Research reports

Effect of rainfall on glyphosate performance on stressed grass weeds following wheat harvest

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Summary

Glyphosate [*N*-(Phosphonomethyl) glycine] was applied to awnless barnyard grass (*Echinochloa colona* (L.) Link), liverseed grass (*Urochloa panicoides* Beauv.), and volunteer wheat (*Triticum aestivum* L.) during a no-till fallow after wheat harvest. The weeds, which were drought stressed, were watered (80 mm) at various days before or after spraying glyphosate to determine how rain just prior to, or after spraying, influences control. Rain-free periods on the day of spraying glyphosate, with 3 mm of simulated rainfall, were also evaluated for volunteer wheat and awnless barnyard grass.

Control of volunteer wheat with 225 g ha^{-1} was best when watered 6 days before applying glyphosate or 1 and 4 days after spraying. A similar trend occurred with awnless barnyard grass. Small liverseed grass (5–10 cm) required 900 g ha^{-1} of glyphosate for only 70% control which diminished rapidly with larger plants and where watering was delayed until 6 days after spraying. Larger barnyard grass also required higher rates of glyphosate and control was better when stress was reduced before rather than after spraying.

Glyphosate at 225 g ha^{-1} required more than 22 hours of rain-free period for control of volunteer wheat and small awnless barnyard grass. Six hours were required to control small awnless barnyard grass when glyphosate rate was 675 g ha^{-1}, but even 900 g ha^{-1} did not control the awnless barnyard grass larger than 10 cm.

Introduction

The use of herbicides to control weeds during the fallow period rather than cultivating is important for wheat production in the semi-arid areas of the World. Glyphosate is widely used in reduced tillage systems during fallow management but with varying success.

Weeds of different sizes are often a problem in broadcast spraying operations since the normal herbicide dosage for the paddock is selected on an economic basis. Farmers tend to allow weeds to become too large for efficient control. In many wheat producing areas of Australia sheep are used to graze weeds in the paddock. Depending upon rainfall, time of harvest, competitiveness of the wheat and management of sheep, weeds could be at various size and age when sprayed with glyphosate. There is less glyphosate translocation in older plants, especially under drought stress (Ahmadi *et al*. 1980). Also there are species of weeds that are more susceptible than others to glyphosate. When a few scattered weeds are left in the paddock these are not sprayed until sufficient new weeds have emerged. The larger weeds will require a higher dosage of glyphosate than the smaller plants. This may not be the best alternative in saving soil water and reducing weed populations.

Barnyard grass (*Echinochloa crus-galli* (L.) Beauv.) and liverseed grass (*Urochloa panicoides* Beauv.) require 540 g ha^{-1} of glyphosate to control 90% or more of the population (Wallens 1984). Wallens (1984) reported that liverseed grass and awnless barnyard grass control is particularly sensitive to water stress. More mature weeds are difficult to control and may require higher glyphosate rates. Barnyard grass and liverseed grass should be sprayed with 360 to 540 g ha^{-1} of glyphosate while volunteer wheat requires 180 to 540 g ha^{-1} of glyphosate for control (Gammie and Dellow 1989).

Rainfall within 6 hours after glyphosate application reduces control (Anon 1988). However, Fraser (1985) reported rainfall after 20 hours reduced control of barnyard grass with 500 g ha^{-1} of glyphosate. In Nebraska weed control from a combination of glyphosate plus 2,4-D (2,4-dichlorophenoxyacetic acid) was negatively correlated with rainfall on the day of application (Wicks *et al*. 1988). Rainfall 3 days before and after spraying improved weed control, but rainfall 6 and 9 days after had a detrimental effect. When examining 12 species of weeds across all post-harvest herbicides in relationship to rainfall events, weed control varied depending on the length of time between rainfall and spraying.

Field bindweed (*Convolvulus arvensis* L.) plants that were grown from seed and placed under drought stress were more resistant to glyphosate action than those that had adequate water (Dall'Armellina and Zimdahl 1989). When using fluazifop [(±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid] to control quackgrass (*Agropyron repens* L. Beauv.), withholding water for 8 days increased herbicide tolerance compared to withholding water for 4 days before treatment (Chandrasena and Sagar 1986).

Factors affecting the rate of penetration of glyphosate and thus the minimum duration of this rain-free period include the dose, concentration and formulation of active ingredient, and physiological condition and size of species (Caseley and Coupland 1985). The relationship between time of rainfall and spraying event needs to be explored more thoroughly with glyphosate on specific weeds.

The objective of this research was to determine if simulated rainfall events before or after weeds have been sprayed with glyphosate, will influence control of stressed summer annual weeds of different stages of growth.

Materials and methods

Two wheat stubble paddocks, planted to Kite in May 1989, were selected at Tamworth, NSW for water stress studies on summer annual grass weeds. In one paddock the major summer annual grasses were awnless barnyard grass and volunteer wheat (Experiment 1), while in the other it was liverseed grass (Experiment 2). The soil was a red clay, Uf 4.41, 152, (Northcote 1979).

The wheat paddock in experiment 1 was harvested for grain on 30 November 1989 and sheep were used to graze the weeds on 1, 2 and 3 December. The weeds were allowed to recover before spraying glyphosate at 0, 225, 450, 675 and 900 g ha^{-1} between 0930 to 1015 hours on 11 January 1990. Picloram (4-amino-3, 5, 6-trichloro-2-pyridine carboxylic acid) plus 2,4-D amine at 25 plus 100 g ha^{-1} were added to the glyphosate to aid in controlling a scattered population of broadleaf weeds, primarily wireweed (*Polygonum aviculare* L.). The spray volume used was 84 L ha^{-1}.

Experiment 1 was divided into two parts: 1a) effect of simulated rainfall on the day of spraying glyphosate on volun-

Table 1. Rainfall events at Tamworth Agricultural Research Centre, N.S.W.

December 1989 Date	Rainfall (mm)	January 1990 Date	Rainfall (mm)	February 1990 Date	Rainfall (mm)
3	1.0	2	0.5	2	8.4
4	19.8	8	28.0	3	0.2
6	23.5	9	0.5	4	52.8
8	0.8	15	2.0	6	0.2
11	8.8	16	29.8	8	0.2
12	4.3	22	8.0	9	3.2
13	1.0			10	5.4
14	5.3			11	0.8
15	2.3			14	16.4
21	1.5			18	4.8
25	26.5			19	0.2
				22	12.0
				24	1.4
				25	0.8
Total, mm	94.8		68.8		106.8
Rain days	11		6		14

Table 2. Minimum and maximum air temperatures in January 1990 at Tamworth, N.S.W.

Day	Min (C°)	Max	Day	Min (C°)	Max	Day	Min (C°)	Max
1	19.2	35.8	11	14.7	28.6	21	18.0	34.4
2	19.3	37.5	12	19.3	32.6	22	19.0	32.4
3	20.4	39.2	13	19.3	33.1	23	16.1	29.8
4	18.6	39.5	14	16.9	30.5	24	13.7	29.0
5	19.1	41.9	15	20.5	32.9	25	15.4	32.5
6	21.6	35.7	16	16.8	25.9	26	17.4	29.8
7	22.8	32.7	17	13.5	27.7	27	16.2	29.9
8	18.4	38.8	18	17.4	30.1	28	20.4	39.2
9	21.4	31.8	19	18.0	31.4	29	24.2	40.5
10	20.3	32.8	20	18.7	34.4	30	17.1	31.9
						31	15.6	31.5

teer wheat and awnless barnyard grass; and 1b) effect of rainfall events that occurred days before or after spraying glyphosate on volunteer wheat and awnless barnyard grass.

Five herbicide treatments, each 18 by 6 m, were arranged in a four randomized complete blocks. Within each plot, 48 0.5 m^2 circular subplots were randomly distributed. These consisted of three sets of the nine simulated rain-free events in experiment 1a, and the seven watering treatments in 1b.

The rainfall amount from wheat harvest (30 November) to spraying time (13 January) was 124 mm (Table 1). The weeds were under stress at various times as rainfall was insufficient to maintain active growth (Table 1). High air temperatures during January aided in maintaining stress (Table 2). The 28 mm of rain on 8 January temporarily revived the drought stressed volunteer wheat and awnless barnyard grass plants but by 12 January, one day after spraying in experiment 1, stress was reappearing on all plants that had not received supplementary watering.

On 12 January the awnless barnyard grass plants in the cylinder area were categorized as follows:

- Stage 1 – plants with less than 6 tillers and no seed heads.
- Stage 2 – plants with 6 to 15 tillers and 0 to 2 seed heads.
- Stage 3 – plants with 15 or more tillers and 3 or more seed heads.

The average height of 10 plants was:

- Stage 1 – 8.2 cm (range 5 to 11 cm)
- Stage 2 – 18.8 cm (range 10 to 22 cm)
- Stage 3 – 34 cm (range 10 to 43 cm)

The height and development stage of volunteer wheat were also recorded. Most of the wheat plants were 20 to 30 cm tall, in the boot stage and had no tillers. The awnless barnyard grass in stage 1 and 2 were under some stress but the leaves on plants in stage 3 were drooped and rolled. The volunteer wheat was bluish green and the leaves were rolled.

Experiment 1a. Effect of rainfall on the day of spraying glyphosate

Awnless barnyard grass and wheat plants within a 0.5 m^2 circular area were sprinkled with 3 mm of water from a sprinkler hose at 1 hour before, and 1, 2, 4, 6, 8, 10 and 22 hours after application of glyphosate. The hose with a shut-off valve was attached to a water container mounted on a vehicle. A pump was used to supply water pressure through a cone nozzle. A stop watch was used to determine the time it took to deliver the equivalent of 3 mm of rain to each 0.5 m^2 subplot. The water droplets tended to collect on the leaves and combined into large droplets. It took 38 minutes to water the subplots per watering time. The replications were watered in the same sequence.

Experiment 1b. Effect of rainfall on days before or after spraying glyphosate

Awnless barnyard grass and volunteer wheat plants were watered (80 mm) 6, 3, and 1 days before spraying glyphosate and at 1, 4, 7 and 11 days after spraying glyphosate. Three 0.5 m^2 metal cylinders (18 gauge) were hammered into the soil in each plot for each date over the designated plants to be watered. The cylinders were moved from one watering site to the next after the water had soaked into the soil. The control was the unwatered area in each plot.

Data from experiments 1a and 1b were collected from 10 days after spraying, when stage 1 weeds and wheat were dying, to 35 days after spraying when the final evaluations were made. A visual rating scheme was used for awnless barnyard grass control but these data are not presented. The number of living and dead plants were counted and recorded at 21 days for wheat and 32 to 35 days after spraying for awnless barnyard grass. These data better reflect actual control.

Experiment 2

A second wheat stubble field, sown to Kite in 1989, that was infested with liverseed grass, was sprayed with glyphosate on 13 and 14 January 1990. Liverseed grass was severely stressed and was grouped into the same stages as given for awnless barnyard grass in experiment 1.

The experimental design was three replications in a randomized complete block of 12 treatments which were the factorial combinations of four application times by three rates of glyphosate. In each plot which was 12 by 6 m, three 0.5 m^2 circular areas were selected and 40 mm of water applied to each subplot 3, 6, 10 and 13 days after the first plot was sprayed. The watering amount, compared to experiment 1, was halved because of a slower infiltration rate in this paddock.

Glyphosate at 450, 675 and 900 g ha^{-1} was applied at 0700, 1100 and 1500 hours on 13 January. The fourth spraying was delayed until 1500 hours on 14 January because of rain. In four showers between 1615 and 1830 hours on 13 January, 3 mm of rain was recorded at the site (independent of data in Table 1). The liverseed grass plants were showing drought stress by 1100 on 14 January. The temperature reached 30 to 32° C by 1500 on both days (Table 2). The number of living and dead plants in the three 0.5 m² subplots were recorded 40 to 45 days after spraying.

Weed control ratings were analysed using a generalized linear model (g.l.m.) with a gamma error distribution and an inverse link function. A g.l.m. with binomial errors and a logit link was used to analyse the percentage of weeds controlled which were calculated by the formula:

$$\% \; control = \frac{no.\ of\ dead\ plants}{no.\ of\ dead + living\ plants} \times 100$$

Rates of application, growth stage, rain-free period and their interactions were included in the model and non-significant terms were deleted by backwards elimination.

Results and discussion

Experiment 1a. Effect of rainfall on the day of spraying glyphosate

Control of volunteer wheat – Rates of glyphosate application and length of the rain-free period had significant effects ($P < 0.001$ and $P < 0.01$ respectively) on the control of volunteer wheat.

Volunteer wheat is highly susceptible to glyphosate and rates necessary for control are less than those required for awnless barnyard grass (Gammie and Dellow 1989). Rates of 675 and 900 g ha⁻¹ provided near 100% control in the rain-free study. Control with 225 g ha⁻¹ was decreased when simulated rain occurred following application, as more than 22 hours were required for control to reach 70% (Table 3). When the glyphosate rate was increased to 450 g ha⁻¹, the degree of control fluctuated over the various watering times (Table 3). Drought caused by lack of rainfall (Table 1) and high temperatures (Table 2) is suspected of contributing to reduced control.

Control of awnless barnyard grass – Percent control after 35 days (Table 4) was significantly affected by rates of glyphosate, rain-free period, growth stage, and the interaction of rate with stage ($P < 0.001$). Applying 3 mm of water at 1, 2, 4, 6, 8, 10 and 22 hours after glyphosate, applied at 225 g ha⁻¹, reduced control of awnless barnyard grass plants in stage 1 (Table 4). Increasing the amount of glyphosate reduced the rain-free period needed after application. Using 900 g ha⁻¹ reduced the rain-free period to 6 hours when spraying stage 1 plants (Table 4), but at least 22

Table 3. Effect of rainfree period on the control of volunteer wheat.

Hours[a]	Glyphosate rate, g a.i. ha⁻¹ 225 % Control	s.e.	450 % Control	s.e.
-1	32.0	2.3	98.7	0.6
1	14.4	2.2	93.2	1.3
2	11.4	1.6	88.2	1.9
4	49.5	2.5	91.0	1.7
6	59.3	2.4	95.5	1.0
8	15.9	1.8	97.0	0.9
10	47.5	2.5	88.7	1.6
22	39.0	2.4	98.2	0.7
Control[a]	69.8	2.3	100.0	0.0

[a] All plots received 3 mm of rainfall 45 hrs after spraying.

Table 4. The effect of simulated rainfall (3 mm) on glyphosate performance on three growth stages of awnless barnyard grass. Percent kill 35 days after spraying.

Hours[a]	Stage 1 % Control	s.e.	Stage 2 % Control	s.e.	Stage 3 % Control	s.e.
Glyphosate at 225 g ha⁻¹						
-1	51.2	2.5	16.8	1.6	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
4	10.6	1.7	2.4	0.5	0.0	0.0
6	19.1	2.3	1.4	0.3	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
10	3.3	1.2	0.2	0.1	0.0	0.0
22	34.6	2.6	2.6	0.5	0.0	0.0
45[b]	73.3	2.2	4.5	0.8	0.0	0.0
Glyphosate at 450 g ha⁻¹						
-1	73.6	1.8	47.8	2.0	5.9	0.8
1	23.1	1.8	8.1	1.0	0.0	0.0
2	14.8	1.7	7.4	1.0	0.3	0.1
4	50.3	2.3	28.7	1.8	4.2	0.6
6	60.2	2.1	16.0	1.5	0.3	0.1
8	35.2	2.1	9.0	1.1	0.6	0.1
10	77.0	1.8	25.8	1.8	2.2	0.4
22	74.5	2.2	22.3	1.7	3.2	0.5
45	97.7	0.5	53.2	2.1	19.8	1.6
Glyphosate at 675 g ha⁻¹						
-1	97.6	0.3	81.6	1.5	44.7	2.0
1	19.0	2.2	2.3	0.4	0.0	0.0
2	46.9	2.4	13.7	1.3	1.7	0.3
4	77.0	1.7	33.8	1.9	13.0	1.3
6	95.9	0.6	50.3	2.1	5.3	0.8
8	92.5	0.9	46.1	2.1	13.1	1.3
10	95.3	0.7	42.0	2.0	11.8	1.2
22	93.9	0.8	34.8	2.0	14.5	1.6
45	99.6	0.1	66.7	1.9	51.9	2.1
Glyphosate at 900 g ha⁻¹						
-1	92.1	0.9	60.6	1.7	39.4	1.8
1	63.8	2.1	19.0	1.7	0.0	0.0
2	70.6	1.9	33.5	2.0	12.3	1.5
4	83.5	1.6	46.0	2.2	37.2	2.2
6	97.2	0.4	62.0	2.1	18.4	1.7
8	90.3	1.1	42.6	2.0	23.4	1.8
10	94.4	0.7	40.6	2.0	23.0	1.7
22	97.8	0.3	61.2	2.0	54.1	2.1
45	99.5	0.1	64.8	1.9	69.3	1.9

[a] Hrs before or after spraying glyphosate that 3 mm of simulated rain was applied.
[b] These control areas only received natural rainfall. Rainfall occurred 45 hours after spraying.

hours were required when plants reached stage 2. Awnless barnyard grass plants in stages 2 and 3 were too large when sprayed and control was generally poor because of the stressed conditions.

Experiment 1b. Effect of rainfall before or after spraying glyphosate

Control of volunteer wheat – The rate of application of glyphosate and time of rainfall had significant effects on the control of volunteer wheat. ($P < 0.001$ and $P < 0.01$ respectively). When the rate of application was 450 g ha^{-1} or greater, 100% control was achieved.

Table 5. Influence of watering (80 mm) several days before and after spraying glyphosate at 225 g a.i. ha^{-1} for the control of volunteer wheat at Tamworth, N.S.W.

Days	% Control	s.e.
-6	80	2
-3	57	2
-1	60	2
1	75	2
4	76	2
7	31	2
11	47	2
Not watered	70	2

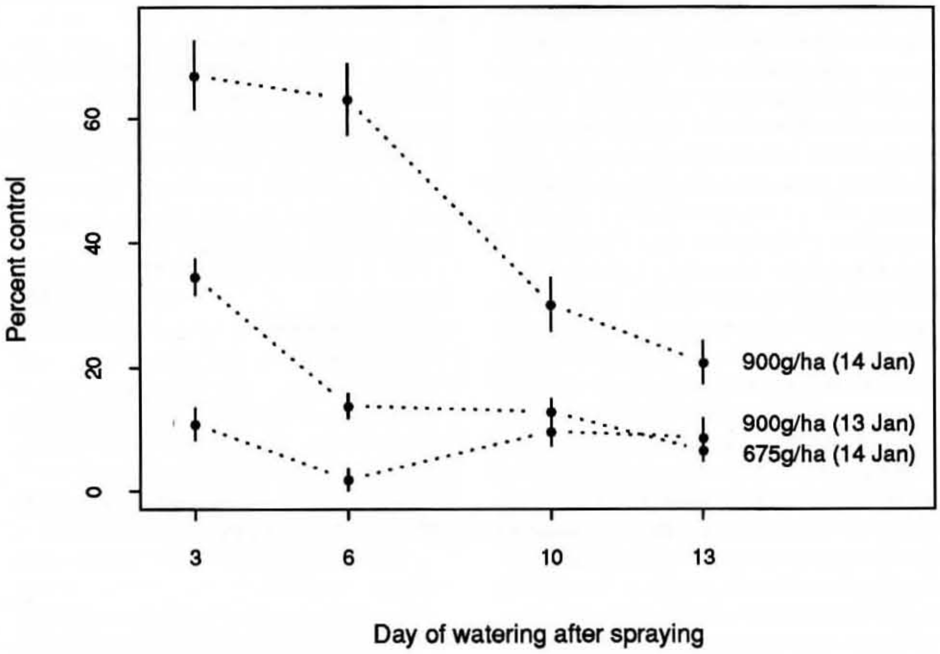

Figure 1. The influence of post-spraying watering and application time of glyphosate on the control of liverseed grass

Control varied with 225 g ha^{-1} from 31% to 80% depending on watering time (Table 5). When wheat received 80 mm of water 6 days before and 1 and 4 days after spraying the best control was achieved. Poorest control occurred when wheat was watered 7 and 11 days after glyphosate was applied.

Table 6. Effect of glyphosate, 32 to 35 days after application to three growth stages of awnless barnyard grass that received supplementary watering prior to, and after, herbicide application.

Rate g ha^{-1}	Day	Stage 1 % Control	s.e.	Stage 2 % Control	s.e.	Stage 3 % Control	s.e.
225	-6	76.9	2.0	55.8	2.2	2.9	0.7
	-3	87.7	1.8	23.3	2.0	0.4	0.1
	-1	62.5	2.4	22.0	1.8	0.3	0.1
	1	63.6	2.7	0.0	0.0	0.0	0.0
	4	75.4	2.4	19.2	1.8	0.1	0.0
	7	69.8	2.0	23.6	1.8	0.2	0.1
	11	77.2	1.8	17.2	1.6	0.2	0.1
450	-6	86.7	1.4	85.1	1.4	71.0	2.0
	-3	97.3	0.5	77.3	1.7	48.5	2.2
	-1	84.7	1.5	68.8	1.9	35.6	2.0
	1	100.0	0.0	80.7	1.8	42.5	2.2
	4	94.8	0.8	76.3	1.7	21.6	1.7
	7	76.0	1.8	50.0	2.1	11.3	1.2
	11	89.7	1.2	55.5	2.0	20.2	1.6
675	-6	95.8	0.7	91.2	1.1	86.8	1.4
	-3	99.3	0.2	87.4	1.3	73.8	1.9
	-1	95.9	0.7	82.7	1.5	64.0	2.0
	1	100.0	0.0	87.3	1.3	64.1	2.1
	4	99.2	0.2	91.7	1.0	58.1	2.2
	7	91.4	1.2	63.8	2.0	25.6	1.8
	11	95.9	0.7	63.6	2.0	34.9	2.0
900	-6	100.0	0.0	100.0	0.0	100.0	0.0
	-3	100.0	0.0	89.5	1.2	80.6	1.7
	-1	100.0	0.0	92.2	1.0	83.9	1.6
	1	100.0	0.0	91.5	1.1	77.0	2.1
	4	100.0	0.0	94.1	0.8	70.5	2.1
	7	100.0	0.0	90.5	1.1	68.8	2.0
	11	100.0	0.0	82.5	1.5	63.4	2.1

Control of awnless barnyard grass

The effects of rate of glyphosate, days of watering and growth stage on the control of awnless barnyard grass were highly significant ($P < 0.001$). Weed control improved as the rate of glyphosate increased (Table 6). Glyphosate was more effective when applied to plants in stage 1 than stages 2 or 3. Control was greater when plants were watered 6 and 3 day before spraying, than when watering occurred 4 or more days after. Ahmadi *et al.* (1980) reported that glyphosate was less effective on barnyard grass when soil water was below field capacity.

The 225 g ha^{-1} treatment was ineffective regardless of stage (Table 6), while control with glyphosate at 450 g ha^{-1} on stage 1 plants was only reduced when watering occurred 1 day before or was delayed until 4 or more days after spraying. Increasing glyphosate rate to 675 or 900 resulted in more effective control of stage 1 plants through the 18-day watering schedule. Awnless barnyard grass was more difficult to control as the plants became larger. Increasing glyphosate rate improved control of stage 2 plants when they were watered 3 to 6 days before and 1 day after spraying. Stage 3 plants needed to have water applied 3 or 6 days before glyphosate application for effective control to be obtained, even at 900 g ha^{-1}. The effectiveness of glyphosate is improved if rainfall occurs 3 to 6 days before application during a period of drought stress. If rain occurs after 4 days following application, control diminishes.

Awnless barnyard grass seeds germinate and seedlings emerge over a wide calendar range. Wheat density influences the development of weed growth. Under dense populations of wheat, awnless barnyard grass tiller formation is less than with thin wheat stands. Although sheep were used to graze weeds, there were still differences in growth stages of plants.

Experiment 2

Control of liverseed grass was significantly influenced by rate of glyphosate ($P < 0.001$), day of watering ($P < 0.001$), growth stage ($P < 0.01$), and time of spraying ($P < 0.001$). There were also significant interactions of rate with day of watering ($P < 0.05$) and rate with time of spraying ($P < 0.001$). Liverseed grass control followed similar trends to awnless barnyard grass in that watering 3 days after glyphosate was applied, resulted in better control than when watered 6, 10 or 13 days after spraying (Figure 1). Dall' Armellina and Zimdahl (1989) found that drought effects could be overcome by increasing glyphosate rates to control field bindweed. In the liverseed grass experiment, 900 g ha^{-1} of glyphosate provided only 70% control (mean of all growth stages) when watered 3 days after spraying. Control was affected by 3 mm rainfall, since plants sprayed on 14 January after rain the previous afternoon, were controlled better than those sprayed at 0700, 1100 and 1500 hours on 13 January. There was no difference in control between the three spraying times on the 13 January and the data in Figure 1 for the 13 January is the means of the 0700, 1100 and 1500 hours times of spraying. Dust may have been washed off unsprayed plants or glyphosate required a longer rainfast period.

In both experiments, the awnless barnyard grass and liverseed grass were regrowing from the base of the plants. New growth was occurring after 28 days from nodes at the base of the plants. If rainfall had occurred earlier, the regrowth would have been larger.

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