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Comparison of glyphosate formulations with and without sequential herbicides for no-till soybean in narrow rows

Comparaison de formulations de glyphosate avec ou sans herbicide séquentiel pour la culture du soja en semis direct et en rangs étroits

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Résumé de l'article

Une lutte efficace contre les mauvaises herbes est essentielle au cours des premiers stades de développement du soja (*Glycine max*) afin de minimiser les pertes de rendement. Pour deux formulations (sels de triméthylsulfonium et d'isopropylamine) de glyphosate appliqué à l'automne ou au printemps, seul ou en combinaison avec des herbicides séquentiels de prélevée ou de postlevée, des expériences ont été réalisées dans le but de comparer la lutte contre les mauvaises herbes et les rendements dans le soja cv. 'Maple Glen' en semis direct planté en rangs étroits sur un retour de céréale. Pour six expériences dans lesquelles le glyphosate a été appliqué (trois à l'automne et trois au printemps), il n'y a pas eu de différence pour la lutte aux mauvaises herbes ou les rendements du soja entre les deux formulations de glyphosate. Par rapport au glyphosate utilisé seul, les rendements ont été meilleurs lors de l'ajout de métribuzine dans toutes les expériences d'automne et dans deux des trois expériences de printemps, et lors de l'ajout de linuron dans deux expériences sur trois tant à l'automne qu'au printemps. Un herbicide qui permet de lutter contre les mauvaises herbes annuelles à feuilles larges a été nécessaire dans toutes les expériences de glyphosate appliqué à l'automne pour obtenir des rendements maximums de soja. L'ajout d'un herbicide séquentiel efficace après l'application printanière de glyphosate a permis d'améliorer les rendements, mais pas autant que pour le glyphosate appliqué à l'automne. Un herbicide rémanent de prélevée, tel que la métribuzine ou le linuron, actif contre une gamme étendue de mauvaises herbes est recommandé après l'application de glyphosate à l'automne ou au printemps afin de maximiser les rendements du soja.

Comparison of glyphosate formulations with and without sequential herbicides for no-till soybean in narrow rows

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Effective control of weeds during early stages of soybean (*Glycine max*) growth is critical to minimize crop yield reduction. Experiments were conducted to compare weed control and crop yield with two glyphosate formulations (trimethylsulfonium and isopropylamine salts) applied in the fall or spring, either alone or in combination with sequential pre-or post-ememergence herbicides in soybean cv. 'Maple Glen' no-till planted in narrow rows into grain stubble. In six experiments where glyphosate was applied (three in the fall and three in the spring), there was no difference in weed control or in soybean yield between the two glyphosate formulations. Crop yield was improved over glyphosate used alone by addition of metribuzin in all fall experiments and in two of three spring experiments and by addition of linuron in two of three experiments in both fall and spring. An herbicide that controlled annual broadleaf weeds was needed after fall-applied glyphosate in all experiments to achieve maximum soybean yield. Addition of an effective sequential herbicide after spring applied glyphosate improved yields but not to the same extent as noted with the fall applied glyphosate. A pre-emergence residual herbicide, such as metribuzin or linuron, that controls a broad spectrum of weeds is recommended after fall or spring applied glyphosate to maximize soybean yield.

[Comparaison de formulations de glyphosate avec ou sans herbicide séquentiel pour la culture du soja en semis direct et en rangs étroits]

Une lutte efficace contre les mauvaises herbes est essentielle au cours des premiers stades de développement du soja (*Glycine max*) afin de minimiser les pertes de rendement. Pour deux formulations (sels de triméthylsulfonium et d'isopropylamine) de glyphosate appliqué à l'automne ou au printemps, seul ou en combinaison avec des herbicides séquentiels de prélevée ou de postlevée, des expériences ont été réalisées dans le but de comparer la lutte contre les mauvaises herbes et les rendements dans le soja cv. 'Maple Glen' en semis direct planté en rangs étroits sur un retour de céréale. Pour six expériences dans lesquelles le glyphosate a été appliqué (trois à l'automne et trois au printemps), il n'y a pas eu de différence pour la lutte aux mauvaises herbes ou les rendements du soja entre les deux formulations de glyphosate. Par rapport au glyphosate utilisé seul, les rendements ont été meilleurs lors de l'ajout de métribuzine dans toutes les expériences d'automne et dans deux des trois expériences de printemps, et lors de l'ajout de linuron dans deux expériences sur trois tant à l'automne qu'au printemps. Un herbicide qui permet de lutter contre les mauvaises herbes annuelles à feuilles larges a été nécessaire dans toutes les expériences de glyphosate appliqué à l'automne pour obtenir des rendements maximums de soja. L'ajout d'un herbicide séquentiel efficace après l'application printanière de glyphosate a permis d'améliorer les rendements, mais pas autant que pour le glyphosate appliqué à l'automne. Un herbicide rémanent de prélevée, tel que la métribuzine ou le linuron, actif contre une gamme étendue de mauvaises herbes est recommandé après l'application de glyphosate à l'automne ou au printemps afin de maximiser les rendements du soja.

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INTRODUCTION

Soybean (*Glycine max* L.) is grown in rotation after a cereal, such as barley or wheat, in Atlantic Canada. The early cereal harvest allows for control of perennial grass and broadleaf weeds with a non-selective herbicide such as glyphosate applied in the fall, or failing that, a similar application can be made the next spring on weed regrowth. The soybean cultivars grown generally are used as a locally grown protein source for animal production, and for an increasing niche market for white hilum types that do not use transgenic technology, for the food market. Quackgrass [*Elytrigia repens* (L) Nevski] is the most common perennial grass species that requires control in Prince Edward Island and growers have widely adopted fall application of 0.9 kg a.i. ha^{-1} glyphosate on quackgrass regrowth after grain harvest. Although there is a short growing period for quackgrass in the spring, some growers successfully apply glyphosate to new growth of quackgrass and plant soybean a few days after application. In both cases, there is increased interest in no-till planting of soybean in order to reduce tillage and soil erosion.

Growers use several herbicides at pre-emergence (PRE) or post-emergence (POST) times of application. Growers note, however, that the PRE herbicides often give better overall results than the POST herbicides. The preferred herbicide for perennial weed control is glyphosate which is registered in two formulations, the trimethylsulfonium and isopropylamine salts, and both are used prior to planting on emerged weeds. Studies comparing the two formulations have not found any difference in control of volunteer crop and weed species including hard red winter wheat (Carlson and Burnside 1984); bermudagrass (Johnson 1988); johnsongrass (Salisbury *et al.* 1991); and quackgrass (Hamill and Zhang 1994; Ivany 1996; Kivlin and Doll 1988). In other studies, however, differences in response to formulation were noted between johnsongrass ecotypes (Brown *et al.* 1987), rye and horseweed (Wilson *et al.* 1985), and tall fescue (Hagood 1988).

Growers want to know if there is any difference in performance of glyphosate formulations when applied in either the fall or spring and when followed by a sequential PRE or POST herbicide to control weeds that emerge after no-till planting of the soybean. Therefore, experiments were conducted to compare weed control and crop yield with two glyphosate formulations applied in the fall or spring alone and in combination with sequential herbicides on soybean no-till planted into grain stubble.

MATERIALS AND METHODS

Fall Applied Glyphosate

Experiments were conducted at the Harrington Research Farm commencing in the fall of each year of 1995 to 1997. The isopropylamine or trimethylsulfonium salts formulations of glyphosate were applied to weed regrowth in barley stubble in October 20, 19 and 19 in 1995, 1996 and 1997, respectively. Weeds consisted mostly of quackgrass regrowth at the 4-leaf stage in 1995 and 1996 and at the 2-3 leaf stage in 1997, and mouse-eared chickweed (*Cerastium fontanum* Baumg. subsp. *hulgatum* (Hartm.) in 1995 and 1997. The treatment containing 2,4-D was applied tank-mixed with each glyphosate formulation in the fall. The 2,4-D was tank-mixed with the glyphosate to reduce the number of application times and to assist in control of perennial broadleaf weeds. All experiments were in a randomized complete block design with a factorial combination of two glyphosate formulations and six selected herbicide treatments plus an untreated control. Treatments were replicated four times on plots measuring 1.75 m x 6.0 m with 12 rows of soybean seeded at 15 cm between the rows. Soil pH ranged from 5.8 to 6.0. Soybean cv. 'Maple Glen' was seeded into a barley stubble using a no-till Tye seeder on May 27, 30 and 30 in 1996, 1997, and 1998, respectively. A total of 300 kg ha^{-1} of 5-20-20 (N:P:K) fertilizer was applied with the seed at planting. The sequential herbicides were applied PRE on June 6 in all 3 yr and POST herbicides were applied on June 24, July 3 and July 3 in 1996, 1997 and 1998, respectively at soybean first trifoliate leaf stage. Herbicides, application rates, and application timings comprising the treatments are listed in Table 1. Herbicides were applied with a tractor-mounted, small-plot sprayer which delivered a spray volume of 200 L ha^{-1} at 275 kPa using a 8003 flat-fan type spray tip. At the time of POST herbicide application in the spring, annual broadleaf weeds were in the four to six leaf stage. Control of predominant weed species, i.e. corn spurry (*Spergula arvensis* L), wild radish (*Raphanus raphanistrum* L), mouse-eared chickweed and quackgrass was rated 6 wk after treatment (WAT) of each time of application of herbicides in the spring on a linear scale of 0 to 100 where 0 = no effect and 100 = death of the weed. An area measuring 1.25 m x 6.0 m was harvested at maturity using a Hege plot combine and yield was adjusted to 16% moisture.

Spring Applied Glyphosate

These experiments were conducted at the Harrington Research Farm commencing in the spring of each yr of 1996, 1997 and 1998 to determine the effect of spring application of two glyphosate formulations followed by selected herbicides for control of quackgrass and other weeds and on soybean yield. Herbicides, application rates, and application timings comprising the treatments are listed in Table 2. Here, glyphosate formulations were applied in the spring to weed growth in barley stubble on May 22, 27 and 13 in 1996, 1997 and 1998, respectively. Weeds consisted predominantly of quackgrass at the 3-leaf stage in 1996 and at the 4-leaf stage in 1997 and 1998, and mouse-eared chickweed in 1997 and 1998. The design and cultural practices were the same as in the previous study. Soil pH ranged from 5.6 to 6.3 at the three sites. The crop was seeded into a barley stubble using a no-till Tye seeder on May 22, 27 and 13 in 1996, 1997, and 1998, respectively. PRE herbicides were applied on May 27, 30 and 19 in 1996, 1997 and 1998 and POST herbicides were applied on June 11, 25, and 24 in 1996, 1997 and 1998, respectively at soybean first trifoliate leaf stage. Weed control was rated and plots were harvested as above.

Statistical analysis

A combined yr analysis of variance of the data was conducted using Genstat (Genstat 5 Committee 1993). Results are presented by yr when treatment by yr interaction was significantly different. Because there were no differences in response to formulations and no interaction for sequential treatment, weed control data are presented as the means across yr when the weed species occurred in more than 1 yr. The untreated control was removed from analysis of weed control data. As transformed weed control data (arcsin) were not different from non-transformed data, actual percentages are presented. Similarly, there was no interaction between formulations on quackgrass control and crop yield, so the means presented were averaged across formulations. Treatment means were separated using the Least significant difference (LSD) test at the $P = 0.05$ level.

RESULTS

Fall applied glyphosate

In all 3 yr, at the time soybean was planted in late May, the predominant weed quackgrass was growing in the untreated control and had reached the 2 to 4 leaf stage, and other perennial weeds had several new leaves and were 2 to 10 cm high. There was no significant difference between glyphosate formulations in level of control of quackgrass, corn spurry or chickweed (Table 1). Quackgrass control with glyphosate was 94% in 1996 and 100% in 1997. However, control was only 56% in 1998 most likely because the quackgrass had only two to three leaves at application. Glyphosate alone and when combined with 2,4-D, or followed in the spring by imazethapyr, thifensulfuron or bentazon in 1996 and by imazethapyr in1998, controlled quackgrass comparably. Addition of the other herbicides after glyphosate did not affect quackgrass control in any yr.

A single application of glyphosate alone, or combined with 2,4-D, had the lowest level of control of mouse-eared chickweed (Table 1). Addition of metribuzin or linuron gave greatest control of wild radish and corn spurry and the perennial, mouse-eared chickweed. Imazethapyr, thifensulfuron, or bentazon control of corn spurry and wild radish ranged from 51 to 86%, well below that provided by addition of metribuzin or linuron.

Addition of a sequential spring-applied herbicide resulted in an increase in soybean yield with several herbicides (Table 3). In 1996, addition of 2,4-D, metribuzin, linuron or bentazon gave higher yields than glyphosate alone. The yields with all other added herbicides were higher than the untreated control except for imazethapyr. Glyphosate used alone in 1996 did not have higher yields than the untreated control. The addition of metribuzin or linuron gave yields that were higher than all the other added herbicides in 1996. In 1997, addition of all herbicides, except 2,4-D, gave higher yields than glyphosate used alone. The yields for all herbicide treatments were higher than the untreated control. The addition of PRE metribuzin or linuron gave higher yields than the POST herbicides. In 1998, addition of metribuzin increased soybean yields over glyphosate used alone. Yields were low in 1998 because of an extended period of below normal rainfall during July and August combined with competitive effects from the lower control of quackgrass.

Table 1. Weed control (%) from glyphosate formulations applied in the fall of the previous year and followed by selected herbicides

Herbicide	Rate applied (kg ha^{-1})	Time applied	Weed control at 6 WAT[a, b] (%)					
			QG			CkW[c]	WR[c]	CS[d]
			1996	1997	1998			
Glyphosate	0.9	POST fall	94	100	56	51	0	0
+ 2,4-D	0.5	POST fall	94	100	56	32	0	0
+ metribuzin	0.5	PRE spring	95	100	61	100	94	100
+ linuron	0.85	PRE spring	96	100	59	100	97	99
+ imazethapyr	0.1	PRE spring	100	100	69	90	86	78
+ thifensulfuron	0.006	POST spring	100	100	61	86	51	79
+ bentazon	1.08	POST spring	99	100	59	84	77	79
Control	—		0	0	0	0	0	0
LSD ($P = 0.05$)			4	ns	9	10	3	4

[a] WAT = Weeks after treatment in spring; QG = quackgrass; CkW = mouse-eared chickweed; WR = wild radish; and CS = corn spurry.
[b] No significant difference between formulations and no interactions in any year, so mean of formulations is presented.
[c] Mean of 2 years.
[d] Mean of 3 years.

Table 2. Weed control (%) from glyphosate formulations applied in the spring of the year and followed by selected herbicides

Herbicide	Rate applied (kg ha^{-1})	Time applied	Weed control at 6 WAT[a, b] (%)					
			QG			CkW[c]	WR[c]	CS[d]
			1996	1997	1998			
Glyphosate	0.9	POST fall	80	96	96	82	0	81
+ metribuzin	0.5	PRE spring	76	93	97	83	98	83
+ linuron	0.85	PRE spring	75	93	96	80	92	75
+ metolachlor	2.0	PRE spring	87	97	97	78	0	76
+ imazethapyr	0.1	PRE spring	77	97	98	82	99	80
+ thifensulfuron	0.006	POST spring	70	97	97	82	0	79
+ fomesafen	0.25	POST spring	84	97	96	81	100	80
Control	—	—	0	0	0	0	0	0
LSD (P = 0.05)			3	3	ns	2	4	3

[a] WAT = Weeks after treatment in spring; QG = quackgrass; CkW = mouse-eared chickweed; WR = wild radish; and CS = corn spurry.
[b] No significant difference between formulations, so mean of formulations is presented.
[c] Mean of three years.
[d] Data for 1998 only.

Spring applied glyphosate

In all 3 yr, at the time the soybeans were planted in May, the predominant weed quackgrass growing in the untreated control had reached the 2 to 4 leaf stage and other perennial weeds had several leaves and were 2 to 10 cm high. Quackgrass control with glyphosate was 96% in 1997 and 1998, however, control was only 80% in 1996, most likely because the quackgrass had only two to three leaves present when the glyphosate was applied (Table 2). In all 3 yr, there was no difference in control of quackgrass or other weeds between the two formulations. Control of quackgrass was marginally improved with addition of metolachlor and fomesafen after glyphosate in 1996 but there was no difference when those herbicides were added in 1997 or 1998. Addition of metribuzin or linuron after glyphosate in 1996 and 1997 gave reduced control but not in 1998. Addition of thifensulfuron in 1996 after glyphosate reduced quackgrass control but not in the other 2 yr.

Glyphosate applied alone or followed by metribuzin, thifensulfuron, imazethapyr, and fomesafen gave 81 to 83% control of mouse-eared chickweed (Table 2). Control of mouse-eared chickweed and corn spurry with linuron and metolachlor was reduced compared to glyphosate alone. All sequential herbicides, except metolachlor or thifensulfuron gave 92% or greater control of wild radish.

The sequential application of metribuzin or linuron increased soybean yield over glyphosate alone in 1996 (Table 4). Yields with addition of all other herbicides and with glyphosate alone were not different from each other but were higher than the untreated

Table 3. Soybean yield from glyphosate formulations applied in the fall of the previous year and followed by selected herbicides

Herbicide	Rate applied (kg ha^{-1})	Time applied	Soybean yield[a] (kg ha^{-1})		
			1996	1997	1998
Glyphosate	0.9	POST fall	795	1503	598
+ 2,4-D	0.5	POST fall	1029	1621	505
+ metribuzin	0.5	PRE spring	1568	2206	952
+ linuron	0.85	PRE spring	1448	2126	703
+ imazethapyr	0.1	PRE spring	755	1730	568
+ thifensulfuron	0.006	POST spring	990	1722	751
+ bentazon	1.08	POST spring	1037	1876	708
Control	—	—	780	930	200
LSD (P = 0.05)			232	203	171

[a] No significant difference between formulations and no interactions in any year, so means of formulations are presented.

control. In 1997, the addition of linuron or fomesafen gave the highest yields. Yields with addition of all other herbicides and with glyphosate alone were not different from each other but were higher than the untreated control. In 1998, the addition of metribuzin gave the highest yields. Yields with addition of all other herbicides and with glyphosate alone were not different from each other but were higher than the untreated control. In 1998, yield was reduced because of an extended period of below normal rainfall during July and August.

DISCUSSION

These experiments showed that there is no difference between trimethylsulfonium and isopropylamine salts formulations of glyphosate in level of control of quackgrass which confirms results of other authors for spring (Hamill and Zhang 1994) and fall application (Ivany 1996; Kivlin and Doll 1988). Control of mouse-eared chickweed was not different between formulations, however, level of control was much lower with fall application (51%) than with spring application (82%).

When glyphosate was applied in the previous fall, a sequential herbicide was required after planting the next spring to control annual broadleaf weeds to maximize yield. Delaying removal of annual weeds that emerged after planting with a POST herbicide did not provide adequate weed control and soybean yield was reduced. Addition of a sequential herbicide after a spring application of glyphosate resulted in higher yields, but not to the level obtained with the fall applied glyphosate. Glyphosate gave good control of quackgrass when either fall or spring applied. Control of other weeds by sequential herbicides had a greater effect on increasing yield after fall applied than spring applied glyphosate most likely due to the weed growth that was present at planting in the spring after fall applied glyphosate. The spring applied glyphosate removed this weed growth, lessening competitive effects and resulting in less response with the sequential herbicides. In both, the fall and spring experiments, glyphosate gave better control if applied when the quackgrass had three to four leaves rather than two to three present at application.

These results indicate that growers in Prince Edward Island can use either formulation of glyphosate to obtain good control of quackgrass with either fall or spring applications to quackgrass that has at least three leaves. Regardless of glyphosate application time, a sequential herbicide should be applied after planting soybeans to control germinating annual weeds. A greater yield increase can be expected after fall applied than spring applied glyphosate. Herbicides, such as metribuzin, linuron or imazethapyr applied PRE are recommended for use as they control weeds early and remove detrimental effects of early weed competition. Herbicides applied POST tend to give lower yields because of weed competition before application and generally less timely and poorer weed control.

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Table 4. Soybean yield from glyphosate formulations applied in the spring and followed by selected herbicides

Herbicide	Rate applied (kg ha^{-1})	Time applied	Soybean yield[a] (kg ha^{-1})		
			1996	1997	1998
Glyphosate[a]	0.9	Preplant spring	1466	1243	1059
+ metribuzin	0.5	PRE spring	1660	1328	1273
+ linuron	0.85	PRE spring	1774	1546	1192
+ metolachlor	2.0	PRE spring	1617	1234	1152
+ imazethapyr	0.1	PRE spring	1534	1419	1172
+ thifensulfuron	0.006	POST spring	1516	1263	1010
+ formesafen	0.25	POST spring	1650	1525	1193
Control	—		1104	648	824
LSD (P = 0.05)			193	201	182

[a] No significant difference between formulations and no interactions in any year, so means of formulations are presented.

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