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Effects of Vegetative Filter Strip Width on Reducing Fluometuron and Norflurazon Losses in Surface Runoff

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Abstract

Although research has shown that grass filter strips may effectively reduce losses of sediment, nutrients, and herbicides in surface runoff, little data exist concerning the appropriate filter strips width to maximize reductions in herbicide loss while minimizing the amount of land taken out of production by these filter strips. A 2-year study was initiated in 1994 near Brooksville, MS on a silty clay soil to evaluate the effects of tall fescue filter strips 0, 0.5, and 1 m(1.5 and 3 ft) wide on sediment, fluometuron, and norflurazon loss in surface runoff from conventionally-tilled cotton. Across years, total sediment loss during the cropping season from the unfiltered treatment averaged 1,660 kg ha^{-1} (1,480 lb/A). The 0.5 and 1-m (1.5 and 3 ft) filter strips reduced total sediment loss by an average of 32%, and no difference was observed between the two widths. Across years, fluometuron and norflurazon losses from the unfiltered treatment averaged 10 and 9% of the total amount applied, respectively. When compared to the unfiltered treatment, the 0.5- and 1-m (1.5 and 3 ft) filter strips reduced fluometuron and norflurazon yearly loss by an average of 48 and 50%, respectively. Increasing filter strip width reduced concentrations of both fluometuron and Norflurazon in runoff. However, the increased efficiency of the 1-m (3-ft) filter strip came at the expense of higher runoff for that treatment. Consequently, there were no differences in total fluometuron and norflurazon losses between the 0.5- and 1-m (1.5 and 3 ft) filter strips. Within a given runoff event, fluometuron and norflurazon concentrations remained relatively constant over time.

Introduction

For decades, researchers have evaluated various perennial grass species, planted perpendicular to the slope, as a means of reducing surface runoff and soil erosion (2, 8, 9, 28). Vegetative buffers planted in 5- to 15-m (5to 15 yd) wide strips are effective in reducing sediment and nutrients from surface water (9, 28). A more recent area of research has focused on narrow vegetative filter strips of less than 1 m (3 ft) in width. Grasses grown in narrow strips tiller more densely and have greater hydraulic resistance than the same species grown as a sward (9). Subsequently, these narrow strips effectively increase infiltration and sedimentation in the upslope backwater created by the vegetative filters.

In 1989, 97% of the cotton acreage in Mississippi utilized intensive conventional tillage practices (20). Conventional tillage practices can be beneficial from an agronomic perspective (7, 12); however, they also contribute to non-point source contamination of surface water (10, 11). Sediment, nutrients, and pesticides are the primary contributors of surface water contamination by agricultural practices (3, 10, 11, 19).

Increasing awareness of surface and ground water contamination by pesticides has created an interest in vegetative filter strips as a low-input technology for reducing the off-site movement of herbicides (22). Metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one] and metolachlor [2-chloro-N-(2-ethyl-6-methyl-phenyl)-N-(2-methoxy-1-methylethyl) acetamidel losses in surface water were reduced by approximately one half when a 2-m (2-yd) filter strip of tall fescue (*Festuca arundinacea* Schreb.) was placed downslope of conventionally-tilled soybeans (*Glycene max*) (22).

Fluometuron (N, N-dimethly-N'-[3-(trifluoromethyl) phenyl]urea) and norflurazon (4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(2H)-pyridazinone) are two of the most widely used herbicides in production of cotton (*Gossypium hirsutum* L.). Previous research concerning pesticide runoff from cotton has primarily focused on insecticides (13, 14, 25, 26), dinitroanaline herbicides (17, 18, 27), and fluometuron (4, 13, 16, 18, 23, 24).

Concentrations of fluometuron were higher in the first runoff event than in subsequent events under conventional tillage (24). The highest concentration of fluometuron recovered through the season was 0.87 mg/L (ppm), and a total of 2% of the amount applied moved off-site in runoff (24). As much as 10% of applied fluometuron can be lost in surface water from conventionally-tilled cotton (5). In that same study, norflurazon loss did not exceed 5% of the total applied.

Although research has shown that vegetative filter strips can effectively reduce sediment and herbicide loss in surface water, research is limited concerning the appropriate filter strip width to maximize reductions in herbicides while minimizing the amount of land taken out of production by these filter strips. The objectives of this research were to determine the effects of tall fescue filter strip width on (**1**) sediment, fluometuron, and norflurazon loss in surface runoff from conventional tilled cotton; and (**2**) herbicide concentrations over time within a single runoff event.

Materials and Methods

The experiment was conducted at the Mississippi Agricultural and Forestry Experiment Station Black Belt Branch near Brooksville, MS in 1994 and 1995. Soil erosion plots 4m by 2m (13 ft by 72 ft), equipped with a 15-cm H-type flume, were located on a Brooksville silty clay (fine montmorillonitic, thermic Aquic Chromudert, 3.0% slope, 3.2% organic matter content, and pH 6.3 in the Ap horizon). The Brooksville series has a low saturated hydraulic conductivity (less than 1.5 to 5 mm/h; 0.06 to 0.2 in/h) (6). However, the high montmorillonitic content of this soil causes shrinking and cracking during dry periods, which can temporarily facilitate infiltration.

In the fall of 1993 and 1994, plots were disked once with a tandem disk-harrow perpendicular to the slope. In mid-April of 1994, tall fescue filter strips were established by transplanting native stands from an adjacent area to the runoff plots. The filter strips were placed at the base of the plots just prior to entry into the H-type flume. Filter strip treatments included none, a 4-m by 0.5m (13-x 1.5-ft) strip, and a 4-m by 1-m (13-x3-ft) strip. Filter strips were clipped to 10 cm (4 in) prior to cotton planting each year and allowed to grow without further maintenance. The experimental design was a randomized complete block with two replications.

Spring seedbed preparation included one pass with a tandem disk-harrow followed by two passes with a two-way bed conditioner equipped with rolling baskets and S-tine harrows. In both years, seedbed preparation preceded planting by no more than 2 days. DES-119 cotton was planted in 76-cm rows parallel to the slope, with 5 rows per plot. Planting dates were May 31, 1994 and June 20, 1995. Immediately after planting, plots were bordered with metal flashing to exclude outside runoff. Fluometuron and norflurazon were applied at 1.68 kg ai/ha (1.5 lb ai/h) each using a CO_2-pressurized backpack sprayer at a spray volume of 190 L/ha (20 gpa). All plots were maintained weed-free throughout the growing season by hand weeding.

A simulated rainfall event was initiated within 2 days after treatment (DAT) both years using a system patterned after that described by Sumner et al. (21). This system applies water through a rotating irrigation sprinkler (Wobbler #13, Senninger Irrigation Inc., 6416 Old Winter Garden Rd., Orlando, FL) mounted on 3-m (10-ft) risers that were spaced 3 m (10-ft) apart. Three irrigation laterals, running parallel to the plots, allowed for simultaneous simulation of all plots at one time with a regulated rainfall intensity of 25 mm/h (1 in/h).

A second rainfall simulation was employed later in the growing season both years. Rainfall simulation for a given event was continued until runoff had occurred on all plots for 10 minutes. The timing and amounts of simulated and natural rainfall for all runoff events are listed in Table 1. In both years, runoff was monitored for 125 days following herbicide application. Previous research indicated that fluometuron and norflurazon losses in surface runoff were negligible beyond 100 days (5).

In 1994, all runoff from each plot was collected in individual 550-L (145-gal) catch basins. Runoff effluent was quantified, agitated, and a 1-L (1-qt) composite sample was obtained from each runoff plot and stored at 2° C until analysis. In 1995, automated flow meters (Isco Model 4230 Flow Meter, Isco, Inc., 531 Westgate Blvd., Lincoln, NE 68528) and water samplers (Isco Model 3700 Portable Sampler, Isco, Inc.) were installed in place of the catch basins. The flow meters were programmed and calibrated to determine total runoff at the outlet of the flume. The automated water samplers were programmed to collect a 0.64-L (0.2-gal) sample from runoff passing through the flume at 200-L (50-gal) intervals during runoff events occurring from natural rainfall. Samples were recovered within 24 hours of the runoff event and stored at 2° C until analysis.

During simulated events, a runoff sample was collected at the initiation of runoff, and then at 5-minute intervals for the first 20 minutes. Beyond 20 minutes, the time sampling interval was increased to 10 minutes until runoff subsided. In 1994, samples were collected by hand where runoff flowed into the catch basins. In 1995, the automated water samplers were programmed to sample at the appropriate time intervals. This procedure allowed for determination of fluometuron and norflurazon concentrations over time within a single runoff event. Additionally, the effect of filter strip width on herbicide concentration in runoff was evaluated for all simulated events.

Water samples were filtered under vacuum through a Buchner funnel containing a 9-cm (3.5-in) diameter filter paper (Glass Fiber Filter F233090, Baxter Diagnostics Inc., 1430 Waukegan Rd., McGaw Park, IL 60085-6787). Filtered sediment was oven-dried at 66°C for 24 hours and quantified. Only the runoff water was used for herbicide extraction. Fluometuron and norflurazon concentrations were determined by liquid-liquid extraction and HPLC (high performance liquid chromatography) analysis. Extraction procedures closely followed those described by Webster Shaw (22). A 500-ml (0.5-qt) aliquot of the runoff water was placed in a liquid-liquid extractor with 250 ml (0.25 qt) of methylene chloride. The sample was diluted with deionized water for continuous extraction. The extractor was then placed on a 500-ml (0.5-qt) flat-bottomed flask containing 300 ml (0.3 qt) of methylene chloride and heated at 215°C for 16 hours.

Samples were dried by rotary evaporation. Concentrated extracts were passed through a 0.2-µm filter (Acrodisc LC 13 PVDF Syringe Filter F3057-31A, Baxter Diagnostics Inc.) and brought to a volume of 10 ml with acetonitrile. An injection volume of 20 µl was used for all samples. HPLC separation utilized a silica C-18 reverse-phase column (Econosphere C18 5µ column, Autech Assoc., Inc., 2051 Waukegan Rd., Deerfield, IL 60015) and an isocratic mobile phase of water:acetonitrile (55:45 v/v at a flow rate of 1 ml min-l. Absorbance was constant 1t 254 nm for both fluometuron and norflurazon, and peak retention times were approximately 9.6 and 11.6 minutes, respectively. The lower detection limits for fluometuron and norflurazon were 14 and 13 µg/L (ppb), respectively.

In 1994, sediment and herbicide concentration values, obtained from the single composite sample, were multiplied by total runoff to determine total loss per event. In 1995, multiple samples were obtained for a given runoff event, as a result of automated sampling. For these events, total sediment and herbicide loss were determined for each sampling interval and combined to obtain total loss per event. Runoff and sediment loss for each event were then combined to determine cumulative amounts on a per ha (per A) basis. Fluometuron and norflurazon loss in runoff was determined in this same manner and converted to a percent of the initial amount applied.

Total runoff, sediment loss, and percent fluometuron and norflurazon loss were subject to analysis of variance to test for year by filter strip treatment interactions. Where appropriate, filter strip treatment means for total runoff, sediment, and herbicide loss were averaged across years and separated using Fisher's protected LSD at $P \leq 0.05$. However, the cumulative loss patterns for these variables are presented by year for clarity.

For simulated events, herbicide concentrations were subjected to analysis of variance to test for interactions between the main effects of year, simulation date, filter strip treatment, and sampling time (minutes). Because of interactions between main effects, mean fluometuron and norflurazon concentrations for each filter strip treatment were separated for each year-sampling date combination using Fisher's protected LSD at $P \leq 0.05$. Regression analysis was also used to determine the effect of increasing filter strip width of fluometuron and norflurazon concentrations in runoff.

Results and Discussion

Total rainfall amounts during the sampling period were 540 and 290 mm (21.3 and 11.4 in) in 1994 and 1995, respectively (Table 1). Runoff was initiated 1 and 2 DAT by rainfall simulation in 1994 and 1995, respectively. Final runoff events from which samples were collected were 123 DAT in 1994 and 107 DAT in 1995.

Runoff and Sediment Loss

In 1994, total runoff ranged from 1,100 kL/ha (130,000 gal/A) for the 0.5-m (1.5-ft) filter strip to 1,500 kL/ha (177,000 gal/A) for the 1-m filter strip (Figure 1). Runoff totals for 1995 ranged from 450 kL/ha (53,000 gal/A) for the 0.5-m (1.5-ft) strip to 1,100 kL/ha (130,000 gal/A) for the unfiltered treatment. Across years, filter strip treatments had no effect on total runoff (Table 2). Across years, sediment loss for the unfiltered treatment averaged 1,660 kg ha (1,482 lb/A) (Table 2). Compared to the unfiltered treatment, the 0.5- and 1-m (1.5- and 3-ft) filter strips reduced sediment loss by 31 and 32%, respectively; no difference was observed between the two filter strip widths (Table 2).

The lack of a filter strip effect on total runoff is consistent with previous research that evaluated *Miscanthus sinesis* (L.) filter strips of 0.2m (0.6 ft) in width on runoff and sediment loss from conventionally-tilled cotton (15). However, other researchers have observed reductions in runoff from conventionally-tilled soybean when a 2-m (6 ft) tall fescue filter strip was included (22). Inconsistency between results could be attributed to differences in filter strip width or differences in rainfall patterns between studies. Previous researchers experienced a more optimal seasonal distribution of precipitation (22).

In this study, periods of relatively high rainfall occurred in relatively short periods of time during both years. In 1994, approximately 130 mm (5.1 in) of rainfall occurred between 23 and 28 DAT, and was followed by approximately 100 mm (3.9 in) of rainfall that occurred within a 7-day period starting at 49 DAT (Table 1). These two periods contributed the majority of total runoff in 1994 (Figure 1).

To a lesser extent, similar rainfall patterns and results were observed 47 and 107 DAT in 1995 (Figure 1). These conditions favor high antecedent soil moisture that, combined with the low saturated hydraulic conductivity of this soil, resulted in substantial runoff. Excessive runoff can inundate vegetative filters and reduce flow-retarding filter effectiveness (8, 9, 10). The hydraulic resistance of stiff grass species grown in narrow strips is greater than that of finer vegetation such as tall fescue (8, 9). Inundation of tall fescue may explain why filter strips were less effective in reducing total sediment loss in this study than previously reported (15). McGregor et al.(15) observed a 42% reduction in sediment loss from conventionally-tilled cotton when a 0.2 m (0.6 ft) *Miscanthus sinesis* filter strip was utilized under similar conditions.

Cumulative Herbicide Loss

Regardless of year or filter strip treatment, the first three runoff events accounted for 60 to 90% of the total fluometuron loss and 58 to 84% of the total norflurazon loss (Figure 3). Across years, total fluometuron and norflurazon losses for the unfiltered treatment averaged 166 and 144 g ai/ha (0.15 and 0.13 lb ai/A), respectively. These losses represent 9.8 and 8.6% of the total amount of fluometuron and norflurazon applied, respectively (Table 2). The presence of a filter strip reduced both fluometuron and norflurazon losses in runoff; however, there was no difference between filter strip widths of 0.5 and 1 m (1.5 and 3 ft) (Table 2). Across year and filter strip widths of 0.5 and 1 m (1.5 and 3 ft), fluometuron and norflurazon losses averaged 86 and 72 g ai/ha (0.08 and 0.06 lb ai/A). When compared to the unfiltered treatment, this represents a 48 and 50% reduction in total fluometuron and norflurazon loss, respectively.

Similar fluometuron loss patterns and total amounts have been observed from conventionally-tilled cotton in the absence of a filter strip. From a 2-year study, Baughman (5) reported that the first three runoff events accounted for the majority of the total fluometuron loss in surface runoff, and that these amounts were approximately equivalent to 10% of the total applied following 380 mm (15 in) of rainfall. Filter strip effectiveness in reducing total herbicide loss is also consistent with previous research. Webster and Shaw (22) found that 2-m (6-ft) tall fescue filter strips reduced total metribuzin and metolachlor losses in surface runoff by approximately 50%.

Herbicide Concentration within Events

Simulated rainfall events were initiated 1 and 49 DAT in 1994 and 2 and 30 DAT in 1995. Analysis of variance indicated fluometuron and norflurazon concentrations could be averaged over filter strip treatments for each year and each simulated runoff event. Fluometuron or norflurazon concentrations were relatively stable over time within a given runoff event (Figure 4). Subsequently, time had no effect on either fluometuron or norflurazon concentrations, regardless of year of timing of the simulated runoff event. However, filter strip treatment affected both fluometuron and norflurazon concentrations in runoff (Tables 3 and 4).

The highest concentration of fluometuron and norflurazon in runoff occurred within 2 DAT, regardless of year or filter strip treatment (Figure 5). In 1994, 1 DAT concentrations of fluometuron averaged 730 µg/L (ppb) across all timed sampling intervals (Table 3). The 0.5- and 1-m (1.5- and 3-ft) filter strips reduced fluometuron concentrations to 420 and 320 µg/L (ppb), respectively. At 49 DAT, fluometuron concentrations were substantially less than 1 DAT, and increasing filter strip width did not affect fluometuron concentrations (Table 4). However, mean fluometuron concentrations for the 1-m (3 ft) filter strip were lower than those for the unfiltered treatment or the 0.5-m (1.5-ft) filter strip (Table 3). In 1995, fluometuron concentrations decreased with increasing filter strip width for both 2 and 30 DAT simulated runoff events (Table 4). When compared to 2 DAT, fluometuron concentrations were again substantially less at 30 DAT (Table 3).

Norflurazon concentrations decreased in runoff from simulated events with increasing filter strip width (Table 4) and increasing time (DAT) (Table 3) in both years. When compared to fluometuron, norflurazon concentrations were typically smaller during initial simulated runoff events and greater during later-season simulated runoff events (Table 3). These results are attributed to differences in chemical properties and soil behavior between these herbicides. Fluometuron has a water solubility of 110 mg/L(ppm), which is approximately four times greater than that of norflurazon (1). Norflurazon persists longer in soil and has an average organic adsorption constant (K_{oc}) of 700 L/kg(388 gal/lb), which is seven times greater than the average (K_{oc}) of fluometuron (1). Consequently, fluometuron can initially serve as a substantial contaminant but quickly degrades to lower levels in soil and runoff. Conversely, norflurazon can serve as a continuing contaminant in runoff for longer periods of time.

This research indicates that narrow tall fescue filter strips are effective management practices for reducing sediment and herbicide losses in surface runoff. Across years, the 0.5- and 1-m (1.5- and 3-ft) filter strips provided substantial reductions in total sediment, fluometuron, and norflurazon losses when compared to the unfiltered treatment. Increasing filter strip width reduced both fluometuron and norflurazon concentrations in runoff. However, the increased efficiency of the 1-m (3ft) filter strip came at the expense of higher runoff for that treatment. Consequently, there were no differences in total fluometuron and norflurazon losses between the 0.5- and 1-m (1.5- and 3-ft) filter strip.

Although filter strip treatments had no statistical effect on cumulative runoff, the 1-m (3-ft) strip tended to have greater runoff in both years (Figure 1). Spatial variability in the infiltration and saturated hydraulic conductivity of this soil may have affected runoff and contributed to the lack of a statistical difference. Future research is needed to further define if the benefits of increasing filter strip width, in terms of reducing herbicide concentration in runoff, are negated by an increase in surface runoff.

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