ENVIRONMENTAL FATE OF FLUOMETURON IN SOIL INFLUENCED BY BEST MANAGEMENT PRACTICES (BMPs)

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INTRODUCTION

Fluometuron is an effective herbicide for annual grass and broadleaf weed control in cotton. Several fluometuron applications applied per growing season may include a preemergence, postemergence when cotton is 7.5 to 15 cm, and postemergence at lay-by (with the last cultivation). The mode of action is inhibition of photosynthetic electron transport by binding to the D1 protein of photosystem II and blocking electron transport from Q_A to Q_B (Ahrens, 1994). Fluometuron was labeled for use in 1965 (Timmons, 1970) and is one of several compounds that belong to the herbicide group known as the phenylureas or substituted ureas. These compounds have three hydrogen atoms of urea replaced or substituted with a variety of carbon chains and rings. Fluometuron is unique from other compounds in this group due to a trifluoromethyl group at the meta position of the phenyl ring (Rickard and Camper, 1978). Fluometuron is considered to be a nonionic molecule that does not ionize over a wide pH range (Patterson et al., 1982). Water solubility is 90 mg L' at 20 to 25 C and is categorized as moderately water soluble (Weber, 1972). Fluometuron was the herbicide of choice to evaluate because cooperating producers at all the MD-MSEA locations apply fluometuron, and detectable levels have been reported in surface water (Coupe et al., 1998; Pereira and Hostettler, 1993). Previous research suggests that herbicide and sediment in runoff is reduced as it moves through grass filter strips and riparian areas. Therefore, research objectives were: to characterize soil properties within different areas of a new (< 1 yr) grass filter strip, established (> 5 yr) grass filter. and a riparian forest to determine the impact of different BMPs on soil properties and the spatial distribution of soil particles within BMP areas; and determine fluometuron adsorption and degradation to these soils to assess the ability of soil from these BMPs to retain fluometuron.

MATERIALS AND METHODS

Soil Characterization

Research was conducted on a Dundee silt loam (fine silty, mixed, thermic, Aeric Ochraqualf) collected from a cropped area, adjacent tall fescue (*Festuca arundinacea* Schreb.) filter strip epipedons (0-2 cm depth); and a Dowling overwash phase (fine, montmorillonitic, thermic, Vertic Epiaquept) from a riparian forest epipedon. These BMP areas surround Beasley Lake in Sunflower Co., MS, in the Mississippi River alluvial floodplain. Samples were collected along a transect beginning at a mixing zone (1 m prior to the filter strip edge, but not in the crop area), the front edge of the filter strip, and at 1 and 2 m from the edge into the filter strip. Riparian forest sampling points were: riparian entrance from 0-25 m, and 50-200 and 400-800 m from the riparian entrance. Samples were analyzed for organic matter (OM) content by a colorimetric procedure (DeBolt, 1974), pH using a 1:2 soil to water suspension (McLean, 1982), and cation exchange capacity (CEC) by extraction and summation of exchangeable acids and bases (Rhoades, 1982). Particle size analyses were conducted using the hydrometer method (Gee and Bauder, 1986).

Fluometuron Adsorption

A batch equilibration method was used to determine fluometuron adsorption to soil collected from all areas described above. Technical grade fluometuron (96.8% chemical purity) was dissolved in 0.01 M $CaCl_2$ to achieve solution concentrations of 0.85, 4.7, 17.7, and 34.9 μmol L^{-1}. Fluometuron solutions contained 166.5 Bq ml^{-1} uniformly ring-labeled ^{14}C-fluometuron (specific activity 17.3 Bq g^{-1}, 99% radiochemical purity). The Langmuir model did not successfully describe the adsorption process for any of the soils evaluated and the Freundlich model only fit adsorption data for some of the soils. Consequently, fluometuron adsorption data were fit to simple quadratic regression equations computed as:

$$y = b_0 + b_1x + b_2x^2 \qquad [1]$$

where y (μmol kg^{-1}) is the amount of herbicide adsorbed at the equilibrium concentration x (pmol L^{-1}), and b_0, b_1, and b_2 (dimensionless) are quadratic coefficients. Estimated fluometuron adsorption from regression equations for different soils was compared at fluometuron equilibrium concentrations of 1 and 12 pmol L^{-1}. The 1 pmol L^{-1} concentration was chosen to describe adsorption of fluometuron to soils at the labeled field rate and 12 pmol L^{-1} was chosen to describe adsorption at a higher rate, approximately 8 times the recommended field rate, based on the concentration range at equilibrium relative to amount added.

fluometuron Degradation

Soils were collected prior to initial fluometuron application in the spring of 1997. Grass filter strip soil sampling points were established 1 m into the strip every 20 m for a 60-m distance. Riparian area soil sampling points were divided into three areas designated as 0 to 25 m (entrance), 50 to 200 m, and 400 to 800 m. The experiment was initiated with the transfer of 40-g soil (oven-dry weight basis) into polypropylene wide-mouth bottles with screw-top caps and treated with an aqueous solution of technical grade fluometuron (96.8% chemical purity) at a rate of 1.75 μg g^{-1} soil. After herbicide amendment, soil moisture was brought to either field capacity (-33 kPa) or moderate to highly saturated conditions by the addition of 0.01 M $CaCl_2$ solution, as determined using a pressure plate apparatus (Cassel and Nielsen 1986). Soil moisture at field capacity resulted in 33%. 40%, 47% (by weight) moisture for cropped area, new filter strip, and established filter strip soils. Moderately saturated soil samples resulted in 64%, 74%, and 76% (by weight) moisture and highly saturated soil samples resulted in 84%. 100%, and 110% (by weight) moisture for soil collected from the riparain entrance, and 50 to 200 and 400 to 800 m from entrance. Samples were weighed and incubated in the dark at 28 C and 50% relative humidity. Samples were frozen at sampling points of 0, 7, 14, 21. 28, 56, and 112 d. Extractable-fluometuron concentration was determined by high performance liquid chromatography (HPLC). Data were fit to a first-order degradation model using the following integrated rate law:

$$\ln[C] = \ln[C]_0 + (-k)t \qquad [2]$$

where [C] (μg g^{-1}) is fluometuron concentration; $[C]_0$ (μg g^{-1}) is initial fluometuron concentration at time zero: k (day^{-1}) is the degradation rate coefficient; and t (day) is time.

The slope from equation [2], which is equal to (k). was used to calculate fluometuron half-life or 50% disappearance time (DT_{50}) in all soils from the equation:

$$DT_{50} = 0.693 / |\text{slope}| \qquad [3]$$

Field Runoff

Field studies were conducted to evaluate the effectiveness of vegetative filter strips in conjunction with three different tillage systems: a conventionally tilled system (CT), a no-till system (NT), and a no-till with wheat (*Triticum* aestivurn L.) residue system (NTR) for reducing runoff volume, sediment, fluometuron and norflurazon in surface runoff. Trials were conducted on runoff plots 4 m x 22 m in Brooksville, MS, on a Brooksville silty clay (fine montmorillinitic, thermic Aquic Chromudert, 3% slope, 3.2% organic matter content, pH 6.3 in Ap horizon). Cotton (*Gossypium hirsutum* L.) was planted in 76 cm rows and all plots received 1.7 kg ailha fluometuron and 1.7 kg ailha norflurazon PRE. A 1-m filter strip of switchgrass (*Panicum virgatum* L.), a perennial grass with a stiff, erect growth habit, was installed at the base of each tillage system, and an unfiltered plot was paired with it for comparison. The samples were analyzed using liquid-liquid extraction and HPLC methodology for determining fluometuron and norflurazon concentrations in runoff. Slope and intercept comparisons at the 10% significance level were used to determine treatment differences. Means of cumulative runoff, sediment and herbicide losses were separated at the 10% significance level using an LS Means procedure. An analysis of variance was used to investigate total runoff, sediment, and herbicide loss. .

RESULTS AND DISCUSSION

Soil Characterization

Sand content was at least 38% in entrance areas for all BMPs, and 5% just prior to entrance into the lake (Table 1). Clay content ranged from 18 to 40% in BMP areas, compared to 13% in the cropped area. This suggests that runoff water kinetic energy decreased as it moved through BMPs, causing coarser fractions to settle out of suspension, and finer sediment to remain suspended before being deposited as distance increased through the BMPs. Gilliam et al. (1994) reported similar results where coarse sediment was deposited close to the field and sediment layers consisting of clay-sized materials developed

with distance. The OM content and CEC were at least 3% and 23 cmol kg^{-1} in soil collected 50-200 and 400-800 m from the riparian entrance, respectively, which was higher than all other experimental soils (Table 1). The OM content and CEC ranged from 2.1 to 2.4% and 18.1 to 18.4 cmol kg^{-1}, respectively, in soil collected from the entrance of the riparian area and interior areas (1 and 2 m) of the established filter strip, which was lower compared to soil from other riparian areas. However, these two soil properties were lowest in soil collected from exterior areas (mixing zone and front edge of the strip) of the established filter strip, all areas of the new filter strip, and the cropped area. The partial decomposition of fescue grass in the established filter strip interior areas likely contributed to higher OM (Benoit et al., 1999). The higher OM content in soil from riparian areas was due to well-decomposed forest litter. Also, slow drainage of surface and subsurface water contributed to saturated conditions in the riparian areas, which can reduce OM decomposition (Lowrance et al., 1985). The higher CEC in these areas results from the combination of higher OM and clay content. Cation exchange capacity was correlated to OM (r = 0.61) and clay (r = 0.76), which emphases the importance of these two soil factors on the CEC (data not shown).

Fluometuron Adsorption

The quadratic parameter coefficients used to model fluometuron adsorption are given in Table 2. Concentrations of adsorbed fluometuron to soils at an equilibrium concentration of 1 pmol L^{-1} ranged from 0.9 to 4.2 *p o l* kg^{-1} (Table 2). Fluometuron concentration adsorbed to soil collected 400-800 m from the riparian entrance was 4.2 pmol kg^{-1} and greater than adsorbed concentrations to all other soils. Adsorption to soil collected 50-200 m from the riparian entrance was 1.3 pmol kg^{-1} less than to soil from the 400-800 m area, and not different than adsorption to soil collected from the riparian entrance and interior areas (1 and 2 m into strip) of the established filter strip. The concentration of adsorbed fluometuron to the riparian entrance and interior areas of the established strip was not different than the 1.6 pmol kg^{-1} adsorbed to cropped area soil, Fluometuron concentrations adsorbed to all areas of the new filter strip and exterior areas of the established filter strip were also not different than the amount adsorbed to cropped area soil. Therefore, retention of fluometuron to soil influenced by the riparian entrance and the new or established filter strip was equal to fluometuron retained in cropped area soil when fluometuron was applied at a labeled field rate.

Fluometuron concentration adsorbed to soils ranged from 5.6 to 49.1 *p o l* kg^{-1} at a higher equilibrium concentration of 12 pmol L^{-1} (Table 2). The concentrations adsorbed to soil collected from new filter strip areas ranged from 5.6 to 9.3 pmol kg^{-1} and were less than the 13.2 pmol kg^{-1} adsorbed to cropped area soil. Therefore, these areas had less adsorptive capacity than the cropped area at this equilibrium concentration. Decreased adsorption to new strip soil was probably due to decreased organic matter (Table 1). Results from other research emphasis a strong correlation of fluometuron adsorption with soil organic matter (Brown et al., 1994; Kozak and Weber, 1983; Mueller et al., 1992; Savage and Wauchope, 1974).

Fluometuron concentrations adsorbed to soil collected from established filter strip areas ranged from less than 14 pmol kg^{-1} in the strip exterior (mixing zone and front edge of strip) to at least 28 μmo kg^{-1} for strip interior when fluometuron equilibrium concentration was 12 pmol L^{-1} (Table 2). Adsorption to soil collected from established filter strip mixing zone was less than to cropped area soil and no different than to soil collected from all areas of the new filter strip. Adsorption to soil from the established filter strip edge was no different than to cropped area soil. However, adsorption to established strip interior was greater than to cropped area soil and at least two times higher than adsorption to soil from all other filter strip areas. Therefore, the potential capacity for retaining fluometuron to soil inside the established filter strip is greater than to soil in the cropped area and to soils associated with all other filter strip areas evaluated. In a similar experiment, Benoit et al. (1999) reported that adsorption of isoproturon, a phenylurea herbicide, to surface soil (0-2 cm) collected from a perennial ryegrass (Lolium perenne L.) filter strip was almost three times higher that to cropped area soil. They attributed higher adsorption to the high density of partially decomposed plant residues.

The concentration of fluometuron adsorbed to soil collected from riparian areas ranged from 25 to 49 pmol kg^{-1} (Table 2). Fluometuron adsorption to soil collected 400-800 m from the riparian entrance was greater than to all other soils in the experiment. Adsorption of fluometuron to soil collected 50-200 m from the riparian entrance was no different than to soil collected 1 m from established filter strip edge and soil from the

riparian entrance was no different than to soil collected 2 m from the established filter strip edge. In general, the retention capacity for several soils influenced by BMPs at an equilibrium concentration of 12 μmol L^{-1} follows the order of magnitude: new strip area and established strip mixing zone < cropped area = established strip edge < established strip 2 m = riparian entrance < established strip 1 m = riparian 50-200 m < riparian 400-800 m (Table 2). There was a strong relationship between fluometuron adsorption and soil OM, clay content, and CEC. which had correlation coefficients of 0.95, 0.56, and 0.89, respectively (Table 3).

The OM content and CEC was highest in soil collected from the riparian area due to the accumulation of well-decomposed forest litter, which can increase herbicide adsorption and prolong herbicide residence time (Reddy et al., 1995). Adsorption increased with an increasing distance into the forest due to increased clay content and an increase in anaerobic conditions, which enhances organic residue preservation (Lowrance et al., 1985). As soil becomes saturated, gas exchange between soil and air is reduced, microbial populations change, soil Eh decreases, and pH changes, which affects enzymatic activity and organic matter decomposition (McLatchey and Reddy. 1998). Spatial differences in texture were due to coarse particle deposition near the forest entrance followed by fine particle deposition as runoff moved downslope. The OM content and fluometuron adsorption in established strip interior soil was greater than strip exterior due to the presence of partially decomposed grass residue. This resulted in an adsorptive capacity for the established strip interior that was comparable to the riparian forest entrance and 200-400 m from the entrance. Adsorption to soil from the new filter strip was lower compared to other BMPs due to the absence of OM accumulation. However, strip maturity should improve OM quality and composition if vegetation is maintained and decomposed plant residues remain on the filter strip (Locke and Bryson, 1997).

Results from this study indicate that fluometuron adsorption to soil from all areas influenced by a new or established filter was no different when applied fluometuron concentrations were within the range of a labeled field rate. Therefore, benefits from the retention of fluometuron should be immediate and only improve over time in a newly installed fescue filter strip if properly maintained. However, fluometuron retention to soil from established filter strip interior and riparian areas was greater than to soils from all other areas when fluometuron was applied to these soils at approximately 8 times the recommended field rate, which should only occur in an accidental spill situation. Therefore, installation of these BMPs promote soil properties such as OM, clay content, and consequent CEC that are proven to enhance the retention capacity of soil media, which should theoretically increase the potential affinity for fluometuron.

Fluometuron Degradation

Fluometuron half-lives in all soils influenced by a BMP, regardless of moisture conditions, were at least 49 d shorter than the 112-d half-life in the cropped area soil (Table 4). Lowest predicted fluometuron half-lives were 12, 14, 28. 35, and 38 d in soil collected 1 m from the established filter strip edge (field capacity), riparian entrance (moderately saturated), riparian 50 to 200 m (highly saturated), riparian 400 to 800 m (highly saturated), and riparian 400 to 800 m (moderately saturated), respectively, and different from all other soils. Half-lives of 55, 61, and 63 d for the new grass filter strip, riparian 50 to 200 m (highly saturated), and riparian entrance (highly saturated), respectively, were only lower than half-life in the cropped area soil. A fluometuron half-life of 12 d in established filter strip soil was the shortest among all soils (Table 4). Half-life in the new filter strip soil was 55 d. Along with the addition of plant residues, the rapid degradation in established versus new filter strip soil could be attributed in part to the growth of dense vegetation compared to the less dense new strip. Living vegetation not only contributes to degradation in soil by uptake and metabolism, but it can enhance microbial populations due to root exudates (Boyle and Shann 1998). Therefore, fluometuron degradation should increase with time in new filter strip soils as OM increases through additions *of* plant residue materials, which provide substrate for microbial activity and populations.

Higher fluometuron degradation by microorganisms in riparian area soils could be attributed to higher OM (Table 1) and soil moisture content compared to the cropped soil. This corresponds to other research that suggests higher moisture and labile organic carbon substrates in surface soil will promote both size and composition of microbial populations (Locke and Bryson 1997). Fluometuron degradation in soil from the riparian entrance occurred more rapidly in moderate (64% by weight) compared to highly (84% by weight) saturated moisture conditions based on half-lives of 14 and 63 d, respectively (Table 4). Wolt et al.

(1992) found similar results for flumetsulam, where half-life was 40 and 183 d in aerobic and strongly anaerobic systems, respectively. In riparian soil collected 50 to 200 m from the entrance, predicted half-life was 33 d shorter in soil under moderate (74% by weight) compared to highly (100% by weight) saturated moisture conditions (Table 4). However, half-life in riparian soil collected 400 to 800 m from the entrance at both moisture contents was the same, and no different than riparian soil collected 50 to 200 m from the entrance under moderately saturated conditions (Table 4). The difference in fluometuron degradation rate in soil from different riparian areas may be due to a change in the composition of microorganisms that degrade fluometuron. A major influence on microbial type and population could be due to the spatial variation in soil moisture conditions influenced by the hydrologic regime in the riparian area. Riparian entrance soil is typically aerobic, but with increasing distance through the riparian area down to the lake, soil becomes wetter and anaerobic conditions occur more frequently. Therefore, the composition of microorganisms near the riparian entrance were likely aerobic in nature and capable of rapidly degrading fluometuron under moderate soil moisture conditions. However, when saturated conditions occur, microbial degradation processes are likely to decline in riparian entrance soil because of the more anaerobic conditions. Fluometuron degradation rate in soil collected 400 to 800 m from the entrance did not change when moisture conditions were changed because inherent microorganisms were likely more anaerobic in nature.

This study demonstrates that soil influenced by an established fescue filter strip and riparian forest can rapidly degrade fluometuron. Fluometuron degradation was more rapid in soil influenced by BMPs by at least 49 d compared to cropped area soil based on half-lives. Degradation in established filter strip soil was no different from riparian entrance soil, but was 43 d more rapid than in new filter strip soil. Half-life increased by 49 and 33 d in soil collected at the riparian entrance and 50 to 200 m from the entrance, respectively, as soil moisture increased from moderate to highly saturated soil moisture conditions. Soil moisture content was the only difference between riparian soil samples, which suggests that as the soil system approaches an anaerobic state, inherent degrading microbes become quiescent. Therefore, fluometuron degradation may decrease in soil at the entrance and 200 to 400 m from the entrance of the riparian area after a runoff event. However, once soil in these areas becomes more aerobic, quiescent microbes become more active and degradation processes increase. Fluometuron degradation in soil at 400 to 800 m from the riparian entrance should remain constant regardless of soil moisture conditions. Since soil in this area likely remains at or near a natural anaerobic state, microbial activity should not be affected by additional water following a runoff event because inherent microbial populations should be principally anaerobic in this area of the forest. In any case, soils influenced by these BMPs have the potential to rapidly degrade fluometuron; thus there should be a strong effort to establish and maintain BMPs.

Field Runoff

When regressed against the natural log of time, there was no difference between the rate of runoff in CT and NTR, regardless of filter strip level (Table 5). However, the rate of total runoff in NT systems was faster than in CT or NTR systems. This can be attributed to a lack of residue present on the NT surface to impede surface runoff. Regardless of filter strip level, total runoff was 59 and 53% lower in CT and NTR than in NT (Table 6).

The majority of fluometuron and norflurazon loss occurred in the initial runoff event after herbicide application. Regardless of tillage system or filter strip presence, fluometuron loss in the initial event was 60 to 89% of the cumulative loss over the sampling period. Norflurazon loss in the initial runoff event constituted 61 to 98% of the cumulative loss over the sampling period. No more than 16% of applied fluometuron and norflurazon was lost during the sampling period. Based on slope and intercept comparisons, filter strips reduced fluometuron rate of loss 54, 46, and 63% in CT, NT and NTR, respectively. Norflurazon rate of loss was 38, 36, and 79% lower in CT, NT, and NTR, respectively (Table 5). Other studies have shown that filter strips reduce the rate of herbicide loss compared to the unfiltered control (Murphy and Shaw 1997, Tingle et al. 1998). When a filter strip was not present, the rate of fluometuron loss from CT was 31 and 33% slower than in NT and NTR, respectively (Table 5). Previous research has shown that total runoff volume may be reduced by physical barriers on the soil surface, either existing plant residue from a cover crop, or by tillage (Yoo and Touchton 1988). Regardless of tillage system, cumulative fluometuron and norflurazon losses were reduced 35 and 36%, respectively, when a filter strip was present (Table 7). Murphy and Shaw (1997) reported that tall fescue filter strips reduced yearly

fluometuron and nofflurazon loss in runoff 48 and 50%, respectively. Cumulative fluometuron loss from CT was 36% less than from NT. Similarly, cumulative norflurazon loss from CT was 53% less than from NT and 40% less than from NTR (Table 6). Norflurazon is less water soluble and more lipophilic than fluometuron. thus less norflurazon moved off-site compared to fluometuron. Other studies have shown that herbicide concentrations in runoff were greatest where the herbicide was applied over-the-top of straw, and lower where it was applied to bare tilled soil (Mote et al. 1990).

Based on slope and intercept comparisons, sediment loss was reduced 81% in NT when a filter strip was present (Table 8). When a filter strip was not present, CT and NTR reduced the rate of sediment loss 49 and 75%. respectively, compared to NT (Table 8). In the absence of a filter strip, cumulative sediment loss was 55 and 80% less in CT and NTR. respectively, compared to NT (Table 8). Thus, when a filter strip is not present, NTR can reduce cumulative sediment loss more than CT or NT. The results of this study indicate that switchgrass filter strips effectively reduce herbicide concentrations in runoff, regardless of tillage system. The most effective combination of tillage system and filter strip for reducing runoff volume, sediment load, and herbicide concentration in runoff is NTR with a switchgrass filter strip.

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Table 1. Various chemical and physical properties of cropped, filter strip, and riparian soils.

Sampling Point	pH	CEC	OM	Sand	Silt	Clay
		cmol kg^{-1}		%		
Crop	4.7	11.7	0.7	28	59	13
New-strip mix	5.7	12.8	0.1	48	21	30
New-strip edge	6.0	13.6	0.1	33	48	19
New-strip 1 m	6.0	14.7	0.2	30	50	21
New-strip 2 m	6.4	14.0	0.5	24	51	25
Established-strip mix	5.9	12.2	0.4	46	36	18
Established-strip edge	6.0	14.4	0.9	40	39	21
Established-strip 1 m	6.3	18.2	2.1	21	58	22
Established-strip 2 m	6.0	18.1	2.4	31	46	23
Riparian 0-25m	6.8	18.4	2.3	38	40	22
Riparian 50-200m	6.4	23.3	3.1	7	62	26
Riparian 400-800m	5.8	31.7	4.5	5	55	40
LSD (α= 0.05)	0.3	2.1	0.6	2	5	3

Table 2. Quadratic regression coefficients determined for fluometuron adsorption.

Sampling Point	Regression equation	R^2	Adsorption at equilibrium	
			1 μmol L^{-1}	12 μmol L^{-1}
			µmo kg^{-1}	
Crop	Y = 0.8440 + 0.7762 **X** - 0.0214	0.99	1.6 cdef	13.2 d
New-strip mix	Y = 0.8110 + 0.0254 **X** - 0.0311	0.98	0.9 f	5.6 h
New-strip edge	Y = 0.5803 + 0.3055 **X** - 0.0199	0.99	0.9 f	7.1 fg
New-strip 1 m	Y = 1.23 + 0.1058 **X** - 0.0317 X^2	0.98	1.2 ef	6.9 gh
New-strip 2 m	Y = 1.24 + 0.1251 **X** - 0.0454 X^2	0.98	1.4 def	9.3 e
Established-strip	Y = 0.7426 + 0.2757 **X** - 0.0295	0.98	1.1 f	8.3 ef
Established-strip	Y = 0.7093 + 0.6827 **X** - 0.0297	0.99	1.4 def	13.2 d
Established-strip 1	Y = 0.2756 + 2.24 **X** - 0.0080 X^2	0.99	2.5 bcd	28.3 b
Established-strip 2	Y = 0.6299 + 1.61 **X** - 0.0325 X^2	0.99	2.3 bcde	24.6 c
Riparian 0-25m	Y = 1.09 + 1.51 **X** - 0.0408 X^2	0.99	2.6 bc	25.1 c
Riparian 50-200m	Y = 0.8227 + 2.09 **X** - 0.0134 $\mathbf{X^2}$	0.99	2.9 b	27.8 b
Riparian 400-800m	Y = 0.9401 + 3.23 **X** - 0.0656 $\mathbf{X^2}$	0.99	4.2 a	49.1 a

Table 3. Correlation coefficients for soil properties with estimated fluometuron adsorption.

Soil properties	Pearson correlation coefficients Across soil samples
pH	0.17
Cation exchange capacity	0.89
Sand	-0.72
Silt	0.48
Clay	0.56
Organic matter	0.95

Table 4. First-order rate and regression coefficicents and predicted fluometuron half-lives.

Sampling Point[a]	Degradation rate	Coefficient of	Half life
	k	R^2	DT_{50}
Crop (SMC_A)	0.0062	0.91	112
New tall fescue filter strip	0.0126	0.99	55
Established tall fescue filter strip	0.0577	0.98	12
Riparian entrance (SMC_A)	0.0495	0.94	14
Riparian entrance (SMC_B)	0.0110	0.93	63
50-200 m from entrance (SMC_A)	0.0248	0.95	28
50-200 m from entrance (SMC_A)	0.0114	0.80	61
400-800 m from entrance	0.0182	0.91	38
400-800 m from entrance	0.0198	0.77	35
LSD (0.05)	0.0047	0.11	16

[a] Abbreviations: soil moisture content A (SMC_A), and soil moisture content B (SMC_B).

Table 5. Slope and intercept comparisons describing the effect of tillage systems and filter strips on runoff, fluometuron, and norflurazon loss over the growing season.

	Regression Parameters								
	Runoff			Fluometuron			Norflurazon		
Treatment	R^2	y-int	Slope	R^2	y-int	Slope	R^2	y-int	Slope
Conventional tillage	0.85	305a	143a	0.96	85a	5.6a	0.92	45a	2.1a
Conventional tillage + filter strip	0.89	259 a	73a	0.87	41b	2.6b	0.93	18b	1.3b
No-tillage	0.71	168a	327b	0.96	31c	8.1c	0.99	92c	3.3c
No-tillage + filter strip	0.89	346 a	350b	0.94	105d	4.4ad	0.92	74d	2.1a
No-tillage w/ residue	0.83	287 a	171a	0.96	135c	8.3c	0.97	94c	4.4d
No-tillage w/ residue + filter strip	0.88	209 a	112a	0.96	81a	3.1bd	0.95	58e	0.92b

Table 6. Effect of tillage system on total runoff and herbicide losses.

Tillage system	Runoff	Herbicide loss	
		Fluometuron	Nomurazon
	kL ha^{-1}	g ha^{-1}	
Conventional tillage	734a	56a	27a
No-tillage	1781b	87b	58b
No-tillage with residue	839a	69ab	45c

Table 7. Effect of filter strips on cumulative herbicide losses.

Filter strip	Herbicide loss	
	Fluometuron	Norflurazon
	g ha^{-1}	
Absent	86a	53a
Present	56b	34b

Table 8. Slope, intercept, and sediment loss comparisons describing the effect of tillage systems and filter strips on sediment loss over the growing season.

Treatment	Sediment loss	Regression parameters		
	kg ha^{-1}	R^2	y-intercept	Slope
Conventional tillage	317b	0.75	41a	58a
Conventional tillage + filter strip	162a	0.76	33a	29ab
No-tillage	701c	0.82	195b	114c
No-tillage + filter strip	129a	0.86	43a	22ab
No-tillage with residue	137a	0.71	19a	28ab
No-tillage with residue + filter strip	50a	0.98	13a	9b