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Weed Management with Reduced Rates of Glyphosate in No-Till, Narrow-Row, Glyphosate-Resistant Soybean (*Glycine max*)[1]

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Abstract: Field studies were conducted at two locations in 1997 and 1998 to evaluate crop injury, weed control, yield, and net economic returns of single and sequential postemergence applications of labeled and reduced rates of glyphosate to no-till, glyphosate-resistant soybean planted in narrow rows. Sequential applications provided at least 91% control of giant foxtail, while single applications provided at least 86% control with labeled rates and 68–93% control with reduced rates. Common waterhemp control was slightly higher with sequential vs. single treatments and with labeled rates vs. reduced rates. Velvetleaf control was greater than 96% with all treatments. Common cocklebur control was 90% or higher with all treatments except a single application of glyphosate at 210 g/ha. Lower control of giant foxtail and common waterhemp with single-application, reduced-rate treatments in two of the four trials resulted in lower yields. Overall, sequential applications, regardless of rate, provided greater weed control, yield, and net income and lower coefficients of variation (C.V.s) of net income than reduced-rate single applications. Single-application treatments showed a trend of decreased weed control, yield, and net income and higher C.V.s of net income with reduced rates of glyphosate.

Nomenclature: Glyphosate, *N*-(phosphonomethyl)glycine; giant foxtail, *Setaria faberi* L. #[3] SETFA; common cocklebur, *Xanthium strumarium* L. # XANST; common waterhemp, *Amaranthus rudis* Sauer # AMATA; velvetleaf, *Abutilon theophrasti* Medik., # ABUTH; soybean, *Glycine max* (L.) Merr. 'Pioneer 9363RR.'

Additional index words: Economic returns, soybean yield, ABUTH, AMATA, SETFA, XANST.

Abbreviations: C.V., coefficient of variation; EPOST, early postemergence; EPP, early preplant; fb, followed by; MPOST, midpostemergence; SD, standard deviation.

INTRODUCTION

No-till soybean production has increased in recent years to the extent that almost 50% of the soybean hectares planted in Missouri are planted no-till (CTIC 1996). As no-till systems have been adopted, the average row width of soybean planted in Missouri has decreased. In 1989, 24% of the soybean hectares planted in Missouri were in rows of 25 cm or less, whereas in 1997, that number had risen to 48% (USDA 1997). A contributing factor to this trend is research that has shown that soybean grown in narrow rows will close the canopy more quickly, suppress weeds by shading the soil more rapidly, and provide more uniform soybean root distribution (Burnside 1979; Carey and DeFelice 1991). The combination of reduced tillage and narrow rows, along with predictions that over 70% of the soybean hectares planted in the future will be glyphosate resistant, requires that information be generated regarding the appropriate use of glyphosate in these production systems.

Several studies have shown that reduced rates of herbicides can provide adequate weed control, soybean yield, and net returns in both conventional and no-till production systems (DeFelice et al. 1989; Devlin et al. 1991; Johnson et al. 1997, 1998; Prostko and Meade 1993). These studies included evaluations of soil-applied and postemergence herbicides other than glyphosate.

The efficacy of glyphosate on some annual weeds in conventional-till systems has been documented. In studies without the utilization of a crop, acceptable control of giant foxtail, fall panicum (*Panicum dichotomiflorum* Michx.), and redroot pigweed (*Amaranthus retroflexus* L.) was attained with glyphosate applied early postemergence (EPOST) or midpostemergence (MPOST)

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Table 1. Planting, spray application, and harvest dates in no-till, narrow-row, glyphosate-resistant soybean at Columbia and Novelty, MO, in 1997 and 1998.

	Columbia		Novelty	
Operation[a]	1997	1998	1997	1998
EPP	April 28	May 4	May 1	May 5
Planting	May 7	May 11	May 23	May 15
EPOST	June 17	May 26	June 20	June 10
MPOST	June 23	May 29	June 26	June 25
Regrowth on EPOST	June 30	June 19, 23	July 2	July 1, 8
Regrowth on MPOST	July 7	June 24	July 21	July 14
Harvest	October 17	October 14	October 3	September 28

[a] Abbreviations: EPOST, early postemergence application to weeds not more than 5 cm tall; MPOST, midpostemergence application to 5- to 10-cm-tall weeds; regrowth on EPOST, application to regrowth of weeds not more than 7.6 cm tall following the EPOST treatment; regrowth on MPOST, application to regrowth of weeds not more than 7.6 cm tall following the MPOST treatment.

Table 2. Average air temperature and precipitation May–October at Columbia and Novelty, MO, in 1997 and 1998.

	Temperature				Precipitation			
	Columbia		Novelty		Columbia		Novelty	
Month	1997	1998	1997	1998	1997	1998	1997	1998
	C				cm			
May	15	21	14	20	14	2	14	16
June	22	23	22	23	15	14	7	20
July	25	25	25	25	2	13	7	14
Aug.	24	25	23	24	10	3	7	3
Sept.	20	23	20	22	7	14	6	10
Oct.	14	15	13	13	6	14	9	24
Mean	20	22	20	21	—	—	—	—
Total	—	—	—	—	54	60	50	87

(Jordan et al. 1997; Krausz et al. 1996). In these same studies, marginal control of pitted [*Ipomoea lacunosa* (L.) Jacq.] and entireleaf morningglory (*Ipomoea hederacea* L.), velvetleaf, and prickly sida (*Sida spinosa* L.) was reported when applications were made MPOST vs. EPOST timing. However, effective herbicide programs combined with a competitive crop canopy are needed to provide the necessary weed-free interval to achieve full yield potential (Burnside and Colville 1964; Johnson et al. 1997, 1998; Wax et al. 1977), especially if herbicides without soil residual activity are utilized. Published research is lacking on the utilization of glyphosate in no-till, narrow-row, glyphosate-resistant soybean. With the low commodity prices experienced in the late 1990s and increased interest in no-till, narrow-row soybean production, research that investigates the use of glyphosate alone at full and reduced rates in no-till, narrow-row, glyphosate-resistant soybean will be useful in formulating weed management strategies.

The objective of this research was to investigate soybean injury, weed control, yield, and net economic returns of labeled and reduced rates of glyphosate in no-till, narrow-row, glyphosate-resistant soybean.

MATERIALS AND METHODS

Field experiments were conducted in 1997 and 1998 near Columbia and Novelty, MO. Soil type for the Columbia site located in central Missouri was a Mexico silt loam (fine, montmorillonitic, mesic, Udollic Ochraqualfs) with pH 6.8, soil organic matter content of 2.7%, and soil textural fractions of 7% sand, 73% silt, and 19% clay. Soil type for the Novelty location in northern Missouri was also a Mexico silt loam (fine, montmorillonitic, mesic, Udollic Ochraqualfs) with pH 6.8, soil organic matter of 2.7%, and soil textural fractions of 5% sand, 74% silt, and 19% clay.

The experimental design at each location was a randomized complete block with four replications. Plot size was 3 m wide and 10.7 m long. An early preplant (EPP) treatment of glyphosate at 840 g ae/ha was applied over the entire experimental area approximately 10–20 d before planting to control existing vegetation. 'Pioneer 9363RR' soybean was planted no-till into field corn (*Zea mays* L.) residue from the previous year (Table 1). No-till drills were used to plant the soybean in 20-cm row spacings at Columbia and 19-cm row spacings at Novelty. Soybean was seeded 2.5–4.0 cm deep at a rate of approximately 95 kg/ha. Weather data for the locations are shown in Table 2.

All postemergence applications were made with CO_2-pressurized backpack sprayers equipped with XR8003VS[4] extended-range flat-fan nozzles, with a spray pressure between 117 and 172 kPa and a spray volume of 187 L/ha. The reduced-rate treatments were initially applied EPOST to weeds no more than 5 cm tall and included glyphosate at 420, 420 followed by (fb) 210, 210, and 210 fb 105 g ae/ha. The labeled-rate treatments were initially applied MPOST to 5- to 10-cm-tall weeds and included glyphosate at 840, 840 fb 420, 630, and 630 fb 420 g ae/ha. All sequential treatments were applied when regrowth/reinfestation of weeds was approximately 7.6 cm. All treatments contained ammonium sulfate at 3.8 kg/ha.

Visual estimates of soybean injury and weed control were recorded approximately 5 wk after the final postemergence treatment. Crop injury and weed control are expressed on a 0 (no effect) to 100% (complete plant death) scale. Soybean grain yield was determined by har-

[4] TeeJet XR8003 VS Spraying Systems Co., North Avenue, Wheaton, IL 60189.

vesting the center 1.5 m of the plot with a plot combine and adjusting final yield to 13% moisture. All data were subjected to ANOVA, tested for homogeneity, and pooled over nonsignificant interactions. Means were separated with Fisher's Protected LSD test at P = 0.05.

Economic Analysis. Gross income was calculated by multiplying soybean yield in kilograms per hectare harvested by $0.24/kg, the 5-yr average soybean price in Missouri. Production expenses included the cost of glyphosate, ammonium sulfate, the custom herbicide application fee, and the seed technology fee. The prices for glyphosate ($7.92/L), ammonium sulfate ($0.46/kg), and the custom application fee ($11.12) were based on a survey of dealer prices in December 1998. The soybean seed technology fee used was $24.09/ha. The cost for herbicide, ammonium sulfate, and custom application for the EPP burndown application was included in the production cost of all treatments. The production costs for the single-application treatments were $97.67, $91.65, $85.63, and $79.61/ha for the 840, 630, 420, and 210 g ae/ha treatments, respectively. The production costs for the sequential application treatments were $128.44, $116.40, $103.37, and $95.34/ha for the 840 fb 420, 630 fb 420 fb 210, and 210 fb 105 g ae/ha treatments, respectively. The production cost for the nontreated check was $60.87/ha. Net income was determined by subtracting estimated production costs from gross income for each treatment in each location. Net income and C.V. of net income were calculated for all treatments to quantify the relative income and risk associated with each treatment. As C.V.s increase, variability in net income increases, and thus, implied risk associated with a particular treatment is greater. The treatments are shown ranked in order of decreasing net income in Figure 1.

RESULTS AND DISCUSSION

Glyphosate did not injure soybean regardless of application rate or timing (data not shown). Giant foxtail control showed a significant year by location interaction. Giant foxtail was controlled greater than 90% when glyphosate was applied sequentially (Table 3). Slightly greater variation in giant foxtail control was associated with single vs. sequential treatments. Single treatments at labeled rates provided at least 86% control, while single treatments at reduced rates controlled giant foxtail 68–93%. Since the reduced-rate treatments were applied earlier in the growing season than the labeled-rate treatments, the lower control with these early treatments was due to reinfestation. For the reduced-rate treatments, single applications controlled giant foxtail less effectively than sequential treatments in seven of eight comparisons. When applied at manufacturers' suggested rates, single applications were less effective than sequential treatments in only two out of eight comparisons. This indicates that with single treatments, labeled rates provided better control overall than reduced rates. Sequential treatments, however, provided equivalent control of giant foxtail regardless of rate.

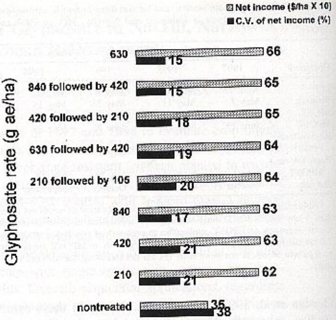

Figure 1. Net income and C.V. of net income in no-till, narrow-row, glyphosate-resistant soybean treated with single and sequential applications of glyphosate at Columbia and Novelty, MO, in 1997 and 1998.

Common waterhemp control also showed a significant year by location interaction. With all sequential treatments, common waterhemp was controlled at least 95%, with the exception of the 210 fb 105 g/ha treatment at Novelty in 1998 (76% control) (Table 3). Single-application treatments provided equal levels of common waterhemp control at Columbia in 1997 and 1998 and at Novelty in 1997, ranging from 85 to 99%. However, in 1998 at Novelty, both reduced-rate single treatments provided no more than 76% control. Excessive rain and wet soil conditions at this location reduced soybean stand, resulting in delayed canopy closure and allowing additional emergence of common waterhemp after the reduced-rate treatments were applied. This most likely contributed to poor control by glyphosate at reduced rates. Overall, single treatments of labeled rates and all sequential treatments, regardless of rate, provided greater than 85% control. Results emphasize the importance of canopy closure and crop competition in managing a

Table 3. Weed control at 5 wk after treatment in no-till, narrow-row, glyphosate-resistant soybean at Columbia and Novelty, MO, in 1997 and 1998.

			Giant foxtail				Common waterhemp					
			Columbia		Novelty		Columbia		Novelty			
Herbicide[a,b]	Rate	Timing[c]	1997	1998	1997	1998	1997	1998	1997	1998	Velvet-leaf[d]	Common cockle-bur[e]
	g ae/ha		%									
Glyphosate	840	MPOST	98	95	86	99	91	88	93	97	98	93
Glyphosate fb glyphosate	840 420	MPOST 7.6-cm regrowth	99	100	99	99	99	100	99	99	99	99
Glyphosate	630	MPOST	99	91	92	98	98	91	99	94	99	93
Glyphosate fb glyphosate	630 420	MPOST 7.6-cm regrowth	99	100	99	99	99	100	97	99	99	99
Glyphosate	420	EPOST	83	93	78	68	85	93	94	76	98	90
Glyphosate fb glyphosate	420 210	EPOST 7.6-cm regrowth	99	99	91	99	96	99	99	99	99	99
Glyphosate	210	EPOST	84	88	83	75	89	90	90	56	97	86
Glyphosate fb glyphosate	210 105	EPOST 7.6-cm regrowth	96	100	97	96	95	100	99	76	98	96
LSD (0.05)			7				12				NS	12

[a] All treatments received an EPP application of glyphosate at 840 g ae/ha. NS, not significant.

[b] All treatments included 3.8 kg/ha of ammonium sulfate.

[c] EPOST, early postemergence application to weeds not more than 5 cm tall; MPOST, midpostemergence application to 5- to 10-cm-tall weeds; 7.6-cm regrowth, application to weeds not more than 7.6 cm tall following the EPOST or MPOST treatment.

[d] Velvetleaf control at Columbia in 1998 and Novelty in 1997 and 1998.

[e] Common cocklebur control at Columbia and Novelty in 1997 and 1998.

weed such as common waterhemp, which has the ability to emerge throughout the growing season.

Velvetleaf and common cocklebur control data showed no significant year by location interactions. Velvetleaf and some annual grasses have been reported to be difficult to control with glyphosate when weeds are large and weather conditions dry at application time (Buhler and Burnside 1983; Jordan et al. 1997; Krausz et al. 1996). In our research, velvetleaf plants were small (< 7.6 cm) and actively growing when glyphosate was applied, and control was greater than 95% (Table 3). Common cocklebur control was at least 90% with all treatments, except with a single application of 210 g/ha (86% control). Sequential treatments provided slightly greater control than single treatments, although differences were not always statistically significant.

Soybean yields showed a significant year by location interaction. Yields for all herbicide treatments were greater than the nontreated control (Table 4). In 1998 at Columbia and in 1997 at Novelty, no significant differences in yield were noted among any herbicide treatments. At Columbia in 1997, single applications of reduced rates of glyphosate and in 1998 at Novelty a single application of 210 g/ha glyphosate yielded less than the other glyphosate treatments. These treatments also provided the lowest control of giant foxtail and common waterhemp in these specific trials. Soybean yields at Columbia in 1997 and at Novelty in 1998 were slightly lower than the other site years. Soybean germination and stands were adversely affected by cool, wet growing conditions and phytophthera (*Phytophthera sojae*) disease (L. Sweets, personal communication) at these two sites. The reduced stands provided less soybean leaf canopy and subsequently allowed giant foxtail and common waterhemp to germinate more readily and compete with the soybean crop, resulting in reduced weed control and soybean yield.

As a result of slightly better weed control, yields tended to be higher with the sequential applications than with single applications, although the differences were not always statistically significant (Table 4). Yield means over all site years for both single and sequential applications tended to decrease as herbicide rate decreased. The standard deviation (SD) of yield tended to be lower with single applications of labeled rates of glyphosate when compared with single applications of reduced rates. This would indicate more variation in yield with reduced rates than with labeled rates. The sequential treatments had SDs that were similar, regardless of rate, implying less variability in yield vs. single-application treatments.

The treatments were ranked by net income, and C.V.s of net income were calculated to determine the amount of variation within treatments in an attempt to evaluate potential risk associated with each treatment (Figure 1). Although differences in both net income and C.V. of net income were small, several trends were noted. First, as

Table 4. Soybean yield in no-till, narrow-row, glyphosate-resistant soybean at Columbia and Novelty, MO, in 1997 and 1998.

Herbicide[a,b]	Rate	Timing[c]	Soybean yield: Columbia 1997	Columbia 1998	Novelty 1997	Novelty 1998	Overall Mean[d]	SD[e]
	g ae/ha		kg/ha					
Glyphosate	840	MPOST	2,540	3,353	3,212	3,031	3,034	355
Glyphosate fb glyphosate	840 420	MPOST 7.6-cm growth	2,755	3,669	3,460	3,158	3,260	397
Glyphosate	630	MPOST	2,601	3,306	3,541	3,071	3,130	401
Glyphosate fb glyphosate	630 420	MPOST 7.7-cm regrowth	2,439	3,642	3,340	3,158	3,144	511
Glyphosate	420	EPOST	2,271	3,501	3,259	2,802	2,958	542
Glyphosate fb glyphosate	420 210	EPOST 7.6-cm regrowth	2,574	3,609	3,400	3,037	3,155	454
Glyphosate	210	EPOST	2,352	3,447	3,259	2,607	2,916	520
Glyphosate fb glyphosate	210 105	EPOST 7.6-cm regrowth	2,419	3,541	3,313	2,937	3,052	490
Untreated	—	—	1,344	2,305	1,849	1,310	1,702	471
LSD (0.05)				399			—	—

[a] All treatments received an EPP application of glyphosate at 840 g ae/ha.

[b] All treatments included 3.8 kg/ha ammonium sulfate.

[c] Abbreviations: EPOST, early postemergence application to weeds not more than 5 cm tall; MPOST, midpostemergence application to 5- to 10-cm-tall weeds; 7.6-cm regrowth, application to 7.6-cm-tall regrowth of weeds following the EPOST or MPOST treatment.

[d] Mean of soybean yield for both years and locations.

[e] Standard deviation of yield for both years and locations.

net income decreased, C.V. of net income tended to increase. Second, sequential applications of glyphosate tended to have higher net income and lower C.V.s of net income than single applications. Finally, as herbicide rates decreased, net income decreased, and C.V. of net income increased, similar to that observed for johnsongrass [*Sorghum halepense* (L.) Pers.] control in soybean (Johnson et al. 1991). Higher C.V. values are associated with greater variability in soybean yield due to variations in weed control. There were no statistical differences in yield between the sequential applications and the single applications of labeled rates. However, because the C.V. of net income increased as herbicide rate decreased, this would indicate that greater variability in net income and greater potential risk for the producer would be a concern of the reduced-rate treatments. The single-application, reduced-rate treatments did have lower yields in two of the four trials due to reduced control of giant foxtail and common waterhemp. These treatments also had the highest C.V.s of net income and the lowest net income, indicating increased risk to the producer. This implies that sequential applications, regardless of rate, would provide less variation in weed control, yield, and net profit compared to the reduced-rate single applications.

Results from this research suggest that reduced rates of glyphosate applied sequentially to young, actively growing weeds can provide acceptable weed control and soybean yield with favorable net income. Single applications of reduced rates generally provided slightly lower weed control and net income. Differences in C.V.s of net income were small compared to other economic studies with a similar net income analysis (Johnson et al. 1997, 1998). This indicates that weed control and soybean yield were very similar with all treatments in this study and that they were arguably better than reduced rates of other soybean herbicides. Another advantage to a reduced-rate program with glyphosate in glyphosate-resistant soybean is flexibility to control a broad spectrum of weeds at a relatively low price for glyphosate. If weed control is not adequate with the initial reduced-rate application, a second application of glyphosate can be made rather inexpensively.

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