RESEARCH

Glyphosate effects on ground cover of tall fescue waterways and estimated soil erosion

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ABSTRACT: Glyphosate use for controlling weeds has increased in the Midwest, but drift or overspraying can damage tall fescue waterways. Farmers and conservation agents fear that glyphosate may reduce tall fescue ground cover in waterways and increase soil erosion. Glyphosate was applied in mid-May to tall fescue waterways at several rates from 0.14 to 2.24 kg ai/ha[1] + ammonium sulfate (2% by volume) to simulate drift or direct overspraying. Percentage cover of live and dead tall fescue, broadleaf weeds, and bare soil was measured after treatment at two sites in Missouri, and annual erosion was estimated using revised universal soil loss equation (RUSLE) software. Total (live + dead) tall fescue ground cover remained greater than 88% even at 10 to 11 months after treatment. Enough live tall fescue remained to grow into gaps. Glyphosate drifts at low rates or single accidental incidents of overspraying glyphosate up to 2.24 kg ai/ha are unlikely to permanently damage tall fescue waterways.

Keywords: Erosion, glyphosate, grass waterways, tall fescue

Recent U.S. Environmental Protection Agency (EPA) summaries of water quality in the Midwest show that agriculture is a major cause of surface water quality degradation (www.epa.gov/305b/). Perennial grasses planted in waterways, filter strips, contour strips, field borders, and riparian buffers along streams help trap sediment, prevent soil erosion, and protect surface water from contamination by sediment, some nutrients, and certain herbicides in runoff from agricultural fields (Dillaha et al. 1989). The land area converted to buffer zones in the Conservation Reserve Program is extensive (USDA 2000, 2001). However, changing patterns of herbicide use (types of herbicides and application rates) can inadvertently damage planted conservation features.

Tall fescue (*Festuca arundinaceae* Schreb.) is a major, widely grown, cool-season grass seeded in grassed waterways and buffer zones in Missouri and throughout the Midwest (Sleper and Buckner 1995). Browning and desiccation of tall fescue waterways within weeks after overspraying glyphosate [*N*-(phosphonomethyl)glycine] can concern landowners and soil conservationists who are unfamiliar with the long-term response of tall fescue to a single accidental application of glyphosate. In overspraying, glyphosate is directly applied to waterways at the same rate as to nearby crops because sprayers are left on while traveling over waterways. Application rates are doubled if spray swaths overlap when sprayers are left on while turning around at field edges. Farmers or conservation agents might fear that glyphosate damage could reduce ground cover in tall fescue waterways enough to increase the chance of soil erosion and of sediment, nutrient, or herbicide contamination of surface water.

Glyphosate use increased throughout the 1990s in the Midwest because of: (1) adoption of no-till farming for erosion control on highly erodible land and (2) commercialization of glyphosate-resistant crops. Glyphosate is applied at 0.56 to 1.68 kg ai/ha to kill winter annual weeds before planting no-till corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), and other field crops, instead of using mechanical seed bed preparation. Widespread adoption of glyphosate-resistant, genetically modified (GMO) corn and soybean varieties (i.e., Roundup-Ready7)[2] may simplify summer annual weed control in these row crops and extend the period of glyphosate application later into the growing season. Consequently, glyphosate can be applied in spring for an extended period, which can last two to three months in Missouri. Corn planting starts in late April and precedes soybean planting, which extends until late June for single-crop soybeans and until July for double-crop soybeans after winter wheat (*Triticum aestivum* L.). Recommended glyphosate rates vary from 0.375 to 1.5 kg ai/ha for glyphosate-resistant soybeans and 0.56 to 0.75 kg ai/ha for glyphosate-resistant corn (Kendig and Johnson 2000). Glyphosate was applied to 66% and 6% of Missouri soybean and corn acreage, respectively, in 2000 (Danekas and Schlegel 2001). Glyphosate use will probably increase and replace other herbicides as adoption of no-tillage farming methods and glyphosate-resistant row crops expands. Some persistent row crop herbicides, such as atrazine [6-chloro-*N*-ethyl-*N*=-(1-methylethyl)-1, 3, 5-triazine-2, 4-diamine], routinely contaminate surface water in streams and reservoirs and some ground water in the Midwest (Pereira et al. 1990). By comparison, glyphosate does not contaminate surface water for extended periods and is relatively nonpersistent in the environment (Franz et al. 1997).

Farmers often hire custom applicators to treat weeds growing in fields with herbicides. But custom applicators who use large-scale, wide-boom sprayers to apply glyphosate increase the chance that tall fescue waterways, filter strips, and field borders may be inadvertently or accidentally sprayed either directly (overspraying) or by drift. Depending upon glyphosate rate and treatment timing throughout spring and early summer, glyphosate may damage and thin tall fescue stands. In turn, glyphosate-damaged tall fescue waterways may be less able to prevent soil erosion and off-field movement of sediment from fields into streams.

No scientific publications were found concerning tall fescue response to glyphosate in terms of objectively measured ground cover, which is needed to estimate erosion control using software, such as revised universal soil loss equation (RUSLE) (Renard et al. 1997).

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Table 1. Times of treatment or observation in terms of date, days after treatment or heat sum (cumulative degree days from April 1).

Treatment or observation	1999-2000			2000-2001		
	Date	DAT[a]	Heat sum[b]	Date	DAT	Heat sum
		days	C days		days	C days
Mow tall fescue	04/12/99	-32	74	04/10/00	-36	60
Apply glyphosate	05/14/99	0	226	05/16/00	0	301
Photograph tall fescue cover and measure height						
0 MAT[c]	05/14/99	0	226	05/17/00	1	306
1 MAT	06/11/99	28	389	06/13/00	28	462
2 MAT	07/09/99	56	534	07/25/00	70	678
3 MAT	08/10/99	88	733	08/16/00	92	791
10 to 11 MAT	04/13/00	335	82	05/01/01	350	172

[a] DAT = days after treatment
[a] Heat sum = degree day sum > 0 C starting heat sum accumulation April 1
[b] MAT = months after treatment

Instead, phytotoxicity was reported as subjective, visually rated weed "control," "estimated" cover (e.g., Broome, M.L. et al. 2000; Washburn and Barnes 2000), or, indirectly, as crop yield compared with untreated check plots. According to the 2001 EPA registration label, glyphosate can be applied at rates up to 3.36 kg ai/ha to kill tall fescue pasture before planting no-till row crops, but application timing influences efficacy. Glyphosate at 1.12 kg ai/ha and 2.24 kg ai/ha is recommended to control tall fescue in fall and spring, respectively. Tall fescue waterways are likely to be either oversprayed directly or receive drift at considerably lower rates than by overspraying in spring.

Fall-applied glyphosate killed established tall fescue at lower rates and more consistently than spring-applied glyphosate at equivalent rates (Smith 1989, 1992). Glyphosate at 0.84 and 1.7 kg ai/ha in September or October controlled established tall fescue sod better than 90% when rated the next May in Georgia (Smith, 1989, 1992). However, one year after treatment, control decreased to 10% to 37% and 60% to 80% at two separate sites. Control was inconsistent between years and failed over time because tall fescue reestablished from root buds on underground rhizomes. Other research verifies the short-term efficacy (DeFelice and Henning 1990; Hagood 1988; Malike and Waddington 1990; Zarnstorff et al. 1990; Washburn and Barnes 2000) and between-year inconsistency (DeFelice and Henning 1990) of fall-applied glyphosate at 1.7 to 2.24 kg ai/ha to control tall fescue.

The response of tall fescue to spring-applied glyphosate depended upon application rate and was even more variable than for fall applications. Glyphosate at 0.21 kg ai/ha applied in mid-May prevented seedhead formation but did not change the color or quality of established tall fescue pasture (Lyman et al. 1989). Elsewhere, glyphosate at 0.31 to 0.43 kg ai/ha +/- nonionic surfactant (0.5% by volume) suppressed, but did not kill, tall fescue growing in roadsides (Downs and Voth 1984). Glyphosate at 0.63 to 0.84 kg ai/ha controlled tall fescue 50% at 90 to 100 days after treatment (DAT) (Downs and Voth, 1984). Likewise, glyphosate at 0.7 kg ai/ha without additives did not effect well-established, 10-year-old stands of tall fescue when applied in April at the early stem stage in Tennessee (Reynolds et al. 1993). Spring-applied glyphosate at 0.6, 1.1, and 2.2 kg ai/ha + X-77 nonionic surfactant (1% by volume) controlled year-old tall fescue 42%, 76%, 93% at 30 to 70 DAT in Kentucky (Weston 1990). Glyphosate was applied at 1.1 to 1.7 kg ai/ha + X-77 nonionic surfactant (0.25% by volume) to renovate well-established, endophyte fungus-infected tall fescue pasture in Missouri about two weeks after it resumed growth in the spring (Bagegni et al. 1994). Although glyphosate at 1.1 kg ai/ha controlled tall fescue shoots 75% to 89% at six to seven weeks after treatment, tall fescue regrew from underground buds on rhizomes. Glyphosate at 1.7 kg ai/ha was required to control tall fescue 97% all spring. However, spring-applied glyphosate at 1.68 to 2.52 kg ai/ha did not consistently control tall fescue in a second Missouri study (DeFelice and Henning 1990). Control was 10%, 79%, and 85% in three consecutive years. In a third Missouri study, tall fescue was killed in 30 cm wide strips with spring-applied glyphosate at 0.6 to 1.2 kg ai/ha + X-77 nonionic surfactant (0.25% by volume) before no-till planting grain sorghum [*Sorghum bicolor* (L.) Moench] (Reinbott and Blevins 1995).

Conservation features such as tall fescue waterways, filter strips, and field borders are occasionally grazed in Missouri. Glyphosate may be less phytotoxic to grazed than ungrazed tall fescue because grazing is likely to reduce foliage and herbicide spray interception. One research goal was to determine whether glyphosate at certain rates irreversibly reduced ground cover of well-established tall fescue waterways when applied in early spring either with or without prior mowing in mid-April to simulate grazing. Note that mowing is more severe and uniform than grazing and does not simulate trampling damage. A second goal was to determine the glyphosate dose dependence of recovery for total and live tall fescue ground cover at one, two, three, and 10 to 11 months after glyphosate damage in spring. These total and live ground cover measurements were used to estimate annual soil erosion with RUSLE software and, consequently, whether a single accidental glyphosate application was likely to reduce the effectiveness of tall fescue waterways for reducing erosion in the short term. Based on the literature review, glyphosate at rates of 1.12 to 2.24 kg ai/ha was expected to kill tall fescue, reduce total and live ground cover, and increase estimated annual soil erosion. Lower application rates were expected to have no or minimal effects.

Methods and Materials

Treatments. Glyphosate[3] was applied to well-established tall fescue waterways at rates of 0 (untreated check), 0.14, 0.28, 0.56, 0.84, 1.12, 1.68, and 2.24 kg ai/ha + ammonium sulfate solution at 2% (by volume) either with or without prior mowing. Glyphosate is normally applied with ammonium sulfate for winter annual weed control in no-till, as suggested on the EPA registration label.

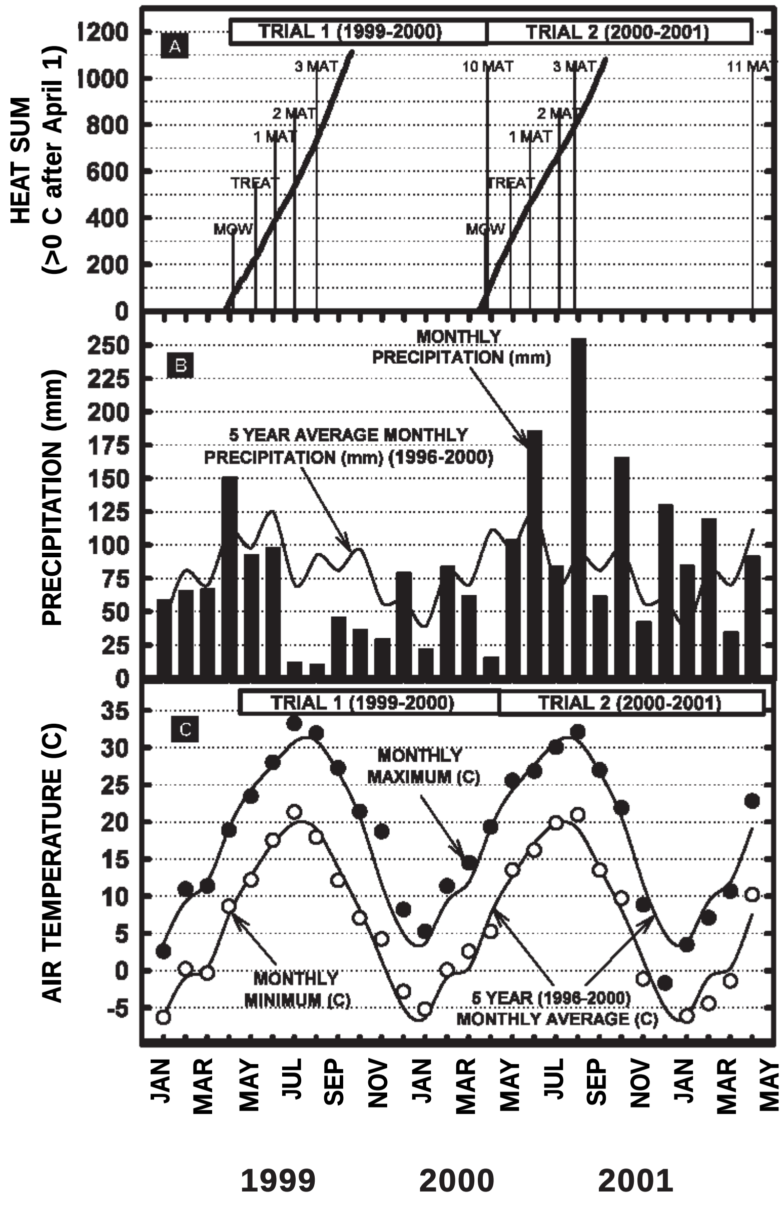
Glyphosate + ammonium sulfate (optional) is also registered for use in glyphosate-resistant corn and soybean. Plot dimensions were 3.04 m by 9.12 m. To simulate grazing and subsequent regrowth for one month before herbicide treatment, half of each plot was mowed twice, once with a sickle bar (jerry) mower (Model 205 BCS Tiller with Sickle Bar Mower, BSC America Inc., Matthews, North Carolina) and then again with either a XL PRO model DR trimmer/mower (Country Home Products, Charlotte, Vermont) or a weed whacker (Ryobi model 780r 790r, Ryobi Outdoor Products, Chandler, Arizona) operated about 10 cm above the soil surface to create an evenly mowed surface. Tall fescue clippings were raked off mowed plots. Mowed and unmowed, unsprayed, weedy check plots were also included. Calendar dates, time before or after glyphosate treatment, and degree (C) day heat sums are summarized for treatments and observation times in Table 1.

Glyphosate + ammonium sulfate were applied with a compressed CO_2 backpack sprayer through Teejet 6501 SS flat-fan spray nozzles (Spraying Systems Co., Wheaton, Illinois) in a water carrier volume of 85 L ha^{-1} at 207 kPa and a ground speed of 4.8 km hr^{-1}. Nozzles were spaced every 50.8 cm on a 3.05 m boom, which was kept about 61 cm above the soil surface. At spraying in May 1999 and 2000, air temperatures were 21˚ C and 26˚ C , respectively, wind speeds were 5 to 13 km h^{-1} and 5 km h^{-1}, respectively, and the soil surfaces were wet and dry, respectively. At spraying in May 1999 about one month after mowing, the live tall fescue ground cover was 58% (± 21% standard deviation) and 77% (± 11% standard deviation) for the mowed and unmowed treatments, respectively. (See Measurements below.) The respective average heights for tall fescue were 18 cm (± 10 cm standard deviation) and 55 cm (± 9 cm standard deviation). At the 2000 site, the live tall fescue ground cover was 41% (± 27% standard deviation) and 46% (± 19% standard deviation) and average heights were 40 cm (± 8 cm standard deviation) and 56 (± 7 cm standard deviation) for these respective treatments.

The experiment was conducted from spring 1999 to 2000 (the "1999 site") and 2000 to 2001 (the "2000 site") at two sites near and on the University of Missouri's Bradford Experimental Farm near Columbia (38˚ 53' 43.5" N, 92˚ 12' 37.9", 883 m altitude). The soils were a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualf). Maximum and minimum air temperature and precipitation data were collected at South Farm weather station in Columbia, Missouri near the experimental sites. Heat sum growing degree C days above 0˚ C were accumulated starting April 1 each year (Figure 1).

Figure 1

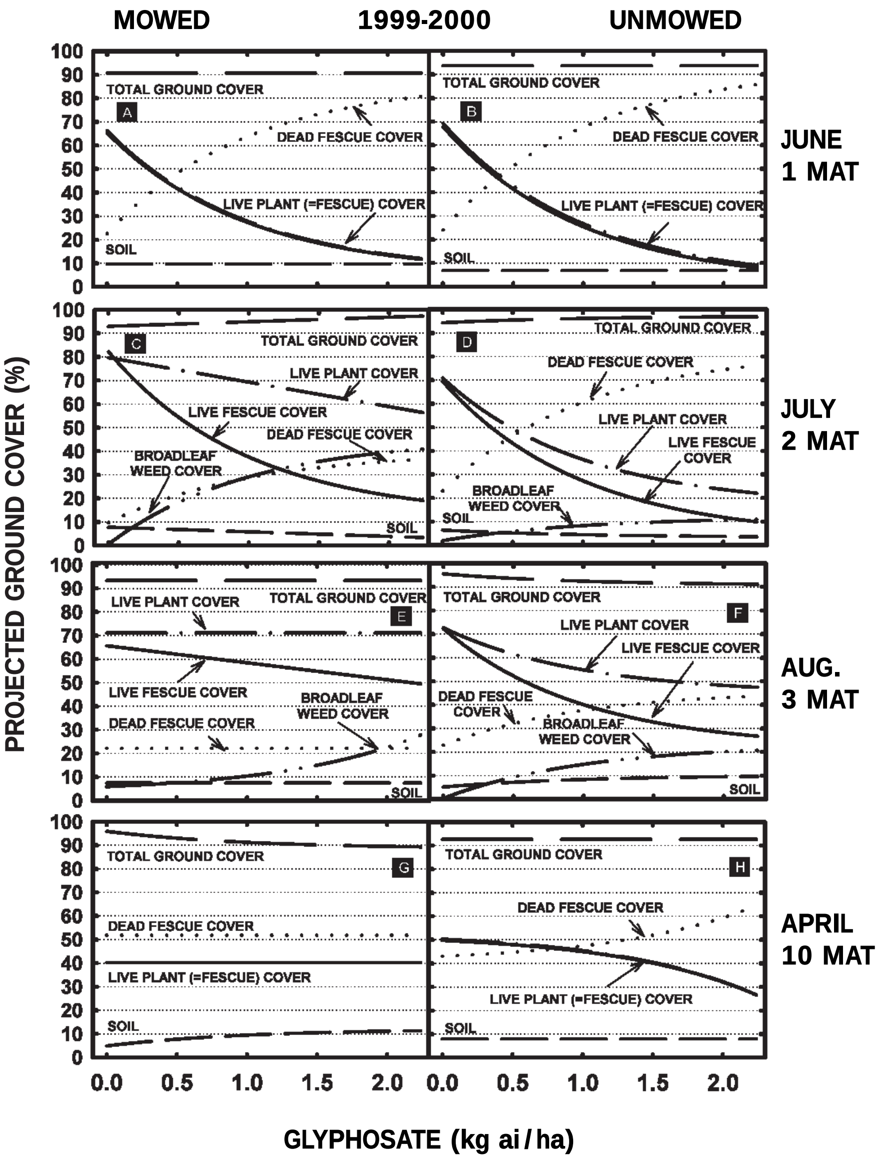
Heat sums (growing degree days accumulated from April 1) (Panel A), monthly rainfall (Panel B), and daily maximum and minimum air temperatures (Panel C) compared with five-year average rainfall and five-year average maximum and minimum air temperature at the South Farm near Columbia, Missouri, in 1999 through 2001. Dates of mowing (mow), glyphosate treatment (treat), and observation (one, two, three, and 10 or 11 months after treatment (MAT)) are indicated by vertical lines in Panel A.



Measurements. Projected ground cover (percentage of the ground surface covered by vegetation) was measured from color digital photographs taken at zero, one, two, three, and 10 to 11 months after glyphosate treatment (MAT) (Table 1 and Figure 1). Three photographs per plot were taken with a digital camera (Olympus D 600-L digital camera,

Figure 2

Linear and nonlinear regression equations of projected ground cover (%) versus glyphosate rate for mowed and unmowed tall fescue treatments observed at one, two, three, and 10 months after treatment (MAT) in 1999-2000. Percent projected ground cover is labeled for total ground cover, live plant cover (tall fescue + broadleaf weeds), live tall fescue cover, dead tall fescue cover, broadleaf weed cover, and bare soil.



Olympus America, Melville, New York) at a height of 132 cm above the soil surface. Each photograph corresponded to 1.04 m^2 at the soil surface, based on photographs of a 30-by-30 cm orange calibration plate. Tall fescue height also was measured for each photograph. Digital photographs formatted as JPG files were archived on CD-ROM for later image analysis (Sigma Scan PRO v. 5, SPSS Inc., Chicago, Illinois). The image analysis software was used to superimpose a 20-by-20 pixel grid on each picture for a 0.24 m^2 area at the ground surface. The number of intersections was counted, and percent projected ground cover was calculated as the ratio of the number of intersections for each cover category divided by the total number of intersections per photograph. Ground cover categories included live (green) tall fescue, dead tall fescue, broadleaf weeds, and bare ground. Total (live + dead) ground cover and total live (live tall fescue + broadleaf weed) plant cover were calculated. Cover categories represent projected ground cover, not leaf area index.

Experimental design and statistical analysis. The experimental design was a randomized split-plot design with three blocks based on slope position, with downslope blocks being wetter. Main plot and subplot treatments were herbicide rate and mowing (i.e., mowed or not mowed), respectively, and the experiment was repeated.

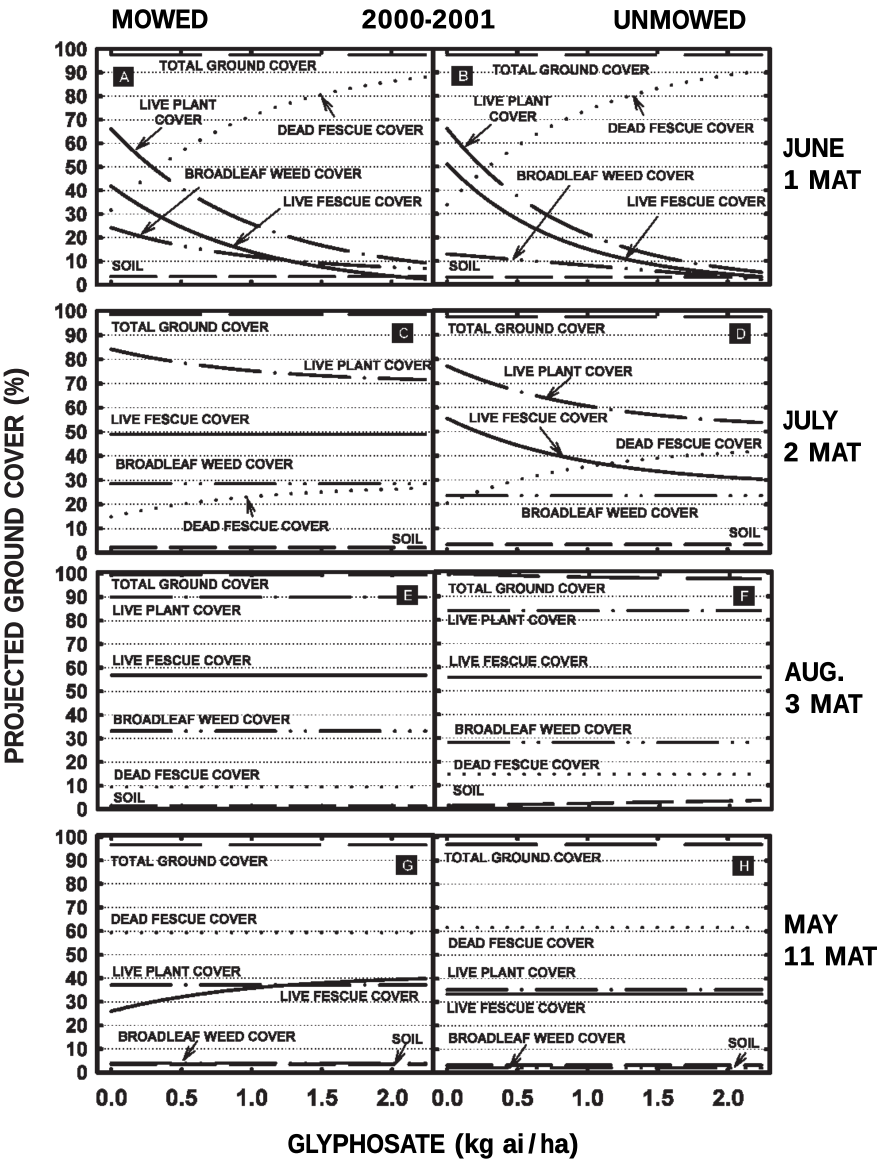
While tall fescue cover was uniform and dense within each block, broadleaf weeds were different among sites and blocks. At the 1999 site, the major broadleaf weeds were common cocklebur (*Xanthim strumarium* L.), common ragweed (*Ambrosia artmesiifolia* L.), horesenettle (*Solanum carolinense* L.), waterhemp sp. (*Amaranthus* spp.), and poison ivy (*Rhus radicans* L.). The broadleaf weeds present at the 2000 site were hemp dogbane (*Apocynum cannabinum* L.), horsenettle, prostrate spurge (*Euphorbia humistrata* Engelm. Ex Gray), sunflower sp. (*Helianthus* spp.), and waterhemp sp. Because individual broadleaf weed species were not uniformly distributed, broadleaf weeds were grouped as a ground cover category for statistical analysis.

Using SPSS statistical software version 10 (SPSS Statistical Software, SPSS Inc., Chicago, Illinois), the percent ground cover categories at each observation time were subjected to linear regression analysis (ANOVA). Percent ground cover was regressed on glyphosate rate for each category with mowing as a dummy variable. Then each ground cover category was subjected to linear and nonlinear regression for each mowing treatment separately at each observation time using TableCurve 2 D version 5 software (SPSS Inc., Chicago, Illinois) (Hoshmand 1994).

RUSLE for Windows version 2, downloaded from the National Resources Conservation Service (NRCS) Web site, was used for calculating yearly erosion using cover measurements. Slopes at the 1999 and 2000 sites were 1.65% and 2.99%, respectively. The percent sand, silt, clay, and organic matter were 15%, 61%, 23% and 2.5% at the 1999 site, respectively, and 12.5%, 68.5%, 19%, and 3.4% at the 2000 site, respectively. Erosion on the mowed and unmowed treatments with or without glyphosate at 2.24 kg ai/ha was calculated using mean cover measurements.

Figure 3

Linear and nonlinear regression equations of projected ground cover (%) versus glyphosate rate for mowed and unmowed tall fescue treatments observed at one, two, three, and 10 months after treatment (MAT) in 2000-2001. Percent projected ground cover is labeled for total ground cover, live plant cover (tall fescue + broadleaf weeds), live tall fescue cover, dead tall fescue cover, broadleaf weed cover, and bare soil.



Results and Discussion

Total (live + dead) ground cover influences soil susceptibility to erosion (Renard et al. 1997) and consisted of live plant cover, chiefly live tall fescue and broadleaf weeds, and dead tall fescue cover. In both years, the total (live + dead) ground cover exceeded 88% for all mowing and glyphosate treatments at all observation times (Figures 2 and 3). Using RUSLE, the greatest soil erosion calculated for any treatment was 0.12 and 0.11 Mg ha^{-1} yr^{-1} at the 1999 and 2000 sites, respectively. Enough tall fescue survived treatment to reestablish ground cover in gaps during the summer. Thus, glyphosate drift or a single accidental overspraying of glyphosate at 1.12 to 2.24 kg ai/ha is unlikely to permanently damage tall fescue waterways for preventing soil erosion.

Total (live + dead) ground cover differed slightly between sites because of historical differences in tall fescue growth, mowing frequency, environment (i.e., standing water), and residue decomposition. While the 1999 site was undisturbed after initial establishment, the 2000 site had been repeatedly mowed in previous years. Mowing tall fescue encourages tillering and can increase tall fescue ground cover (Sleper and Buckner 1995).

In general, glyphosate did not reduce total (live + dead) ground cover at any rate (Figure 2 and 3). Those few regression equations relating total ground cover to glyphosate rate that were statistically significant (e.g., 1999 mowed at two and 10 MAT; 1999 unmowed at two and three MAT; and 2000 unmowed at three MAT) "explained" little data variability (i.e., coefficients of determination (r^2) ≤ 0.12). (Regression equations for Figures 2 and 3 are available upon request.)

Continued growth of tall fescue helps maintain ground cover and helps trap sediment in waterways over time. Broadleaf weeds are poor replacements for tall fescue because broadleaf weeds provide ground cover for only part of the year and do not adequately filter and trap sediment in overland flow. But they may prevent soil detachment by raindrop impact. Consequently, it was important to determine the extent to which glyphosate at different rates reduced live tall fescue and broadleaf weed ground cover, as well as whether decreases in live tall fescue ground cover were great enough to impair functioning of waterways over time (i.e., ability to prevent erosion).

When glyphosate was applied in May, the mowed and unmowed treatments differed from each other in cover and height at the 1999 and 2000 sites. The live tall fescue cover in the mowed and unmowed treatments was 58% (± 3 standard error of mean) and 82% (± 2), respectively, at the 1999 site, whereas it was 61% and 64% at the 2000 site, respectively. Recovery of mowed glyphosate-treated tall fescue at the 1999 site may reflect lower spray coverage and subsequent uptake of herbicide compared with the unmowed treatment. Greater recovery of both mowed and unmowed treatments at the 2000 site compared with the 1999 site may be caused by the combined effects of spray coverage and more favorable weather conditions for regrowth in 2000 than in 1999 (Figure 1).

Weather differed dramatically between the 1999 and 2000 sites (Figure 1). Knowledge of weather differences between years is needed to understand changes in total live plant cover and the relative contributions of different cover categories to total live plant cover over time after glyphosate treatment. May 1999 was slightly drier and cooler than May 2000 before and after glyphosate treatment. In 1999, rainfall was below the five-year average for more than five consecutive months after spraying in May (Figure 1, Panel B). In contrast, rainfall in 2000 was well above normal from May to August and in October. Heat sums (˚C days accumulated starting April 1) were similar in April but increased earlier and more rapidly in May 2000 than in May 1999 (Figure 1, Panel A). Average day and night temperatures in May 2000 were greater than in May 1999 (Figure 1, Panel C). Warmer, moister conditions earlier in the growing season may have encouraged greater broadleaf weed cover development at the 2000 site than at the 1999 site when observed one MAT. Initial mowing in April was timed to degree day accumulation, whereas glyphosate treatment in May and subsequent observations were at roughly monthly intervals.

The relative contribution of live tall fescue, dead tall fescue, and broadleaf weed cover to total (live + dead) ground cover differed between site-years and varied with glyphosate rate, mowing pretreatment, and observation time after treatment (Figures 2 and 3). Likewise, these factors influenced the relative contributions of live tall fescue and broadleaf weed cover to total live plant cover between site-years.

At both sites at one MAT, glyphosate reduced both live plant cover and live tall fescue cover as negative exponential functions of increasing glyphosate rate (e.g., equations of the form $Y = a * \exp(-X/b)$ or $Y = a + b * \exp(-X/c)$) for both mowed and unmowed treatments (Figures 2 and 3, Panels A and B, respectively). Live and dead tall fescue cover were inversely related, and live tall fescue cover decreased as glyphosate rate increased, as expected. The extent of damage to waterways that was seen might concern conservationists and farmers. However, the superficial shoot die-off of tall fescue one MAT was more apparent than real. Total (live + dead) ground cover remained high enough to prevent soil erosion, and tall fescue was able to reestablish live fescue ground cover by the next spring, 10 to 11 MAT, only slightly less extensive than pretreatment live fescue ground cover. In fact, at this time, the live tall fescue ground cover was uninfluenced by glyphosate treatment or mowing.

Live tall fescue cover was the major component of live plant cover for both mowed and unmowed treatments at both sites one MAT (Figure 2 and 3, Panels A and B). At the 1999 site, live tall fescue cover was the sole component of total live plant cover because of broadleaf weed emergence and canopy growth above the tall fescue canopy later than one MAT. Although broadleaf weed cover contributed less to total plant cover than did live tall fescue cover at the 2000 site at one MAT, broadleaf weed cover also decreased in a dose-dependent fashion as glyphosate rate was increased. At the 2000 site one MAT, broadleaf weed cover after mowing was greater than for unmowed tall fescue across all glyphosate rates. Mowing tall fescue allowed greater light intensities to reach the soil surface, which probably stimulated broadleaf weed germination and emergence and encouraged broadleaf weed cover development (Ballare and Casal 2000). In contrast, soil surface shading by live + dead tall fescue cover in unmowed tall fescue probably suppressed broadleaf weed germination and growth.

Total live plant cover increased from one to two MAT for most mowing and glyphosate treatment combinations, suggesting plant community (live tall fescue + broadleaf weed) recovery from initial dose-dependent glyphosate phytotoxicity (Figures 2 and 3, Panels C and D). By two MAT at both site-years, glyphosate still suppressed live plant cover in a dose-dependent fashion, but live plant cover had recovered somewhat and had regrown more for mowed than unmowed treatments. Thus, mowing pretreatment and glyphosate rate interacted to impact live plant cover at this time. Recovery of live plant cover was greater at the 2000 site than at the 1999 site, presumably because growing conditions were more favorable in 2000 than in 1999 (Figure 1). The relative contribution of live tall fescue and broadleaf weed cover to live plant cover at two MAT also differed between site-years. At the 1999 site at two MAT for both mowing treatments, tall fescue contributed more than broadleaf weed cover to total live plant cover at low glyphosate rates. As glyphosate rate increased, broadleaf weed cover contributed relatively more to total live plant cover than did live tall fescue cover. Live tall fescue and broadleaf weeds overarched and shaded one another differently depending upon glyphosate rate and mowing pretreatment. Dead tall fescue residue became compressed above the soil surface as it decayed and live tall fescue and broadleaf weed increased in height and cover, overarching it (Figures 2 and 3, Panels C and D). At the 2000 site at two MAT for both mowing treatments, broadleaf weed cover was independent of glyphosate rate and contributed much less than live tall fescue cover to total live plant cover. These differences between site-years and trends continued and became more pronounced at three MAT (Figures 2 and 3, Panels E and F).

By 10 or 11 MAT, total (live + dead) ground cover remained great enough to prevent erosion and did not differ between mowing and glyphosate rate treatments (Figures 2 and 3, Panels G and H). For the mowed treatment at this time, dead tall fescue cover contributed more than live tall fescue cover to total ground cover, and both cover categories were independent of glyphosate rate in both years. The 1999 and 2000 sites differed for the unmowed treatment. At the 1999 site, live tall fescue cover decreased nonlinearly as glyphosate rate increased above 1.12 kg ai/ha for the unmowed treatment. At the 2000 site, live tall fescue cover was independent of glyphosate rate and similar for both the unmowed and mowed treatments.

Summary and Conclusion

Enough tall fescue survived a single glyphosate treatment to reestablish ground cover in gaps during the summer. Glyphosate drift or single accidental incidents of overspraying glyphosate at 1.12 to 2.24 kg ai/ha are unlikely to permanently damage tall fescue waterways for preventing soil erosion. While not examined in this study, repeated treatment with glyphosate at rates below 1.12 kg ai/ha is unlikely to reduce tall fescue ground cover. Nevertheless, such treatment is inconsistent with the EPA registration label, which cautions against applying glyphosate to surface water or desirable vegetation, such as tall fescue waterways.

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