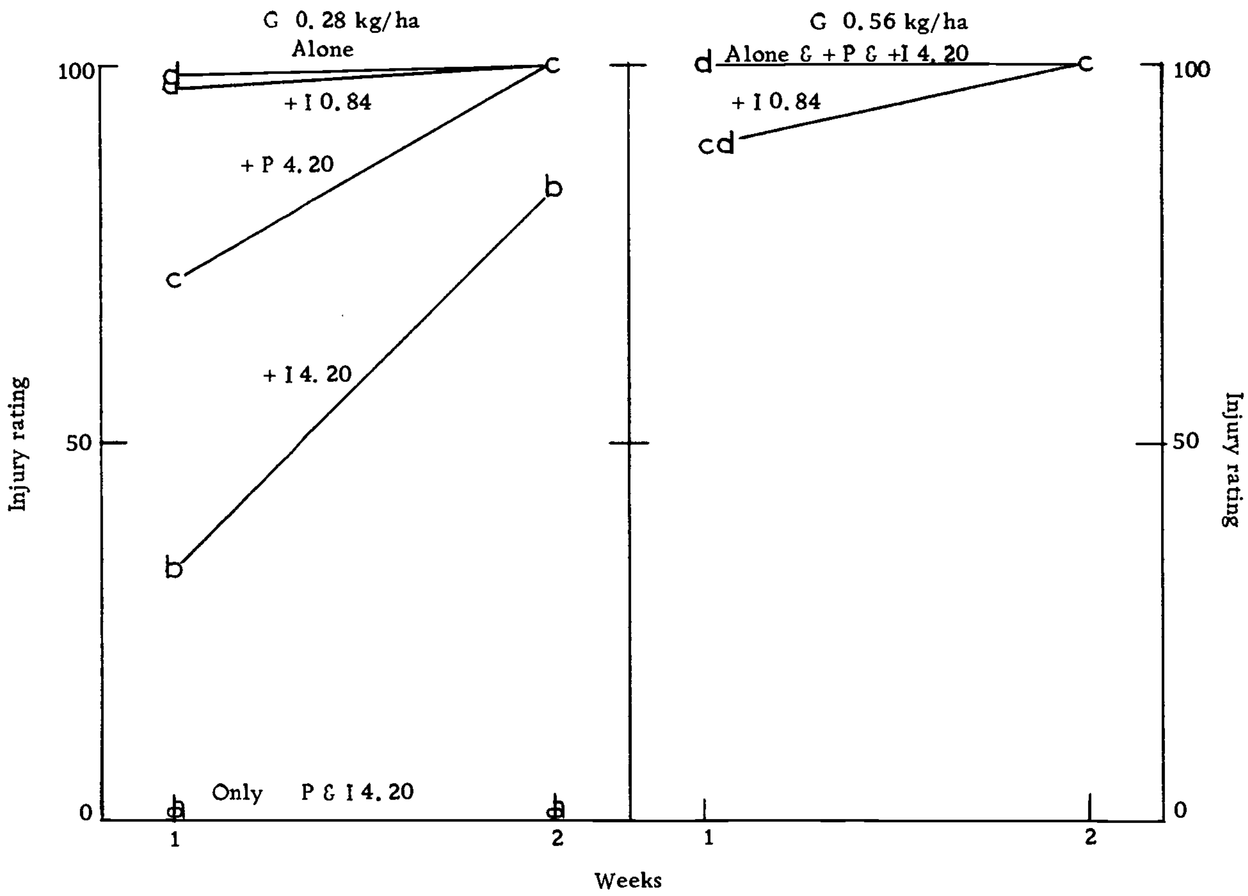

Figure 25. Experiment 15. Injury of bean plants treated with glyphosate, commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product or inert ingredients (G = glyphosate, P = commercial product of simazine, and I = inert ingredients). Points with the same letter are not significantly different at P = 0.05.

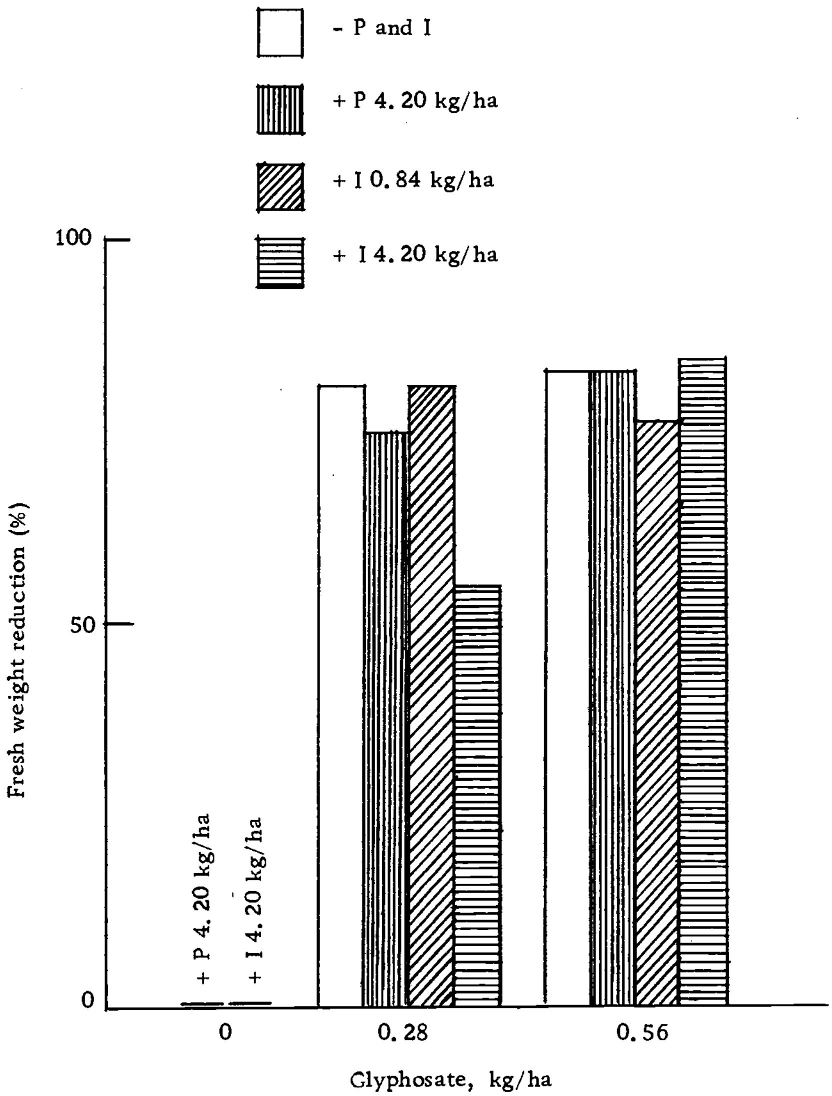

Figure 26. Experiment 15. Fresh weights of bean plants treated with glyphosate, commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product or inert ingredients (G = glyphosate, P = commercial product of simazine, and I = inert ingredients).

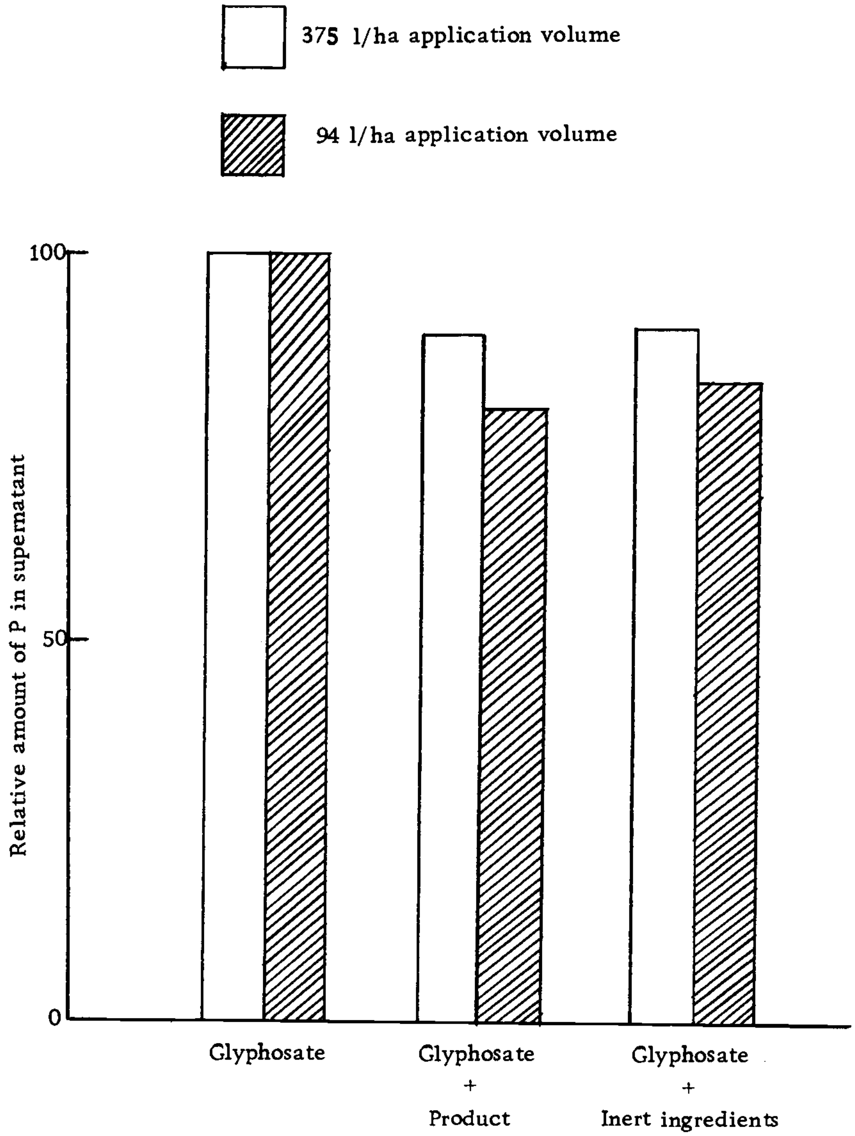

Figure 27. Experiment 16. Amounts of P in the supernatants of glyphosate, glyphosate-commercial product of simazine, and glyphosate-inert ingredient spray solutions prepared at two application volumes.

was adsorbed by the suspended materials of the solutions when the application volume was reduced to 94 l/ha (Figure 27). As expected, when the solutions became more concentrated, more glyphosate adsorbed to the suspended particles.

Bioassay of the Supernatants. Injury of bean plants treated with the supernatants of the glyphosate-commercial product of simazine and glyphosate-inert ingredient solutions are summarized in Figure 28 (also see Appendix Table 32).

The supernatants of the glyphosate-commercial product and glyphosate-inert ingredient solutions clearly caused less injury to bean plants than the glyphosate solution at both evaluations. Extra surfactant added to the supernatants of the combinations did not increase their herbicidal activity. This suggests that the reduction in activity of the combinations probably did not involve a withdrawal of the surfactant from the solutions by the suspended materials. The same results were obtained in terms of the fresh weights of top growth harvested 1 week after treatment (Appendix Table 33).

Elution Study. The results from washing the pellets obtained from the centrifugation of the glyphosate-commercial product of simazine and glyphosate-inert ingredient solutions are presented in Figure 29. When both wet and dry pellets were washed for 1 hour, the amounts of glyphosate, as estimated from the total P determined, released from the dry pellets were only 43 and 50% of that released

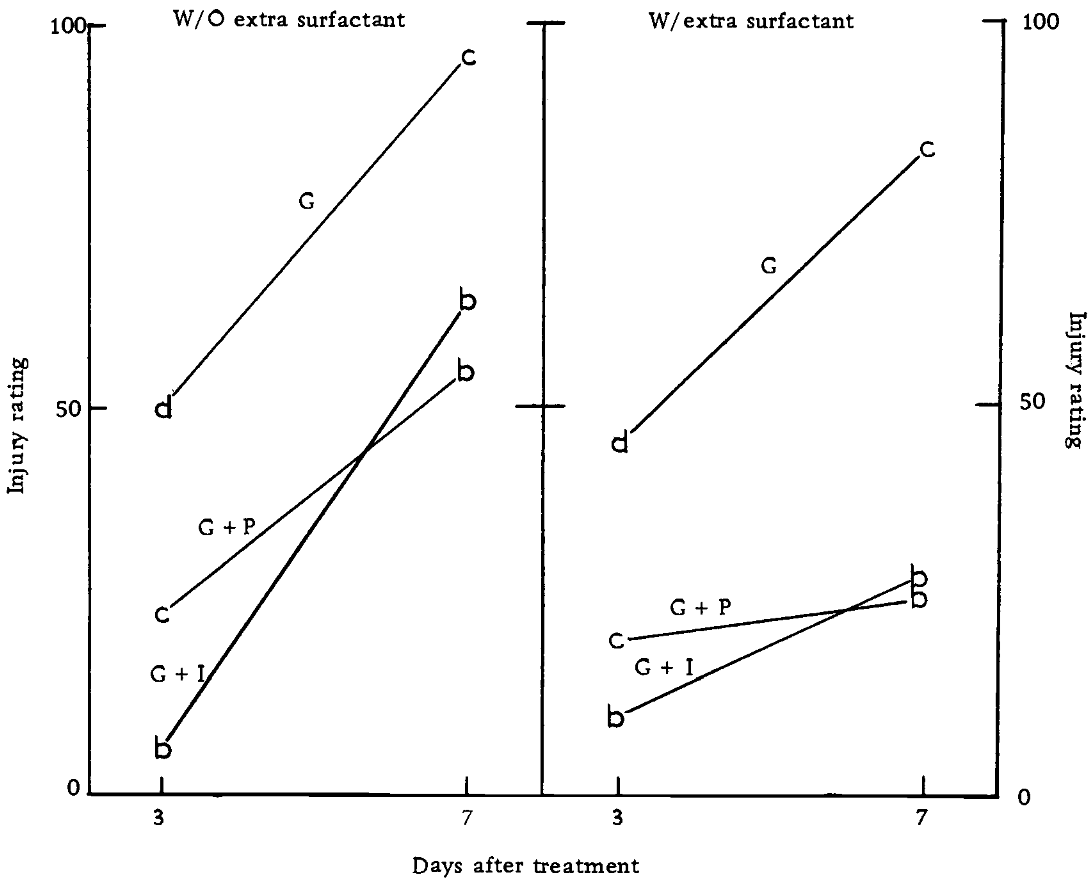

Figure 28. Experiment 16. Injury of bean plants treated with supernatants of glyphosate-commercial product of simazine and glyphosate-inert ingredient spray solutions in comparison with the glyphosate treatment (G = glyphosate, I = inert ingredients, and P = commercial product of simazine). Points with the same letter are not significantly different at P = 0.05.

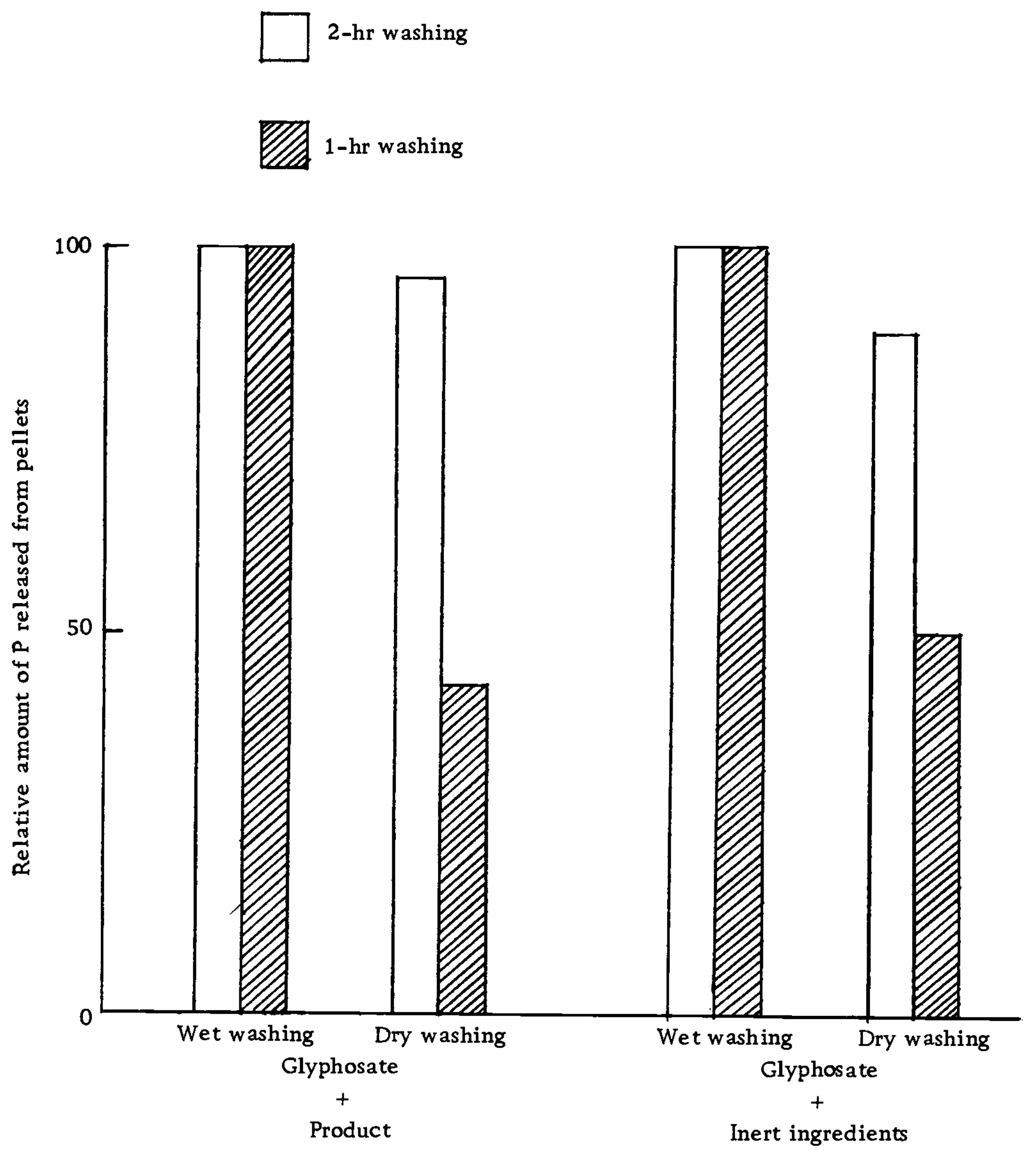

Figure 29. Experiment 16. Amounts of P released from the pellets[a] resulting from washing with distilled water and recentrifugation at 15, 000 rpm for 15 minutes of the glyphosate-commercial product of simazine and glyphosate-inert ingredient spray solutions.

[a]Consisted of some trapped glyphosate solution, suspended materials, and glyphosate adsorbed on the suspended materials.

from the corresponding wet pellets of the glyphosate-commercial product and glyphosate-inert ingredient solutions, respectively. The amounts of released glyphosate from the dry pellets were increased to 96 and 89% of that of the corresponding wet pellets, respectively, when the washing time was increased to 2 hours. These results indicated that the low percentage of the released glyphosate from the dry pellets in the 1-hour-washed group was not due to loss by volatilization.

Experiment 17: Response of Beans to Varying Doses of Glyphosate

Data on plant injury ratings and fresh weights are summarized in Figure 30. Significant differences in injury could be observed by varying the dose of glyphosate by 10%, especially when the rating was made before the injury symptoms became too severe. The data support the conclusion that even small reductions in glyphosate concentration caused by physical or chemical interaction in the spray solution can significantly reduce phytotoxicity.

Discussion

A series of greenhouse and laboratory studies has provided several observations which are relevant to an explanation of the observed interaction between glyphosate and simazine or other

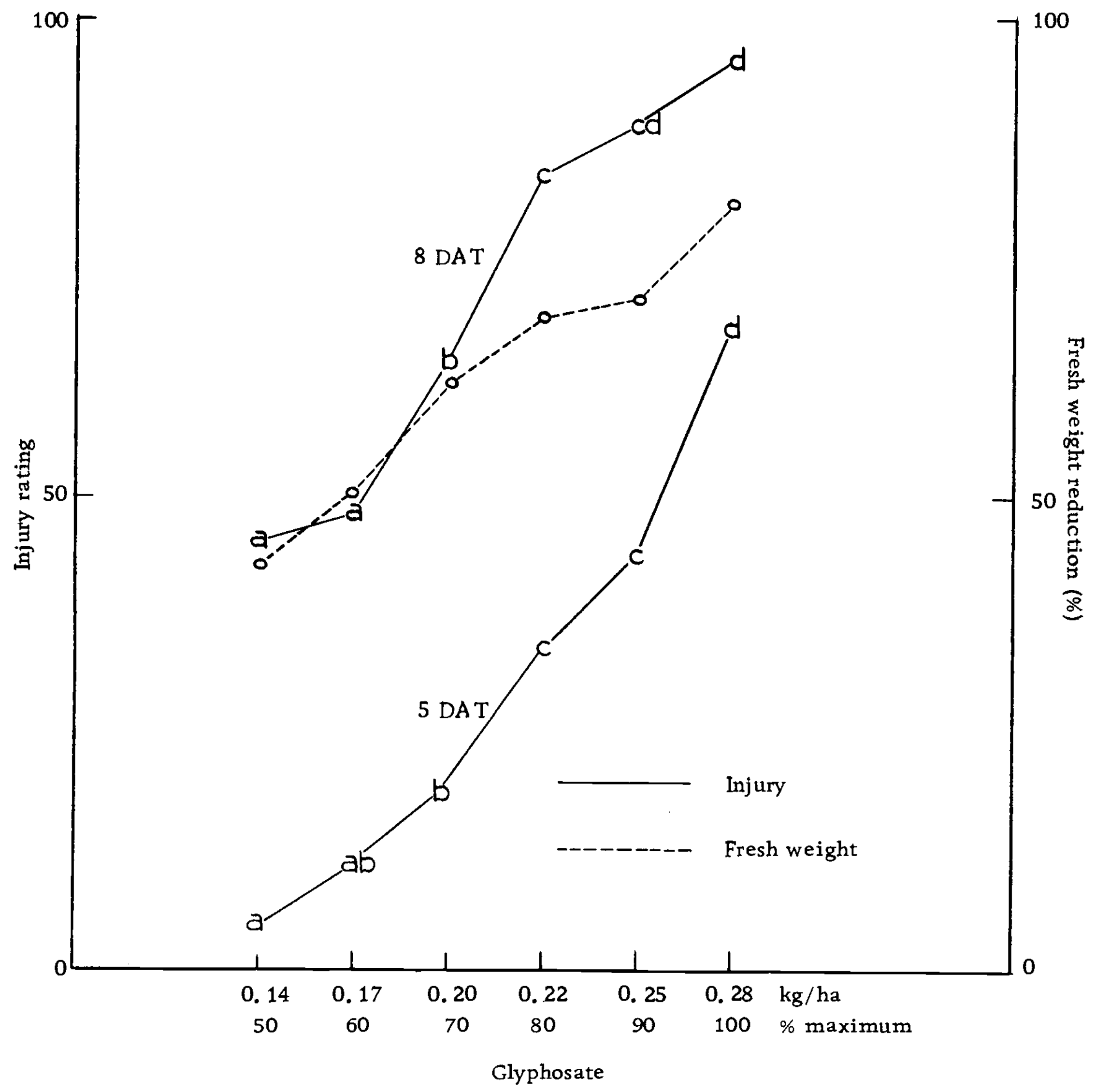

Figure 30. Experiment 17. Response of bean plants to varying doses of glyphosate (DAT = days after treatment). Points with the same letter are not significantly different at P = 0.05.

herbicides.

1. The antagonistic interaction between glyphosate and simazine was obtained only when they were applied together as a mixture to corn and beans, not when they were applied separately on different leaves of the same plants or when glyphosate was applied to the foliage and simazine to the soil. Although a significant amount of simazine applied to the foliage was probably taken up by corn and bean plants (Biswas, 1964), it could have failed to move out of the treated leaves (Foy, 1964). This could explain why no interactions were obtained when the herbicides were applied separately on different leaves of the same plants. However, better uptake and movement from soil application of simazine was evident from simazine effects in bean leaves, but still no interaction was observed. These results suggest that the interaction occurs outside the plants.

2. The inert ingredients of the commercial product of simazine also reduced the activity of glyphosate as much as the product itself when it was added to the solutions of glyphosate. This also provides strong evidence against simazine effects on physiological functions being a primary cause of the interaction.

3. In all experiments in this section and previously, the interaction consistently could be best observed only at or near the threshold rate of glyphosate. When the application rate was increased beyond this level, little or no interaction was observed.

4. Only about 10% of the glyphosate, as indicated by P analyses, was adsorbed by the commercial product of simazine or the inert ingredients in the 0.28 kg/ha spray solutions with the application volume of 375 l/ha. However, slightly more adsorption of glyphosate in more concentrated solutions was observed in the same study. These results indicate that the adsorption of glyphosate on the suspended materials of the spray solutions might actually play a more important role in reducing glyphosate activity on test plants than one would expect by merely considering the amounts adsorbed in the 375 l/ha solutions. This may be the case as the spray droplets dry on the leaf surface. The effect of water molecules on the adsorption of pesticides to soil components and other materials has been widely recognized. Weber (1972) has presented an excellent review on this matter. Greenhouse studies by Brewster and Appleby (1972) showed that glyphosate at usual rates could cause some injury to winter wheat if applied to wet soil shortly before emergence, while no noticeable injury was observed when glyphosate, even at unusually high rates, was applied preplant and incorporated into dry soil. These results indicate that less glyphosate is available under dry conditions and that the water molecules can compete with glyphosate molecules on an adsorptive surface. The fact that water can compete with herbicides for adsorption sites in soil is well-documented (Deming, 1963; Fang _et al._, 1961; and Hance, 1965). The results of the elution

study also may provide some support for this view. After glyphosate had been forced to adsorb on the suspended materials by drying, it was more difficult to remove by washing with water.

5. A greenhouse study showed that reducing the application rate of glyphosate by 10% caused a significant reduction in plant injury, especially when evaluation was made before the plants became too severely injured.

6. With or without extra surfactant added, all supernatants derived from the centrifugation of the glyphosate combinations caused less injury to bean plants than glyphosate alone. This indicated that the withdrawal of the surfactant from the solutions by the suspended materials was not the primary cause of the observed interaction.

All of these results are consistent with the hypothesis that physical and/or chemical interaction between glyphosate and simazine or other herbicides or the inert materials outside the plants is a major cause of the reduction of glyphosate activity on test plants treated with these herbicide combinations. Although the extent of the removal of glyphosate by the suspended materials in the solutions with high application volume was not large, the availability of glyphosate for foliar uptake could decrease as the spray droplets dry on the leaf surface.

However, other possible explanations have not been disproved by the results of these studies and should be investigated in the future. First, it is possible that glyphosate samples are contaminated with a very small amount of a compound which is extremely phytotoxic and is preferentially adsorbed by the suspended materials in the spray mixtures. A contamination of 2, 4, 5-T samples with dioxin is a good example of this. Dioxin, although not phytotoxic, is extremely toxic to mammals. It is sometimes present in small amounts in formulations of 2, 4, 5-T (Courtney et al., 1970 and Sparschu et al., 1971). A second possibility is the chemical alteration of glyphosate molecules by the other herbicide used in the combination. The chemical analysis used in these studies was not specific and would not distinguish between intact glyphosate molecules and any break-down products. A third possiblity may be an interference with glyphosate uptake or action in the sprayed leaves caused by some unknown water-soluble factor in the spray mixtures. Other explanations also could be possible.

V. SUMMARY AND GENERAL CONCLUSIONS

Studies were conducted in the field, greenhouse, growth chamber, and laboratory to determine the extent of the interaction between glyphosate and certain s-triazine herbicides and an explanation for such an interaction.

Greenhouse and growth chamber studies showed that glyphosate was very active on test plants as a foliarly-applied herbicide with very little crop selectivity. Shortly after treatment, glyphosate increased the transpiration rate of wheat, but transpiration sharply dropped below the control between the second and third day as the injury symptoms began to appear on the foliage. Glyphosate affected the growth of roots and shoots of wheat plants equally, as measured by dry weights of the treated plants. When corn leaf sections were floated in glyphosate solutions, no significant early changes in cell membrane permeability to electrolytes attributable to glyphosate were found. Probably, the primary action of glyphosate does not involve direct damage of cell membranes although this could be a secondary effect. No significant differences were found in injury and growth of wheat plants treated with different available formulations of glyphosate.

No clear interaction was observed between glyphosate and simazine on quackgrass in a field study. However, an antagonistic interaction was clearly observed between glyphosate and either simazine or atrazine when combinations were applied as a tank mix to corn, beans, and quackgrass in the greenhouse, especially at low application rates of glyphosate. In one corn study in the greenhouse, glyphosate also antagonistically interacted with alachlor and with 2, 4-D. The interaction of glyphosate with alachlor was similar to that with simazine or atrazine while the interaction with 2, 4-D appeared to be short-lived.

In a series of experiments in the greenhouse, glyphosate activity was reduced by simazine only when both were applied together as a mixture to corn and beans, not when applied separately on different leaves of the same plants or when glyphosate was applied to the foliage and simazine to the soil surface. An equivalent rate of the inert ingredients used in commercially formulated simazine also reduced the activity of glyphosate on test plants. The results of these studies up to this point strongly suggested physical and/or chemical interaction between glyphosate molecules and those of simazine or inert ingredients in the spray solution as the primary factor responsible for the observed antagonism.

About 10% of the glyphosate was found adsorbed to the suspended materials of the spray solution including 0. 28 kg/ha of glyphosate and either 4. 20 kg/ha of a commercial simazine formulation or the same rate of its inert ingredients in 375 l/ha of water in a laboratory study. When the application volume of the solutions was reduced, somewhat more glyphosate was adsorbed by the suspended materials. Less glyphosate was removed by washing dry pellets derived from the centrifugation of glyphosate-simazine and glyphosate-inert ingredient solutions in comparison with the amounts of glyphosate removed by washing wet pellets. In a greenhouse bioassay study, reducing the rate of glyphosate alone by 10% caused a definite reduction in plant injury. The supernatants derived from the centrifugation of the mixtures of glyphosate and the commercial product of simazine and inert ingredients were applied to bean plants in the greenhouse. All supernatants caused less plant injury than glyphosate alone, with or without extra surfactant added. Apparently, withdrawal of the surfactant by the suspended materials from the spray solutions is not the cause of the interaction. The results of these studies all support the view that physical and/or chemical interaction of glyphosate and other materials in the spray solution is the primary cause of the observed interaction in the greenhouse studies.

The findings from these studies obviously bear some practical significance. The antagonism indeed exists when glyphosate is applied as a tank mix with certain residual herbicides. Weed control with glyphosate under some circumstances could fail simply because of mixing with another herbicide in the same container. As indicated by these results, increasing the application rate of glyphosate would generally overcome the interaction. However, the activity of glyphosate is also greatly influenced by changes in environmental factors, especially temperature. Weed control with glyphosate may be affected as much as 50% by a temperature change of about 10 °C (Upchurch and Baird, 1972). The increase in application rate of glyphosate to compensate for the interaction may be inadequate if the situation is further complicated by changes in environmental conditions.

Further investigations are required to explore other possibilities for a better understanding of the interaction itself and to develop application methods to minimize this type of interaction.

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APPENDIX

Appendix Table 1. Injury of certain crops and weeds treated with different rates of glyphosate.

Glyphosate kg/ha	Injury rating[a] 1st rating[b] I	II	III	IV	Avg	2nd rating[c] I	II	III	IV	Avg
					Beans					
0	0	0	0	0	0	0	0	0	0	0
0.14	0	0	10	5	4	0	20	90	0	28
0.28	40	40	50	40	43	100	100	100	95	99
0.56	70	65	75	90	75	100	100	100	100	100
1.12	90	80	75	85	83	100	100	100	100	100
					Corn					
0	0	0	0	0	0	0	0	0	0	0
0.14	10	10	20	10	13	35	15	20	40	28
0.28	40	45	40	60	46	85	95	80	85	86
0.56	85	90	65	75	79	100	95	100	100	99
1.12	95	90	90	85	90	100	100	100	100	100
					Soybeans					
0	0	0	0	0	0	0	0	0	0	0
0.14	10	10	5	5	8	20	5	5	15	11
0.28	15	30	25	20	23	20	20	35	25	25
0.56	20	20	25	20	21	30	25	25	30	28
1.12	25	35	40	35	34	60	40	35	50	46
					Oats					
0	0	0	0	0	0	0	0	0	0	0
0.14	5	5	5	5	5	30	20	30	40	30
0.28	85	80	70	80	79	90	80	100	100	93
0.56	95	100	100	95	98	100	100	100	100	100
1.12	95	100	100	100	99	100	100	100	100	100

Appendix Table 1. (Continued)

Glyphosate kg/ha	Injury rating[a]									
	1st rating[b]					2nd rating[c]				
	I	II	III	IV	Avg	I	II	III	IV	Avg
					Wheat					
0	0	0	0	0	0	0	0	0	0	0
0.14	20	35	30	10	24	50	80	50	50	58
0.28	85	75	75	80	79	100	100	100	100	100
0.56	85	85	90	90	88	100	100	100	100	100
1.12	90	95	90	95	93	100	100	100	100	100
					Downy brome					
0	0	0	0	0	0	0	0	0	0	0
0.14	5	5	20	5	9	50	45	85	50	58
0.28	50	55	55	70	58	90	95	80	100	91
0.56	60	60	65	80	66	95	95	90	100	95
1.12	85	80	75	85	81	100	100	100	100	100
					Green foxtail					
0	0	0	0	0	0	0	0	0	0	0
0.14	70	75	80	65	73	95	90	95	95	94
0.28	75	80	85	85	81	95	100	95	100	98
0.56	95	85	90	90	90	100	100	100	95	99
1.12	85	90	95	95	91	100	100	100	100	100
					Barnyardgrass					
0	0	0	0	0	0	0	0	0	0	0
0.14	5	5	5	5	5	20	30	25	25	25
0.28	60	50	40	50	50	80	75	70	75	75
0.56	70	80	65	60	69	95	95	90	90	93
1.12	75	85	85	85	83	100	100	100	100	100

Appendix Table 1. (Continued)

Glyphosate kg/ha	Injury rating[a]									
	1st rating[b]					2nd rating[c]				
	I	II	III	IV	Avg	I	II	III	IV	Avg
					Quackgrass					
0	0	0	0	0	0	0	0	0	0	0
0.14	5	0	5	5	4	20	10	5	10	11
0.28	50	15	30	40	34	50	60	30	80	55
0.56	80	60	75	80	74	100	85	95	100	95
1.12	90	80	80	80	83	100	100	100	100	100
					Pigweed					
0	0	0	0	0	0	0	0	0	0	0
0.14	90	70	50	90	75	100	100	100	100	100
0.28	95	65	95	70	81	100	100	100	100	100
0.56	90	90	95	85	90	100	100	100	100	100
1.12	95	95	85	85	90	100	100	100	100	100

[a]0 = no injury and 100 = complet kill; see page 13 for the definitions in detail.

[b]2 days after treatment for pigweed, 3 days for beans, and 1 week for all other species.

[c]5 days after treatment for pigweed and beans and 2 weeks for all other species.

Appendix Table 2. Fresh weights of certain crops and weeds treated with different rates of glyphosate.

Glyphosate kg/ha	Fresh weight of top growth (g)				
	I	II	III	IV	Avg
			Beans		
0	2.790	3.295	3.174	4.212	3.368
0.14	3.666	2.961	1.793	4.524	3.236
0.28	1.526	1.582	1.431	1.823	1.591
0.56	1.158	1.103	1.430	1.028	1.180
1.12	0.772	1.570	1.108	0.744	1.049
			Corn		
0	15.2	26.6	25.9	21.8	22.375
0.14	23.9	19.0	25.1	15.1	20.775
0.28	7.1	5.3	2.5	5.0	4.975
0.56	1.4	2.5	1.0	1.8	1.675
1.12	1.3	1.6	1.6	1.5	1.500
			Soybeans		
0	6.955	6.126	6.604	6.563	6.562
0.14	5.845	6.319	6.387	6.076	6.157
0.28	5.185	4.906	5.434	5.103	5.157
0.56	4.331	5.066	5.192	4.562	4.788
1.12	3.332	4.545	4.383	3.020	3.820
			Oats		
0	13.378	12.993	13.543	13.325	13.310
0.14	8.708	8.732	6.677	9.367	8.371
0.28	2.542	1.703	1.110	1.232	1.647
0.56	0.876	0.799	0.749	0.768	0.798
1.12	0.635	0.682	0.778	0.368	0.616
			Wheat		
0	12.736	12.760	11.173	12.602	12.309
0.14	2.947	3.527	5.374	5.898	4.437
0.28	1.108	1.046	0.810	1.126	1.023
0.56	1.066	0.853	0.994	0.895	0.952
1.12	0.867	0.975	0.970	0.695	0.877
			Downy brome		
0	12.106	11.096	7.217	8.612	9.758
0.14	4.466	1.934	5.454	3.997	3.963
0.28	1.098	0.625	1.184	1.201	1.027
0.56	0.919	0.892	0.850	1.095	0.939
1.12	1.125	0.822	0.767	0.703	0.854

Appendix Table 2. (Continued)

Glyphosate kg/ha	Fresh weight of top growth (g) I	II	III	IV	Avg
			Green foxtail		
0	15.759	14.676	18.504	17.249	16.547
0.14	1.121	1.397	1.160	1.342	1.255
0.28	0.487	0.539	1.265	1.138	0.857
0.56	0.754	0.783	0.942	0.657	0.845
1.12	0.848	0.562	1.271	0.697	0.845
			Barnyardgrass		
0	21.314	26.196	20.971	23.117	22.900
0.14	16.718	11.865	14.613	11.433	13.657
0.28	3.668	3.987	4.493	3.233	3.845
0.56	1.195	1.249	3.132	1.291	1.717
1.12	0.940	0.920	1.283	1.144	1.072
			Quackgrass		
0	18.816	25.479	19.829	20.593	21.179
0.14	24.532	10.433	13.323	13.115	15.351
0.28	9.377	4.443	5.541	3.660	5.740
0.56	3.805	3.216	1.747	1.682	2.613
1.12	2.229	1.601	2.476	1.810	2.029
			Pigweed		
0	3.400	3.987	3.669	6.804	4.465
0.14	0.475	0.449	0.437	0.247	0.402
0.28	0.556	0.513	0.247	0.552	0.467
0.56	0.674	0.396	0.363	0.532	0.491
1.12	0.436	0.465	0.563	0.742	0.552

Appendix Table 3. Changes of electrical conductivity of the glyphosate solutions with floating leaf sections of corn.

Treatment	Conductivity change, umho/g F.W.				
	I	II	III	IV	Avg
			0.5 hr		
Water check	5.91	3.84	9.27	7.63	6.66 a[a]
Surfactant check	5.25	7.15	6.81	8.12	5.33 a
50 uM glyphosate	5.18	6.56	6.66	8.00	6.60 a
100 uM glyphosate	4.52	7.49	7.09	9.81	7.23 a
			1.0 hr		
Water check	6.65	5.10	10.94	7.52	7.55 a
Surfactant check	6.86	7.39	8.49	11.29	8.51 a
50 uM glyphosate	5.62	9.64	8.74	10.40	8.60 a
100 uM glyphosate	4.52	8.21	9.85	11.34	8.48 a
			2.0 hrs		
Water check	7.00	6.79	10.31	7.97	8.02 a
Surfactant check	7.13	11.46	10.84	11.46	10.22 a
50 uM glyphosate	6.66	12.15	10.05	12.26	10.28 a
100 uM glyphosate	5.74	11.45	12.61	12.87	10.67 a
			5.0 hrs		
Water check	8.82	8.65	13.30	9.45	10.06 a
Surfactant check	14.10	15.46	16.89	18.06	16.13 b
50 uM glyphosate	14.21	18.06	17.25	19.96	17.37 b
100 uM glyphosate	14.27	17.57	21.97	22.23	19.01 b
			7.0 hrs		
Water check	9.80	10.17	13.48	9.56	10.75 a
Surfactant check	16.91	18.54	17.90	20.57	18.48 b
50 uM glyphosate	21.46	21.79	21.11	20.75	21.28 bc
100 uM glyphosate	21.23	21.74	24.04	24.21	22.81 c
			14.0 hrs		
Water check	10.92	10.85	11.31	12.40	11.37 a
Surfactant check	24.15	29.78	19.80	22.07	23.95 b
50 uM glyphosate	28.42	33.13	27.29	20.33	27.29 b
100 uM glyphosate	27.49	33.98	25.62	24.03	27.78 b

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 4. Transpiration rate in ml per pot per hour of wheat treated with glyphosate in the growth chamber.

Glyphosate Molar	Plant no. / pot	Replications I	II	III	IV	Mean	Relative
0 hour after treatment:							
0	4	2.3	2.0	2.2	2.2	2.2	100
4.98×10^{-4}	4	1.5	2.4	2.2	2.1	2.1	96
9.95×10^{-4}	4	2.2	1.9	2.0	2.0	2.0	91
1.97×10^{-3}	4	2.0	2.0	2.1	2.1	2.1	96
24 hours after treatment:							
0	4	1.0	1.1	1.3	1.3	1.18	100
4.98×10^{-4}	4	1.1	0.6	2.1	1.3	1.28	109
9.95×10^{-4}	4	1.6	1.4	1.4	1.2	1.40	119
1.97×10^{-3}	4	1.3	1.0	1.8	1.7	1.45	123
48 hours after treatment:							
0	4	1.7	2.0	1.7	2.0	1.85	100
4.98×10^{-4}	4	1.5	1.5	1.6	1.6	1.55	84
9.95×10^{-4}	4	1.3	1.7	1.8	1.6	1.60	87
1.97×10^{-3}	4	1.9	1.8	1.6	2.2	1.88	102
72 hours after treatment:							
0	4	1.9	2.9	1.0	1.5	1.83	100
4.98×10^{-4}	4	1.7	1.9	1.7	1.7	1.75	96
9.95×10^{-4}	4	1.3	1.4	1.5	1.7	1.48	81
1.97×10^{-3}	4	1.8	2.0	1.2	1.1	1.53	84
96 hours after treatment:							
0	4	3.5	3.3	3.7	3.7	3.55	100
4.98×10^{-4}	4	1.8	1.7	2.1	2.3	1.98	56
9.95×10^{-4}	4	1.3	1.0	1.7	1.6	1.40	39
1.97×10^{-3}	4	1.3	1.7	1.4	1.6	1.50	42
144 hours after treatment:							
0	4	4.0	4.1	3.6	4.4	4.03	100
4.98×10^{-4}	4	2.2	1.8	2.7	2.6	2.33	58
9.95×10^{-4}	4	1.4	1.7	1.4	1.4	1.48	37
1.97×10^{-3}	4	1.6	1.6	1.4	1.3	1.48	37
168 hours after treatment:							
0	4	4.1	3.8	3.1	3.3	3.58	100
4.98×10^{-4}	4	1.4	1.8	1.8	2.0	1.75	49
9.95×10^{-4}	4	1.5	1.3	1.7	1.7	1.55	43
1.97×10^{-3}	4	1.7	2.0	1.5	1.4	1.65	46
336 hours after treatment:							
0	4	3.2	3.2	2.8	3.5	3.18	100
4.98×10^{-4}	4	2.1	3.0	3.4	3.6	3.03	95
9.95×10^{-4}	4	1.8	2.1	2.6	2.5	2.25	71
1.97×10^{-3}	4	2.1	2.8	1.8	1.8	2.13	67

Appendix Table 5. Dry weight in grams per pot on effect of glyphosate on wheat in the growth chamber.

Glyphosate Molar	Plant no./pot	Replications I	II	III	IV	Mean[a]
3 days after treatment:						
0	4	0.721	0.712	0.765	0.747	0.736 b
4.98×10^{-4}	4	0.736	0.744	0.739	0.713	0.733 b
9.95×10^{-4}	4	0.729	0.743	0.699	0.603	0.694 b
1.97×10^{-3}	4	0.620	0.608	0.616	0.542	0.597 a
7 days after treatment:						
0	4	1.462	1.478	1.401	1.700	1.510 c
4.98×10^{-4}	4	1.069	0.968	0.855	0.887	0.945 b
9.95×10^{-4}	4	1.020	0.894	0.927	0.918	0.938 b
1.97×10^{-3}	4	0.747	0.965	0.685	0.650	0.760 a
14 days after treatment:						
0	4	2.689	2.798	2.234	3.085	2.702 c
4.98×10^{-4}	4	1.620	1.726	1.913	1.899	1.790 b
9.95×10^{-4}	4	1.250	1.499	1.630	1.499	1.457 a
1.97×10^{-3}	4	1.413	1.560	1.386	1.420	1.445 a

[a]Numbers followed by the same letter are not significantly different at $P = 0.05$.

Appendix Table 6. Root:shoot ratio in percent on effect of glyphosate on wheat in the growth chamber.

Glyphosate Molar	Plant no./pot	Replications I	II	III	IV	Mean[a]
3 days after treatment:						
0	4	16.5	16.7	17.9	17.1	17.05 a
4.98×10^{-4}	4	16.8	19.4	17.1	15.9	17.30 a
9.95×10^{-4}	4	18.0	16.6	15.9	18.9	17.35 a
1.97×10^{-3}	4	19.0	18.8	19.2	19.1	19.03 a
7 days after treatment:						
0	4	14.5	16.4	15.8	15.8	15.63 a
4.98×10^{-4}	4	15.3	17.2	17.1	15.7	16.33 a
9.95×10^{-4}	4	16.2	17.6	16.6	18.0	17.10 a
1.97×10^{-3}	4	18.4	17.6	17.8	17.3	17.78 a
14 days after treatment:						
0	4	18.7	20.7	26.6	16.8	20.70 a
4.98×10^{-4}	4	21.2	18.3	19.7	20.1	19.83 a
9.95×10^{-4}	4	18.3	16.3	19.8	21.6	19.00 a
1.97×10^{-3}	4	18.1	19.3	18.2	27.8	20.85 a

[a] Numbers followed by the same letter are not significantly different at $P = 0.05$.

Appendix Table 7. Visual evaluations of injury of wheat treated with different formulations of glyphosate.

Treatment	Rate kg a.e./ha	Replications I	II	III	IV	Mean[a]
2 weeks after treatment:						
Control	--	0[b]	0	0	0	0 a
MON 0468	0.28	80	75	80	75	78 b
MON 0139	0.28	85	40	80	80	71 b
MON 2139	0.28	85	85	80	80	83 b
3 weeks after treatment:						
Control	--	0	0	0	0	0 a
MON 0468	0.28	90	90	90	85	89 b
MON 0139	0.28	95	75	90	90	88 b
MON 2139	0.28	85	95	85	85	88 b

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

[b]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

Appendix Table 8. Fresh weight in grams per plant of wheat treated with different formulations of glyphosate.

Treatment	Rate kg a.e./ha	Replications I	II	III	IV	Mean[a]
Control	--	0.60	0.82	0.69	0.87	0.74 b
MON 0468	0.28	0.16	0.28	0.28	0.15	0.22 a
MON 0139	0.28	0.20	0.21	0.18	0.20	0.20 a
MON 2139	0.28	0.23	0.13	0.18	0.20	0.19 a

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 9. Control of quackgrass from Experiment 5 on interaction between glyphosate and simazine.

Treatment	Rate kg/ha	Replications I	II	III	IV	Mean
1 month after treatment:						
Control	--	0[a]	0	0	0	0 a[b]
Simazine	2.80	10	10	0	0	5 a
Glyphosate	2.24	90	80	70	70	78 c
Glyphosate	4.48	95	90	90	90	91 d
Glyphosate + simazine	2.24+2.80	50	75	50	50	56 b
Glyphosate + simazine	4.48+2.80	80	85	90	90	86 c
Glyphosate followed by simazine	2.24+2.80	70	65	60	50	61 b
Glyphosate followed by simazine	4.48+2.80	95	95	90	95	94 d
3 months after treatment:						
Control	--	0	0	0	0	0 a
Simazine	2.80	0	0	0	0	0 a
Glyphosate	2.24	95	70	40	70	69 bc
Glyphosate	4.48	100	95	95	95	96 d
Glyphosate + simazine	2.24+2.80	70	60	40	60	58 b
Glyphosate + simazine	4.48+2.80	95	95	95	80	91 d
Glyphosate followed by simazine	2.24+2.80	90	85	50	80	76 c
Glyphosate followed by simazine	4.48+2.80	100	100	95	80	94 d
7 months after treatment:						
Control	--	0	0	0	0	0 a
Simazine	2.80	0	0	0	0	0 a
Glyphosate	2.24	80	50	50	50	58 b
Glyphosate	4.48	95	90	85	85	89 d
Glyphosate + simazine	2.24+2.80	70	50	40	40	50 b
Glyphosate + simazine	4.48+2.80	95	95	80	80	88 d
Glyphosate followed by simazine	2.24+2.80	90	80	60	60	73 c
Glyphosate followed by simazine	4.48+2.80	95	95	90	65	86 d
8 months after treatment:						
Control	--	0	0	0	0	0 a
Simazine	2.80	0	0	0	0	0 a
Glyphosate	2.24	60	30	30	30	38 b
Glyphosate	4.48	90	80	75	75	80 d
Glyphosate + simazine	2.24+2.80	40	30	20	30	30 b
Glyphosate + simazine	4.48+2.80	85	90	70	70	79 d
Glyphosate followed by simazine	2.24+2.80	70	50	40	50	53 c
Glyphosate followed by simazine	4.48+2.80	80	90	80	60	78 d

Appendix Table 9. (Continued)

Treatment	Rate kg/ha	Replications				Mean
		I	II	III	IV	
9 months after treatment:						
Control	--	0	0	0	0	0 a
Simazine	2.80	0	0	0	0	0 a
Glyphosate	2.24	50	10	15	30	26 b
Glyphosate	4.48	65	55	40	50	53 c
Glyphosate + simazine	2.24+2.80	20	10	10	10	13 ab
Glyphosate + simazine	4.48+2.80	60	70	50	40	55 c
Glyphosate followed by simazine	2.24+2.80	40	20	25	10	24 b
Glyphosate followed by simazine	4.48+2.80	60	70	60	25	54 c

[a] 0 = no control and 100 = complete control; see page 27 for the definitions in detail.

[b] Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 10. Injury of corn plants treated with glyphosate, atrazine, and their combinations.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	Avg[b]
		1 week				
Control	--	0	0	0	0	0 a
Atrazine	4.48	0	0	0	0	0 a
Glyphosate	0.28	50	60	50	50	53 c
Glyphosate + atrazine	0.28+4.48	50	50	40	40	45 b
Glyphosate	0.56	60	50	50	60	55 c
Glyphosate + atrazine	0.56+4.48	60	50	50	50	53 c
		2 weeks				
Control	--	0	0	0	0	0 a
Atrazine	4.48	0	0	0	0	0 a
Glyphosate	0.28	80	80	90	100	88 c
Glyphosate + atrazine	0.28+4.48	50	60	60	50	55 b
Glyphosate	0.56	100	100	100	90	98 d
Glyphosate + atrazine	0.56+4.48	90	90	90	80	88 c
		3 weeks				
Control	--	0	0	0	0	0 a
Atrazine	4.48	0	0	0	0	0 a
Glyphosate	0.28	95	100	100	100	99 c
Glyphosate + atrazine	0.28+4.48	60	60	70	60	63 b
Glyphosate	0.56	100	100	100	100	100 c
Glyphosate + atrazine	0.56+4.48	100	100	100	95	99 c

[a]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 11. Fresh weight of corn plants treated with glyphosate, atrazine, and their combinations.

Treatment	Rate kg/ha	Fresh weight in g I	II	III	IV	Avg[a]
Control	--	31.6	31.7	29.1	34.2	31.650 d
Atrazine	4.48	36.5	33.0	32.0	19.0	30.125 c
Glyphosate	0.28	2.5	2.5	1.1	1.5	1.900 a
Glyphosate + atrazine	0.28+4.48	5.8	5.6	8.5	8.5	7.100 b
Glyphosate	0.56	0.7	1.2	1.1	1.1	1.025 a
Glyphosate + atrazine	0.56+4.48	1.2	1.2	0.8	3.7	1.725 a

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 12. Injury of quackgrass treated with glyphosate, simazine, and their combinations in the greenhouse. Plants treated 2 weeks after clipping.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	V	Avg
		1 week					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	10	20	20	30	20	20 bc
Glyphosate + simazine	0.56+2.80	10	10	10	20	20	14 b
Glyphosate	1.12	95	95	95	100	100	97 e
Glyphosate + simazine	1.12+2.80	30	20	20	40	20	26 c
Glyphosate	2.24	100	100	100	100	100	100 e
Glyphosate + simazine	2.24+2.80	40	50	50	80	60	56 d
		2 weeks					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	30	40	50	40	40	40 c
Glyphosate + simazine	0.56+2.80	25	25	30	25	25	26 b
Glyphosate	1.12	95	95	95	100	100	97 f
Glyphosate + simazine	1.12+2.80	50	60	60	80	40	58 d
Glyphosate	2.24	100	100	100	100	100	100 f
Glyphosate + simazine	2.24+2.80	85	90	80	90	90	87 e
		3 weeks					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	40	50	60	50	60	52 c
Glyphosate + simazine	0.56+2.80	40	30	40	40	30	36 b
Glyphosate	1.12	95	95	95	100	100	97 f
Glyphosate + simazine	1.12+2.80	60	70	70	80	70	70 d
Glyphosate	2.24	100	100	100	100	100	100 f
Glyphosate + simazine	2.24+2.80	85	90	80	95	90	88 e

[a]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

Appendix Table 13. Injury of quackgrass treated with glyphosate, simazine, and their combinations in the greenhouse. Plants treated 4 weeks after clipping.

Treatment	Rate	Injury rating[a]					
.	kg/ha	I	II	III	IV	V	Avg
		1 week					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	15	20	15	10	10	14 b
Glyphosate + simazine	0.56+2.80	10	10	10	10	10	10 b
Glyphosate	1.12	40	60	30	50	40	44 c
Glyphosate + simazine	1.12+2.80	20	10	15	20	15	16 b
Glyphosate	2.24	80	75	60	80	75	74 e
Glyphosate + simazine	2.24 +2.80	60	50	40	80	50	56 d
		2 weeks					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	10	10	5	10	10	9 b
Glyphosate + simazine	0.56+2.80	10	15	15	15	10	13 b
Glyphosate	1.12	90	90	70	90	80	84 d
Glyphosate + simazine	1.12+2.80	30	40	20	30	20	28 c
Glyphosate	2.24	100	100	95	100	100	99 e
Glyphosate + simazine	2.24+2.80	80	95	90	100	70	87 d
		4 weeks					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	20	25	30	20	30	25 b
Glyphosate + simazine	0.56+2.80	15	20	30	20	20	21 b
Glyphosate	1.12	95	95	85	90	80	89 d
Glyphosate + simazine	1.12+2.80	30	40	30	30	40	34 c
Glyphosate	2.24	100	100	95	100	100	99 e
Glyphosate + simazine	2.24+2.80	90	95	90	100	90	93 de

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

Appendix Table 14. Injury of quackgrass treated with glyphosate, simazine, and their combinations in the greenhouse. Plants treated 6 weeks after clipping.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	V	Avg
		1 week					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	50	25	50	30	25	36 c
Glyphosate + simazine	0.56+2.80	10	20	20	10	20	16 b
Glyphosate	1.12	60	60	90	75	80	73 d
Glyphosate + simazine	1.12+2.80	40	20	65	30	20	35 c
Glyphosate	2.24	90	80	85	80	80	83 d
Glyphosate + simazine	2.24+2.80	70	95	65	90	65	77 d
		2 weeks					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	60	20	50	25	30	37 c
Glyphosate + simazine	0.56+ 2.80	15	20	25	30	20	22 b
Glyphosate	1.12	90	90	95	90	80	89 d
Glyphosate + simazine	1.12+2.80	50	35	70	40	30	45 c
Glyphosate	2.24	100	100	100	100	100	100 d
Glyphosate + simazine	2.24+2.80	90	100	80	100	90	92 d
		5 weeks					
Control	--	0	0	0	0	0	0 a
Glyphosate	0.56	80	40	70	70	60	65 c
Glyphosate + simazine	0.56+2.80	40	40	30	50	30	39 b
Glyphosate	1.12	100	100	100	90	95	98 d
Glyphosate + simazine	1.12+2.80	70	50	70	40	40	55 c
Glyphosate	2.24	100	100	100	100	100	100 d
Glyphosate + simazine	2.24+2.80	100	100	95	100	95	99 d

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

Appendix Table 15. Injury of beans treated with glyphosate, simazine, and their combinations, evaluated 1 week after treatment.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	Avg[b]
Control	--	0	0	0	0	0 a
Simazine	2.80	0	60	0	10	18 a
Glyphosate	0.56	50	60	100	100	78 b
Glyphosate + simazine	0.56+2.80	10	10	20	20	15 a
Glyphosate	1.12	100	100	100	100	100 b
Glyphosate + simazine	1.12+2.80	95	40	95	95	81 b

[a]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 16. Dry weights of bean plants treated with glyphosate, simazine, and their combinations.

Treatment	Rate kg/ha	Dry weight (g) I	II	III	IV	Avg[a]
Control	--	4.230	3.904	4.096	4.165	4.099 e
Simazine	2.80	4.066	1.679	3.841	3.266	3.213 cd
Glyphosate	0.56	3.562	2.992	2.284	2.247	2.771 bc
Glyphosate + simazine	0.56+2.80	3.995	3.676	4.156	2.791	3.655 de
Glyphosate	1.12	1.821	1.784	1.874	2.210	1.922 a
Glyphosate + simazine	1.12+2.80	2.214	2.825	2.034	1.579	2.163 ab

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 17. Injury of corn plants treated with glyphosate, simazine, alachlor, 2, 4-D, and combinations between glyphosate and all of the three herbicides.

Treatment	Rate kg/ha	Injury rating[a]				
		I	II	III	IV	Avg[b]
		------------- 1 week -------------				
Control	--	0	0	0	0	0 a
Simazine	3.36	0	0	0	0	0 a
Alachlor	3.36	10	5	5	5	6 a
2, 4-D	0.56	10	0	0	5	4 a
Glyphosate	0.28	30	30	25	40	31 bc
Glyphosate + simazine	0.28+3.36	35	20	30	50	34 bcd
Glyphosate + alachlor	0.28+3.36	20	50	40	30	35 cd
Glyphosate + 2, 4-D	0.28+0.56	20	15	5	30	18 ab
Glyphosate	0.56	95	85	90	50	80 f
Glyphosate + simazine	0.56+3.36	95	50	30	50	56 e
Glyphosate + alachlor	0.56+3.36	35	80	40	40	49 de
Glyphosate + 2, 4-D	0.56+0.56	35	30	25	25	29 bc
		------------- 2 weeks -------------				
Control	--	0	0	0	0	0 a
Simazine	3.36	0	0	0	5	1 a
Alachlor	3.36	5	0	5	0	2 a
2, 4-D	0.56	10	5	5	5	6 a
Glyphosate	0.28	80	90	75	80	81 de
Glyphosate + simazine	0.28+3.36	50	60	50	70	58 bc
Glyphosate + alachlor	0.28+3.36	15	65	60	60	50 b
Glyphosate + 2, 4-D	0.28+0.56	50	15	55	60	45 b
Glyphosate	0.56	100	100	95	95	98 e
Glyphosate + simazine	0.56+3.36	95	50	90	95	83 de
Glyphosate + alachlor	0.56+3.36	65	70	100	60	74 cd
Glyphosate + 2, 4-D	0.56+0.56	85	90	90	95	90 de

[a]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 18. Fresh weights of corn plants treated with glyphosate, simazine, alachlor, 2, 4-D, and combinations between glyphosate and all of the three herbicides.

Treatment	Rate kg/ha	Fresh weight (g)				
		I	II	III	IV	Avg[a]
Control	--	43. 2	40. 8	45. 3	44. 3	43. 400 d
Simazine	3. 36	39. 5	42. 0	38. 1	21. 6	35. 300 d
Alachlor	3. 36	36. 2	43. 4	32. 6	42. 0	38. 550 d
2, 4-D	0. 56	33. 5	39. 6	33. 8	34. 9	35. 450 d
Glyphosate	0. 28	3. 9	6. 2	8. 0	8. 3	6. 600 ab
Glyphosate + simazine	0. 28+3. 36	18. 6	14. 1	6. 9	32. 8	18. 100 bc
Glyphosate + alachlor	0. 28+3. 36	16. 4	11. 5	12. 6	34. 0	18. 625 c
Glyphosate + 2, 4-D	0. 28+0. 56	12. 2	9. 3	11. 0	42. 8	18. 825 c
Glyphosate	0. 56	3. 4	2. 7	2. 1	4. 6	3. 200 a
Glyphosate + simazine	0. 56+3. 36	3. 2	2. 9	5. 3	12. 9	6. 075 a
Glyphosate + alachlor	0. 56+3. 36	5. 8	2. 4	7. 9	8. 0	6. 025 a
Glyphosate + 2, 4-D	0. 56+0. 56	4. 4	3. 5	4. 3	5. 2	4. 350 a

[a]Numbers followed by the same letter are not significantly different at P = 0. 05.

Appendix Table 19. Injury of glyphosate-treated corn plants as affected by different placements of simazine on the foliage.

Treatment	Injury rating[a]				
	I	II	III	IV	Avg[b]
	2 weeks				
Control	0	0	0	0	0 a
Simazine					
3.96×10^{-2} M	0	0	0	0	0 a
Glyphosate					
4.93×10^{-3} M	85	90	95	90	90 c
9.86×10^{-3} M	95	95	100	85	94 c
1.87×10^{-2} M	95	95	100	95	96 c
Glyphosate + simazine					
$4.93\times10^{-3} + 3.96\times10^{-2}$ M in mixture	65	65	50	85	66 b
$4.93\times10^{-3} + 3.96\times10^{-2}$ M separately	90	90	95	95	93 c
$9.86\times10^{-3} + 3.96\times10^{-2}$ M in mixture	80	95	95	85	89 c
$9.86\times10^{-3} + 3.96\times10^{-2}$ M separately	95	95	90	90	93 c
$1.97\times10^{-2} + 3.96\times10^{-2}$ M in mixture	95	95	90	90	93 c
$1.97\times10^{-2} + 3.96\times10^{-2}$ M separately	95	90	95	100	95 c
	3 weeks				
Control	0	0	0	0	0 a
Simazine					
3.96×10^{-2} M	0	0	0	0	0 a
Glyphosate					
4.93×10^{-3} M	100	100	95	95	98 c
9.86×10^{-3} M	100	100	100	100	100 c
1.97×10^{-2} M	100	100	100	100	100 c
Glyphosate + simazine					
$4.93\times10^{-3} + 3.96\times10^{-2}$ M in mixture	95	85	75	100	89 b
$4.93\times10^{-3} + 3.96\times10^{-2}$ M separately	100	95	100	100	99 c
$9.86\times10^{-3} + 3.96\times10^{-2}$ M in mixture	95	100	100	100	99 c
$9.86\times10^{-3} + 3.96\times10^{-2}$ M separately	95	100	95	95	96 c
$1.97\times10^{-2} + 3.96\times10^{-2}$ M in mixture	100	100	95	100	99 c
$1.97\times10^{-2} + 3.96\times10^{-2}$ M separately	100	100	95	100	99 c

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b] Numbers followed by the same letter are not significantly different at $P = 0.05$.

Appendix Table 20. Fresh weights of glyphosate-treated corn plants as affected by different placements of simazine on the foliage.

Treatment	Fresh weight (g)				
	I	II	III	IV	Avg[a]
Control	22.35	17.95	19.60	19.45	19.84 c
Simazine					
3.96×10^{-2} M	21.40	11.05	15.80	18.50	16.69 b
Glyphosate					
4.93×10^{-3} M	3.36	2.64	2.60	1.60	2.55 a
9.86×10^{-3} M	2.80	1.75	2.40	2.65	2.40 a
1.97×10^{-2} M	1.82	1.12	1.76	2.50	1.80 a
Glyphosate + simazine					
$4.93 \times 10^{-3} + 3.96 \times 10^{-2}$ M in mixture	3.02	5.10	6.20	2.35	4.17 a
$4.93 \times 10^{-3} + 3.96 \times 10^{-2}$ M separately	3.40	2.40	2.25	1.95	2.50 a
$9.86 \times 10^{-3} + 3.96 \times 10^{-2}$ M in mixture	2.85	1.55	2.25	3.00	2.41 a
$9.86 \times 10^{-3} + 3.96 \times 10^{-2}$ M separately	2.46	2.60	3.55	3.22	2.96 a
$1.97 \times 10^{-2} + 3.96 \times 10^{-2}$ M in mixture	0.82	1.25	2.02	2.27	1.59 a
$1.97 \times 10^{-2} + 3.96 \times 10^{-2}$ M separately	1.78	2.13	1.18	1.95	1.76 a

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 21. Injury of glyphosate-treated bean plants as affected by different placements of simazine on the foliage.

Treatment	Injury rating[a]				
	I	II	III	IV	Avg[b]
Control	0	0	0	0	0 a
Simazine					
3.96×10^{-2} M	0	0	0	0	0 a
Glyphosate					
4.93×10^{-3} M	90	95	100	90	94 c
9.86×10^{-3} M	95	90	100	95	95 c
1.97×10^{-2} M	95	95	95	95	95 c
Glyphosate + simazine					
$4.93 \times 10^{-3} + 3.96 \times 10^{-2}$ M in mixture	70	70	55	30	56 b
$4.93 \times 10^{-3} + 3.96 \times 10^{-2}$ M separately	95	90	95	100	95 c
$9.86 \times 10^{-3} + 3.96 \times 10^{-2}$ M in mixture	95	90	90	95	93 c
$9.86 \times 10^{-3} + 3.96 \times 10^{-2}$ M separately	100	95	100	95	98 c
$1.97 \times 10^{-2} + 3.96 \times 10^{-2}$ M in mixture	95	90	95	95	94 c
$1.97 \times 10^{-2} + 3.96 \times 10^{-2}$ M separately	100	95	95	95	96 c

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

Appendix Table 22. Fresh weights of glyphosate-treated bean plants as affected by different placements of simazine on the foliage.

Treatment	Fresh weight (g)				
	I	II	III	IV	Avg[a]
Control	4.165	3.837	3.582	3.972	3.889 c
Simazine					
3.96×10^{-2} M	4.125	5.256	4.191	4.254	4.457 c
Glyphosate					
4.93×10^{-3} M	2.223	0.788	0.912	1.622	1.386 a
9.86×10^{-3} M	0.765	1.106	0.491	1.142	0.876 a
1.97×10^{-2} M	1.576	1.144	0.984	0.911	1.154 a
Glyphosate + simazine					
$4.93 \times 10^{-3} + 3.96 \times 10^{-2}$ M in mixture	1.691	1.507	2.937	4.457	2.648 b
$4.93 \times 10^{-3} + 3.96 \times 10^{-2}$ M separately	0.966	1.049	1.473	1.469	1.239 a
$9.86 \times 10^{-3} + 3.96 \times 10^{-2}$ M in mixture	1.472	1.364	0.649	1.699	1.296 a
$9.86 \times 10^{-3} + 3.96 \times 10^{-2}$ M separately	0.956	0.769	0.858	1.027	0.903 a
$1.97 \times 10^{-2} + 3.96 \times 10^{-2}$ M in mixture	1.483	0.943	0.779	1.267	1.118 a
$1.97 \times 10^{-2} + 3.96 \times 10^{-2}$ M separately	0.717	0.894	1.127	1.040	0.945 a

[a] Numbers followed by the same letter are not significantly different at $P = 0.05$.

Appendix Table 23. Injury of glyphosate-treated corn plants as affected by site of simazine placement.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	Avg[b]
		1 week				
Control	--	0	0	0	0	0 a
Simazine on foliage	3.36	0	0	0	0	0 a
Simazine in soil	3.36	0	0	0	0	0 a
Glyphosate	0.28	10	15	10	80	29 bc
Glyphosate + simazine on foliage	0.28+3.36	15	5	0	15	9 ab
Glyphosate + simazine in soil	0.28+3.36	30	20	25	40	29 bc
Glyphosate	0.56	85	75	85	60	76 d
Glyphosate + simazine on foliage	0.56+3.36	50	25	25	60	40 c
Glyphosate + simazine in soil	0.56+3.36	70	75	75	80	75 d
Glyphosate	1.12	80	85	85	85	84 d
Glyphosate + simazine on foliage	1.12+3.36	85	80	70	70	76 d
Glyphosate + simazine in soil	1.12+3.36	85	85	90	80	85 d
		2 weeks				
Control	--	0	0	0	0	0 a
Simazine on foliage	3.36	0	0	0	0	0 a
Simazine in soil	3.36	0	0	0	0	0 a
Glyphosate	0.28	60	95	90	100	86 c
Glyphosate + simazine on foliage	0.28+3.36	60	40	20	20	35 b
Glyphosate + simazine in soil	0.28+3.36	95	60	95	95	86 c
Glyphosate	0.56	100	100	100	95	99 cd
Glyphosate + simazine on foliage	0.56+3.36	100	95	100	95	98 cd
Glyphosate + simazine in soil	0.56+3.36	100	100	100	100	100 d
Glyphosate	1.12	100	100	100	100	100 d
Glyphosate + simazine on foliage	1.12+3.36	100	100	100	100	100 d
Glyphosate + simazine in soil	1.12+3.36	100	100	100	100	100 d

[a]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 24. Fresh weights of glyphosate-treated corn plants as affected by site of simazine placement.

Treatment	Rate kg/ha	Fresh weight (g)				
		I	II	III	IV	Avg[a]
Control	--	27.0	29.6	38.8	19.0	28.600 c
Simazine on foliage	3.36	19.3	29.2	29.8	29.3	26.900 c
Simazine in soil	3.36	22.4	19.5	33.7	28.8	26.100 c
Glyphosate	0.28	2.3	6.5	10.5	5.4	6.175 a
Glyphosate + simazine on foliage	0.28+3.36	11.3	18.5	18.8	19.1	16.925 b
Glyphosate + simazine in soil	0.28+3.36	3.9	5.1	7.4	3.7	5.025 a
Glyphosate	0.56	3.7	2.4	2.2	1.9	2.550 a
Glyphosate + simazine on foliage	0.56+3.36	4.2	4.4	6.1	4.2	4.725 a
Glyphosate + simazine in soil	0.56+3.36	2.0	2.3	1.9	3.2	2.350 a
Glyphosate	1.12	1.8	2.4	2.0	2.1	2.075 a
Glyphosate + simazine on foliage	1.12+3.36	1.9	3.8	3.2	2.8	2.925 a
Glyphosate + simazine in soil	1.12+3.36	1.8	2.1	2.6	2.5	2.250 a

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 25. Injury of glyphosate-treated bean plants as affected by site of simazine placement.

Treatment	Rate kg/ha	Injury rating[a]				
		I	II	III	IV	Avg[b]
		1 week				
Control	--	0	0	0	0	0 a
Simazine on foliage	3.36	0	0	0	0	0 a
Simazine in soil	3.36	0	0	0	0	0 a
Glyphosate	0.28	80	80	60	85	76 cd
Glyphosate + simazine on foliage	0.28+3.36	0	30	10	10	13 b
Glyphosate + simazine in soil	0.28+3.36	65	70	60	75	68 c
Glyphosate	0.56	70	70	95	95	83 de
Glyphosate + simazine on foliage	0.56+3.36	95	80	90	90	89 e
Glyphosate + simazine in soil	0.56+3.36	100	85	90	95	93 ef
Glyphosate	1.12	95	95	95	95	95 f
Glyphosate + simazine on foliage	1.12+3.36	95	95	85	90	91 ef
Glyphosate + simazine in soil	1.12+3.36	95	95	95	95	95 f
		2 weeks				
Control	--	0	0	0	0	0 a
Simazine on foliage	3.36	75	88	94	88	86 b
Simazine in soil	3.36	92	90	92	90	91 c
Glyphosate	0.28	100	100	100	100	100 d
Glyphosate + simazine on foliage	0.28+3.36	86	84	94	86	88 bc
Glyphosate + simazine in soil	0.28+3.36	100	100	100	100	100 d
Glyphosate	0.56	100	100	100	100	100 d
Glyphosate + simazine on foliage	0.56+3.36	100	100	100	100	100 d
Glyphosate + simazine in soil	0.56+3.36	100	100	100	100	100 d
Glyphosate	1.12	100	100	100	100	100 d
Glyphosate + simazine on foliage	1.12+3.36	100	100	100	100	100 d
Glyphosate + simazine in soil	1.12+3.36	100	100	100	100	100 d

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b] Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 26. Fresh weights of glyphosate-treated bean plants as affected by site of simazine placement.

Treatment	Rate kg/ha	Fresh weight (g)				
		I	II	III	IV	Avg[a]
Control	--	8.000	6.230	8.841	8.425	7.874 c
Simazine on foliage	3.36	3.591	2.602	1.594	2.204	2.498 b
Simazine in soil	3.36	2.103	2.138	2.081	2.509	2.208 b
Glyphosate	0.28	0.587	0.739	0.812	0.683	0.705 a
Glyphosate + simazine on foliage	0.28+3.36	1.908	1.701	1.946	2.216	1.943 b
Glyphosate + simazine in soil	0.28+3.36	0.793	0.810	0.689	0.765	0.764 a
Glyphosate	0.56	0.569	0.736	0.774	0.886	0.741 a
Glyphosate + simazine on foliage	0.56+3.36	0.504	0.728	0.594	0.650	0.619 a
Glyphosate + simazine in soil	0.56+3.36	0.661	0.580	0.620	0.615	0.619 a
Glyphosate	1.12	0.854	0.566	0.812	0.546	0.695 a
Glyphosate + simazine on foliage	1.12+3.36	0.703	0.559	0.429	0.576	0.567 a
Glyphosate + simazine in soil	1.12+3.36	0.640	0.587	0.812	0.703	0.686 a

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 27. Injury of corn plants treated with glyphosate, the commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product and inert ingredients.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	Avg[b]
		1 week				
Control	--	0	0	0	0	0 a
Commercial product of simazine	4. 20	0	0	0	0	0 a
Inert ingredients	4. 20	0	0	0	0	0 a
Glyphosate	0. 28	20	10	10	20	15 bc
Glyphosate + product	0. 28+4. 20	15	5	0	5	6 ab
Glyphosate + inert ingredients	0. 28+0. 84	20	10	5	0	9 abc
Glyphosate + inert ingredients	0. 28+4. 20	0	0	5	5	3 a
Glyphosate	0. 56	20	50	50	40	40 d
Glyphosate + product	0. 56+4. 20	10	20	20	30	20 c
Glyphosate + inert ingredients	0. 56+0. 84	60	40	30	30	40 d
Glyphosate + inert ingredients	0. 56+4. 20	0	10	5	5	5 b
		2 weeks				
Control	--	0	0	0	0	0 a
Commercial product of simazine	4. 20	0	0	0	0	0 a
Inert ingredients	4. 20	0	0	0	0	0 a
Glyphosate	0. 28	30	70	25	20	36 bc
Glyphosate + product	0. 28+4. 20	30	10	5	10	14 a
Glyphosate + inert ingredients	0. 28+0. 84	30	15	10	5	15 ab
Glyphosate + inert ingredients	0. 28+4. 20	5	5	30	20	15 ab
Glyphosate	0. 56	95	50	100	95	85 d
Glyphosate + product	0. 56+4. 20	40	30	25	60	39 c
Glyphosate + inert ingredients	0. 56+0. 84	100	60	85	95	85 d
Glyphosate + inert ingredients	0. 56+4. 20	70	35	25	30	40 c

[a]0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b]Numbers followed by the same letter are not significantly different at P = 0. 05.

Appendix Table 28. Fresh weights of corn plants treated with glyphosate, the commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product and inert ingredients.

Treatment	Rate kg/ha	Fresh weight (g)				
		I	II	III	IV	Avg[a]
Control	--	44.4	59.5	53.6	64.8	55.58 c
Commercial product of simazine	4.20	45.9	78.8	67.2	58.0	62.48 c
Inert ingredients	4.20	74.6	70.3	70.5	58.7	68.53 c
Glyphosate	0.28	48.0	9.2	27.8	46.3	32.83 b
Glyphosate + product	0.28+4.20	26.4	27.2	37.8	48.2	34.90 b
Glyphosate + inert ingredients	0.28+0.84	51.9	31.0	32.3	36.6	37.95 b
Glyphosate + inert ingredients	0.28+4.20	61.1	30.5	21.2	24.8	34.40 b
Glyphosate	0.56	8.6	14.3	17.1	16.0	14.00 a
Glyphosate + product	0.56+4.20	34.1	33.2	51.0	22.2	35.13 b
Glyphosate + inert ingredients	0.56+0.84	6.8	8.6	9.2	28.7	13.33 a
Glyphosate + inert ingredients	0.56+4.20	9.8	38.6	35.3	22.5	26.55 ab

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 29. Injury of bean plants treated with glyphosate, the commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product and inert ingredients.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	Avg[b]
		1 week				
Control	--	0	0	0	0	0 a
Commercial product of simazine	4.20	0	0	0	0	0 a
Inert ingredients	4.20	0	0	0	0	0 a
Glyphosate	0.28	95	100	100	100	99 d
Glyphosate + product	0.28+4.20	85	40	90	70	71 c
Glyphosate + inert ingredients	0.28+0.84	90	95	100	100	96 d
Glyphosate + inert ingredients	0.28+4.20	10	70	40	10	33 b
Glyphosate	0.56	100	100	100	100	100 d
Glyphosate + product	0.56+4.20	100	100	100	100	100 d
Glyphosate + inert ingredients	0.56+0.84	61	95	100	100	89 cd
Glyphosate + inert ingredients	0.56+4.20	100	100	100	100	100 d
		2 weeks				
Control	--	0	0	0	0	0 a
Commercial product of simazine	4.20	0	0	0	0	0 a
Inert ingredients	4.20	0	0	0	0	0 a
Glyphosate	0.28	100	100	100	100	100 c
Glyphosate + product	0.28+4.20	100	100	100	100	100 c
Glyphosate + inert ingredients	0.28+0.84	100	100	100	100	100 c
Glyphosate + inert ingredients	0.28+4.20	90	100	100	40	82 b
Glyphosate	0.56	100	100	100	100	100 c
Glyphosate + product	0.56+4.20	100	100	100	100	100 c
Glyphosate + inert ingredients	0.56+0.84	100	100	100	100	100 c
Glyphosate + inert ingredients	0.56+4.20	100	100	100	100	100 c

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b] Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 30. Fresh weights of bean plants treated with glyphosate, the commercial product of simazine, inert ingredients of the product, and different combinations between glyphosate and the product and inert ingredients.

Treatment	Rate kg/ha	Fresh weight (g)				
		I	II	III	IV	Avg[a]
Control	--	3.634	4.689	5.162	3.993	4.370 c
Commercial product of simazine	4.20	4.228	5.680	4.073	4.598	4.645 c
Inert ingredients	4.20	4.268	5.340	5.225	5.757	5.148 c
Glyphosate	0.28	0.829	0.700	0.904	0.822	0.814 a
Glyphosate + product	0.28+4.20	0.959	1.141	0.836	1.490	1.107 ab
Glyphosate + inert ingredients	0.28+0.84	1.154	0.796	0.742	0.657	0.826 a
Glyphosate + inert ingredients	0.28+4.20	1.368	0.794	1.154	4.596	1.978 b
Glyphosate	0.56	0.833	0.864	0.628	0.632	0.739 a
Glyphosate + product	0.56+4.20	0.623	0.905	0.619	0.745	0.723 a
Glyphosate + inert ingredients	0.56+0.84	1.160	1.235	1.016	0.822	1.058 ab
Glyphosate + inert ingredients	0.56+4.20	0.730	0.826	0.587	0.651	0.699 a

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 31. Amounts of P in the supernatant of the spray solutions of the glyphosate-commercial product of simazine and glyphosate-inert ingredient combinations after centrifuged at 15, 000 rpm for 15 minutes.

Herbicide	Rate kg/ha	OD_{830}								Avg	Relative
		I	II	III	IV	V	VI	VII	VIII		
Application volume, 375 l/ha:											
Glyphosate (+ product)[a]	0. 28+4. 20	. 504	. 490	. 483	. 517	. 523	. 534	. 529	. 525	. 514 d[b]	100
Product	4. 20	. 016	. 002	. 015	. 014	. 005	. 001	. 008	. 011	. 009 a	-
Inert ingredients	4. 20	. 008	. 007	. 007	. 008	. 006	. 005	. 007	. 006	. 007 a	-
Glyphosate+product	0. 28+4. 20	. 445	. 438	. 446	. 445	. 479	. 468	. 473	. 475	. 459 c	89
Glyphosate + inert ingredients	0. 28+4. 20	. 475	. 460	. 461	. 455	. 462	. 464	. 468	. 465	. 465 c	91
Application volume, 94 l/ha:											
Glyphosate (+ product)[a]	0. 28+4. 20	. 504	. 512	. 540	. 552	. 390	. 401	. 398	. 402	. 463 c	100
Product	4. 20	. 012	. 011	. 011	. 015	. 003	. 001	. 015	. 010	. 010 a	-
Inert ingredients	4. 20	. 000	. 000	. 003	. 006	. 015	. 008	. 009	. 003	. 006 a	-
Glyphosate+product	0. 28+4. 20	. 392	. 424	. 396	. 420	. 349	. 320	. 333	. 331	. 371 b	80
Glyphosate + inert ingredients	0. 28+4. 20	. 388	. 387	. 397	. 402	. 378	. 364	. 360	. 356	. 380 b	83

[a] Aliquot of the supernatant of the commercial product of simazine solution added before digestion.

[b] Numbers followed by the same letter are not significantly different at P = 0. 05.

Appendix Table 32. Injury of bean plants treated with the supernatants of the glyphosate-commercial product of simazine and glyphosate-inert ingredient spray solutions.

Treatment	Rate kg/ha	Injury rating[a] I	II	III	IV	Avg
		------------- 3 days -------------				
Without extra surfactant:						
Control	-	0	0	0	0	0 a[b]
Glyphosate	0.28	30	60	40	70	50 c
Product	4.20	0	0	0	0	0 a
Inert ingredients	4.20	0	0	0	0	0 a
Glyphosate + product	0.28+4.20	60	10	15	10	24 b
Glyphosate + inert ingredients	0.28+4.20	10	0	10	5	6 a
With extra surfactant (0.1%):						
Control	-	0	0	0	0	0 a
Glyphosate	0.28	60	40	40	40	45 d
Product	4.20	0	0	0	0	0 a
Inert ingredients	4.20	0	0	0	0	0 a
Glyphosate + product	0.28+4.20	25	20	20	15	20 c
Glyphosate + inert ingredients	0.28+4.20	10	5	15	10	11 b
		------------- 7 days -------------				
Without extra surfactant:						
Control	-	0	0	0	0	0 a
Glyphosate	0.28	95	95	95	95	95 c
Product	4.20	0	0	0	0	0 a
Inert ingredients	4.20	0	0	0	0	0 a
Glyphosate + product	0.28+4.20	65	95	30	25	54 b
Glyphosate + inert ingredients	0.28+4.20	75	80	75	25	64 b
With extra surfactant (0.1%):						
Control	-	0	0	0	0	0 a
Glyphosate	0.28	95	90	60	85	83 c
Product	4.20	0	0	0	0	0 a
Inert ingredients	4.20	0	0	0	0	0 a
Glyphosate + product	0.28+4.20	25	30	25	20	25 b
Glyphosate + inert ingredients	0.28+4.20	35	30	20	25	28 b

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b] Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 33. Fresh weights of bean plants treated with the supernatants of the glyphosate-commercial product of simazine and glyphosate-inert ingredient spray solutions.

Treatment	Rate kg/ha	Fresh weight (g) I	II	III	IV	Avg	Relative
Without extra surfactant:							
Control	--	10.385	9.222	6.737	8.059	8.601 c[a]	100
Glyphosate	0.28	2.819	3.982	4.031	2.968	3.450 a	40
Product	4.20	8.365	13.373	10.749	9.312	10.450 c	122
Inert ingredients	4.20	9.126	10.479	8.471	12.363	10.110 c	118
Glyphosate + product	0.28+4.20	5.760	2.482	7.825	8.336	6.101 b	71
Glyphosate + inert ingredients	0.28+4.20	5.392	4.489	6.089	7.092	5.766 b	67
With extra surfactant (0.1%):							
Control	-	9.155	7.555	9.759	10.215	9.171 bc	100
Glyphosate	0.28	2.946	3.433	6.761	4.756	4.474 a	49
Product	4.20	11.693	8.442	11.229	8.565	9.982 bc	109
Inert ingredients	4.20	9.181	12.229	11.227	10.821	10.865 c	119
Glyphosate + product	0.28+4.20	8.631	8.881	10.267	8.990	9.192 bc	100
Glyphosate + inert ingredients	0.28+4.20	5.669	8.274	9.789	9.298	8.258 b	90

[a]Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 34. Amounts of P washed from wet and dry pellets derived from the centrifugation of the glyphosate-commercial product of simazine and glyphosate-inert ingredient solutions.

Herbicide	Rate kg/ha	OD_{830}				Avg	Relative
		I	II	III	IV		
2-hr washing:							
Glyphosate + product, wet pellet	0. 28+4. 20	.619	.600	.615	.608	.611 d[a]	100
Glyphosate + product, dry pellet	0. 28+4. 20	.579	.580	.588	.606	.588 c	96
Glyphosate + inert ingredients, wet pellet	0. 28+4. 20	.492	.485	.507	.494	.495 b	100
Glyphosate + inert ingredients, dry pellet	0. 28+4. 20	.434	.452	.438	.440	.441 a	89
1-hr washing:							
Glyphosate + product, wet pellet	0. 28+4. 20	.524	.530	.538	.534	.531 c	100
Glyphosate + product, dry pellet	0. 28+4. 20	.241	.232	.240	.236	.237 a	45
Glyphosate + inert ingredients, wet pellet	0. 28+4. 20	.485	.493	.489	.498	.491 b	100
Glyphosate + inert ingredients, dry pellet	0. 28+4. 20	.244	.237	.248	.250	.245 a	50

[a]Numbers followed by the same letter are not significantly different at $P = 0.05$.

Appendix Table 35. Injury of bean plants treated with different rates of glyphosate.

Glyphosate kg/ha	Percent of highest rate	Injury rating[a]				Avg
		I	II	III	IV	
		5 days				
Control	-	0	0	0	0	0 a[b]
0.14	50	10	0	5	5	5 a
0.17	60	15	10	10	10	11 ab
0.20	70	10	20	30	15	19 b
0.22	80	30	25	60	20	34 c
0.25	90	20	30	75	50	44 c
0.28	100	65	85	70	50	68 d
		8 days				
Control	-	0	0	0	0	0 a
0.14	50	50	35	60	35	45 b
0.17	60	30	60	50	50	48 b
0.20	70	50	70	60	75	64 c
0.22	80	85	80	90	80	84 d
0.25	90	85	85	95	90	89 de
0.28	100	90	100	95	100	96 e

[a] 0 = no injury and 100 = complete kill; see page 13 for the definitions in detail.

[b] Numbers followed by the same letter are not significantly different at P = 0.05.

Appendix Table 36. Fresh weights of bean plants treated with different rates of glyphosate.

Glyphosate kg/ha	Percent of highest rate	Fresh weight (g)				Avg	Relative
		I	II	III	IV		
Control	-	3.661	5.571	3.697	6.840	4.942 d[a]	100
0.14	50	2.603	3.000	2.551	3.131	2.821 c	57
0.17	60	3.621	2.454	2.146	1.557	2.445 bc	49
0.20	70	1.553	2.250	1.697	2.023	1.881 abc	38
0.22	80	1.808	1.852	1.214	1.402	1.569 ab	31
0.25	90	1.545	1.158	0.883	1.136	1.431 a	29
0.28	100	1.128	0.903	0.826	0.825	0.921 a	19

[a]Numbers followed by the same letter are not significantly different at $P = 0.05$.