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Glyphosate Application Timing and Rate for Annual Ryegrass (*Lolium multiflorum*) Cover Crop Desiccation

Ryan D. Lins, Charles M. Cole, Richard P. Affeldt, Jed B. Colquhoun, Carol A. Mallory-Smith, Ronald A. Hines, Larry Steckel, and Robert M. Hayes*

Annual ryegrass has been proposed as a cover crop in the corn–soybean cropping systems of the U.S. Midwest because of its low seed cost, rapid establishment, contribution to soil quality, weed suppressive abilities, and susceptibility to common broad-spectrum herbicides. However, cover crops can reduce the subsequent main crop yield by creating unfavorable germination and emergence conditions, harboring pests, and if not controlled, competing with the main crop. This study, conducted in Illinois, Oregon, and Tennessee, investigated the efficacy of glyphosate for annual ryegrass winter cover crop removal. Glyphosate at 415, 830, and 1,660 g ae/ha was applied to annual ryegrass at late tiller, second node, boot, and early flowering stages. Annual ryegrass control was consistently maximized with the highest glyphosate rate applied at the boot or early flower stage. Annual ryegrass biomass was generally the lowest with the highest rate of glyphosate applied at the earlier stages. Overall, no single application timing at any glyphosate rate provided complete control or biomass reduction of the annual ryegrass cover crop. A sequential herbicide program or a glyphosate plus a graminicide tank-mix probably will be needed for adequate annual ryegrass stand removal.

Nomenclature: Glyphosate; annual ryegrass *Lolium multiflorum* L. LOLMU; corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.

Key words: Cover crop removal, sustainable agriculture.

Cover crops can reduce soil erosion and nitrate leaching, increase soil organic matter, preserve soil water, and suppress weed growth between row crop production seasons (Altieri and Liebman 1988; Ruffo et al. 2004; Sainju and Singh 1997; Shipley et al. 1992). When grown following low residue crops, such as soybean, the beneficial properties of cover crops can become especially important (Laflen and Moldenhauer 1979). However, as a result of variable yield responses following cover crops (Eckert 1988; Hively and Cox 2001, Williams et al. 2000) and reduced net profitability (Reddy 2001, 2003), broad adoption of cover crops into the traditional corn and soybean systems of the U.S. Midwest has not occurred.

Many crop species, such as annual ryegrass, barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), hairy vetch (*Vicia villosa* Roth.), and various clovers (*Trifolium* spp.) have been identified for their utility as cover crops (Johnson et al. 1998; Kuo et al. 1997; Teasdale and Mohler 1993; Weston 1990). Some of these cover crops suppress weeds with allelopathic compounds (White et al. 1989), establish quickly, produce or scavenge residual nitrogen (Strock et al. 2004), and can be easily controlled or suppressed prior to main-crop planting. Annual ryegrass, although not reported to be strongly allelopathic (Smith and Martin 1994), has several advantages over other cover crops in a corn–soybean rotation (Johnson et al. 1996). Advantages of annual ryegrass relative to other cover crops include low seed cost, partial recovery of residual nitrogen, rapid establishment, cold tolerance, disease tolerance, weed suppression, and susceptibility to burn-down herbicides such as glyphosate and paraquat (Reddy 2001; Shipley et al. 1992; Weston 1990).

However, annual ryegrass has been reported to reduce crop yield both as a cover crop and as a weed. In studies by Vyn et al. (1999) and Reddy (2001), corn and soybean yield following an annual ryegrass cover crop was reduced by as much as 18 and 29%, respectively, compared to where no cover crop had been grown. Additionally, annual ryegrass, called Italian ryegrass when growing as a weed, can become a severe weed problem if not controlled within the main crop. For example, Italian ryegrass competition with wheat can reduce grain yield by 92% or more when compared to weed-free wheat (Appleby et al. 1976, Hashem et al. 1998). Therefore, if annual ryegrass is to be successfully utilized as a cover crop, it is critical to eliminate the main crop yield loss that has been reported. Main crop yield reduction can be minimized by annual ryegrass stand removal at the optimum timing.

Although a few studies have reported annual ryegrass cover crop removal with herbicides prior to main crop planting (Reddy 2001; Vyn et al. 1999; Weston 1990), limited information exists on the effect of herbicide application timing and rate on annual ryegrass cover crop control. Glyphosate is the most commonly used herbicide to remove a cover crop. Therefore, the objective of this research was to evaluate the effect of glyphosate application timing and rate on annual ryegrass cover crop desiccation and seed viability in both U.S. western and midwestern environments.

Materials and Methods

Field experiments were initiated in 2001 and repeated in 2003 near Simpson, IL, Corvallis, OR, and Jackson, TN on

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Table 1. Annual ryegrass planting, glyphosate application, and sampling dates for experiments near Simpson, IL, Corvallis, OR, and Jackson, TN.

	Illinois		Oregon		Tennessee	
	2002	2004	2002	2004	2002	2004
Planting date[a]	September 13	September 30	September 19	September 25	October 5	October 13
Annual ryegrass growth stage at glyphosate application						
Late tiller	February 22	March 2	February 13	February 4	February 11	February 18
Second node	April 10	March 29	April 12	March 3	March 11	March 25
Boot	April 23	April 19	April 23	April 27	April 22	April 16
Early flower	May 10	May 5	May 1	May 19	April 29	April 29
Sampling date	May 23	May 25	May 23	June 11	May 21	May 19

[a] 2002 and 2004 experiments were planted in 2001 and 2003, respectively.

a Grantsburg silt loam (fine-silty, mixed, active, mesic Oxyaquic Fragiudalf), Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll), and Loring-Calloway silt loam (fine-silty, mixed, thermic, Typic Fragiudalf), respectively. Fields were plowed, disked, and harrowed in autumn and a custom-mixed blend of several common annual ryegrass cultivars was sown at a rate of 33.6 kg/ha (Table 1). Three rates of glyphosate, 415, 830, and 1,660 g ae/ha, were applied at each of four annual ryegrass growth stages: late tiller, second node, boot, and early flower (Table 1). Spray volume for all applications was 94 L/ha. A nontreated check was included for visual reference, but not included in the analyses.

Treatments were arranged in a randomized complete block design with four replications. Plot size was 3 m by 4.6 m. Annual ryegrass control and biomass were evaluated 10 to 25 d after the final glyphosate application (Table 1). Annual ryegrass control was estimated visually on a scale of 0 (no control) to 100 (complete desiccation). A 1-m^2 sample was cut at ground level from each plot, dried at 70 C for 72 h, and weighed. Biomass sampling was performed at 10 to 25 d after the last herbicide application and approximately 120 d after the first application, depending on location.

Annual ryegrass control and biomass data were analyzed as a factorial with ANOVA using the Proc GLM procedure in SAS (SAS 2000) and the nontreated check excluded from the analyses. Data for years within each location were tested for combined analysis (McIntosh 1983) and presented for individual site-years if significant interactions ($P < 0.05$) existed. Treatment means were separated by Fisher's protected least significant difference test at the $P < 0.05$ level of significance.

Results and Discussion

Annual ryegrass control generally increased with increasing glyphosate rate, regardless of growth stage at the time of application (Table 2). However, control was variable between years and data could not be combined for any location. In both years, control at the Illinois location increased in all but one instance with increasing glyphosate rate regardless of ryegrass stage at application. Annual ryegrass control was maximized with 1,660 g/ha glyphosate applied to second node ryegrass in 2002 (79%) and early flower ryegrass in 2002 (75%) and 2004 (88%). In 2002 in Oregon, control was maximized with late tiller application of glyphosate at 830 (91%) or 1,660 (96%) g/ha and boot stage application at 1,660 g/ha (94%). Other treatments resulted in no greater than 75% control. In 2004, second node application at 1,660 g/ha (96%) and all rates of glyphosate applied at the boot and early flower stages (94 to 99%) maximized control while all other treatments controlled ryegrass no greater than 83%. At Tennessee in 2002, annual ryegrass control was equivalent and greater than 85% with glyphosate applied at 830 g/ha at the late tiller stage and at 1,660 g/ha at the late tiller, boot, or early flower stage. Control was no greater than 73% with other treatments. In 2004, control with glyphosate at 1,660 g/ha applied to second node, boot, or early flower ryegrass ranged from 97 to 99% and was greater than all other treatments (33 to 84%). Variability in biomass data between years at each location again prohibited combined analysis. In general, annual ryegrass biomass was lowest when glyphosate was applied at the highest rate and earlier stages of development (Table 3).

Our study demonstrates that no timing or rate of glyphosate was effective for complete control or removal of

Table 2. Annual ryegrass control as influenced by glyphosate rate and application timing in 2002 and 2004.

Glyphosate treatment	Rate	Annual ryegrass control[a] Illinois 2002	Illinois 2004	Oregon 2002	Oregon 2004	Tennessee 2002	Tennessee 2004
Timing	g ae/ha	%					
Late tiller	415	6	13	65	56	69	33
	830	11	40	91	69	85	59
	1,660	29	73	96	79	90	80
Second node	415	13	15	29	76	13	30
	830	45	23	40	83	14	71
	1,660	79	38	60	96	24	97
Boot	415	24	23	39	95	44	33
	830	58	33	65	95	64	84
	1,660	70	70	94	97	89	97
Early flower	415	38	53	68	94	50	45
	830	63	80	75	99	73	82
	1,660	75	88	75	99	90	99
LSD (0.05)		6	8	8	15	8	12

[a] Annual ryegrass control visually estimated prior to biomass sampling 10 to 25 d after early flower application. A custom blend of several common annual ryegrass cultivars was sown at 33.6 kg/ha in 2001 and 2003.

Table 3. Annual ryegrass biomass as influenced by glyphosate rate and application timing in 2002 and 2004.

Glyphosate treatment	Rate	Annual ryegrass biomass[a] Illinois 2002	Illinois 2004	Oregon 2002	Oregon 2004	Tennessee 2002	Tennessee 2004
Timing	g ae/ha	g/m^2					
Nontreated check[b]	0	3,445	3,216	1,060	702	942	536
Late tiller	415	2,616	1,463	271	91	346	91
	830	2,885	291	207	7	180	38
	1,660	2,029	115	171	1	153	8
Second node	415	1,270	1,788	411	604	514	193
	830	1,044	1,045	174	595	120	184
	1,660	164	133	68	297	3	177
Boot	415	1,693	1,920	528	582	416	190
	830	1,362	1,487	389	528	89	257
	1,660	724	1,126	372	405	44	251
Early flower	415	2,120	2,421	735	568	580	206
	830	1,771	2,623	797	605	346	238
	1,660	1,668	2,403	613	599	341	290
LSD (0.05)		NS	425	NS	109	64	40

[a] Annual ryegrass biomass sampling conducted at physiological maturity. A custom blend of several common annual ryegrass cultivars was sown at 33.6 kg/ha in 2001 and 2003.

[b] Nontreated check excluded from factorial analyses.

an annual ryegrass cover crop. There is some evidence that glyphosate efficacy is lower for certain annual ryegrass cultivars (unpublished data). Differential response of these cultivars was mainly because of morphological differences, so cultivars within the seed blend used for this study may have been at different stages than the rest of the stand and were injured but recovered. There also may have been later emergence in some of the earlier treatments.

While no treatment was 100% effective in eliminating the annual ryegrass cover crop, glyphosate at 1,660 g ae/ha consistently maximized control of the annual ryegrass stand when applied at the boot or early flower stage. Biomass data from this study suggests that reduction is greatest with the highest glyphosate rate applied at the earlier stages of development. Integration of sequential herbicide applications or a graminicide tank-mix with glyphosate into an herbicide program could provide the tools necessary for complete annual ryegrass cover crop removal. These types of applications could allow annual ryegrass to be more successfully utilized as a cover crop in the Midwest. Hoskins et al. (2005) reported that mid- to late-March applications of the acetyl-CoA carboxylase inhibiting herbicides diclofop, clodinafop, and tralkoxydim in southern Illinois controlled and reduced Italian ryegrass seedhead density at levels of 91% or greater relative to nontreated plots. More research is needed to establish the effectiveness of sequential and tank-mix programs for removing annual ryegrass winter cover crops.

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