WATER QUALITY IMPACTS OF NATURAL FILTER STRIPS IN KARST AREAS

B. J. Barfield, R. L. Blevins, A. W. Fogle, C. E. Madison, S. Inamdar, D. I. Carey, V. P. Evangelou

ABSTRACT. *Naturally occurring riparian filter strips are widely recommended as a technique for removing chemicals from flow prior to entering a stream. Data on their effectiveness is sparse as is information on the partitioning of chemicals trapped by various mechanisms in these strips. Studies were conducted on the effectiveness of natural riparian grass buffer strips in removing sediment, atrazine, nitrogen and phosphorus from surface runoff. The strips were located in a karst watershed. No-till and conventional-tillage erosion plots served as the sediment and chemical source area. Runoff from the plots was directed onto 4.57, 9.14, and 13.72 m filter strips where the inflow and outflow concentrations and flow rates were measured. Trapping percentages for sediment and chemicals typically ranged above 90%. An evaluation was made of the distribution of trapped chemicals among infiltrated mass and mass stored in the surface layer. The analysis showed that most of the chemicals were trapped by infiltration into the soil matrix and that trapping efficiency increased with filter stip length and with fraction of water infiltrated.*
Keywords. *Sediment, Filter strips, Agricultural chemicals, Trapping efficiency, Infiltration.*

Widespread interest in improving quality of surface waters has led to emphasis on best management practices for controlling agricultural non-point source pollution. Physical reasoning coupled with limited data led a number of researchers and agency officials to the conclusion that the best places to control non-point source pollution are on-site, where flows are not concentrated into channels. Thus, control of sediment and chemicals is best accomplished while the flow is still classed as shallow overland flow.

One practice that has received widespread interest is the use of naturally occurring filter strips to remove chemicals from the flow prior to their entry into a stream. The filter strips serve a number of functions related to surface water quality, including:

- Reducing flow velocity, resulting in loss of transport capacity which leads to deposition of sediment and adsorbed chemicals on the exchange phase.
- Enhancing infiltration of water, sediment, and chemicals into the soil matrix.
- Adsorbing chemicals onto the litter, vegetation, and surface layer of soil, all of which reduce the outflow concentration.
- Storing chemicals in the stored soil water in the surface layer for subsequent biological or chemical transformation, or uptake between runoff events.

Several studies have been conducted on trapping of sediment and chemicals in natural and constructed grass filter strips. Studies on the movement of sediment have been the most definitive, with a number of investigators collecting laboratory and field data as well as developing process-based models. Empirical studies have been conducted on grasslands of varying slopes from flat lands near 0% slope to steep slopes near 30%. Trapping efficiencies were frequently greater that 90%, depending on sediment size, slope steepness and length, propensity of runoff to channelize, and density of vegetation (Hayes and Harriston, 1983; Hayes et al., 1984; Barfield and Albrecht, 1982; Wilson, 1967; Dillaha et al., 1986, 1989; Neibling and Alberts, 1979). These studies, along with computer models, show that coarser sediments (both primary particles and aggregates) are deposited in a delta at the leading edge of a filter strip, causing channelization to occur after significant deposition. Downstream of the delta, silt-size aggregates and primary particles are trapped by settling and infiltration with actual percentages depending on velocity, flow depth, and media density. Clay-size primary particles are typically trapped only by movement of particles into the soil matrix with infiltrating water. The studies also showed that the effectiveness of the filter strips for trapping sediment decreased with time, particularly if the filter strip became inundated with sediment.

Studies by Dillaha et al. (1986, 1988, 1989) on 4.6 and 9.1 m plots indicate that trapping is most efficient when flow is spread over the filter strip, and that channelization reduces trapping significantly. Even with channelization, trapping was in the range of 30 to 60%. Research by Cooper et al. (1987) and Lowrence et al. (1984, 1988) on naturally occurring riparian vegetation also indicate that these zones are major sinks for sediment.

Article has been reviewed and approved for publication by the Soil & Water Div. of ASAE. Presented as ASAE Paper No. 92-2100.

The authors are **Billy J. Barfield, *ASAE Fellow Engineer*,** Professor Emeritus of Agricultural Engineering (currently Head, Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater); **Robert L. Blevins**, Professor Emeritus of Agronomy, **Alex W. Fogle**, Hydrologist, Kentucky Geological Survey; **C. Elizabeth Madison**, former Graduate Assistant, Agronomy; **Shreeram Inamdar**, former Graduate Assistant, Agricultural Engineering; **Daniel I. Carey**, Hydrologist, Kentucky Geological Survey; and **V. P. Evangelou**, Professor of Agronomy, University of Kentucky, Lexington, Ky. **Corresponding author:** Prof. Billy J. Barfield, Biosystems and Agricultural Engineering Dept., Oklahoma State University, Stillwater, OK 74078-0497; tel: (405) 744-5431; fax: (405) 744-6059; e-mail: bill@agen.okstate.edu.

Table 1. Examples of previous studies on nutrient trapping on nutrient trapping

Reference	Study Location	Filter Description	Nutrient Source	Plot Length (m)	Nutrient	Trapping Efficiency (%)
Dillaha et al., 1989	Blacksburg, Va.	Orchardgrass (5-16% slope)	Cropland runoff	4.6	P(total)	75
					N(total)	61
				9.1	P(total)	87
					P(total)	61
Dillaha et al., 1988	Blacksburg, Va.	Orchardgrass (5-16% slope)	Simulated feedlot	4.6	P(total)	39
					N(total)	43
				9.1	P(total)	52
					N(total)	52
Doyle et al., 1977	Unknown	Fescue (10% slope)	Dairy waste on silt loam soil	1.5	P(dissolved)	8
					NO_3	57
				4.0	P(dissolved)	62
					NO_3	68
Young et al., 1980	Unknown	Corn-oats-or orchardgrass mixture (4% slope)	Feedlot	13.7	P(total)	88
					N(total)	87
		Sorghum - sudangrass mixture (4% slope)	Feedlot	13.7	P(total)	81
					N(total)	84
Thompson et al., 1978	Minnesota	Orchardgrass (slope unknown)	Dairy manure on frozen orchardgrass	12	P(total)	55
					N(total)	45
				30	P(total)	61
					N(total)	69
Magette et al., 1989	Maryland	Fescue (slope unknown)	Cropland runoff	4.6	P(total)	6
					N(total)	–15
				9.2	P(total)	20
					N(total)	35
Parsons et al., 1991	Raleigh, N.C.	Bermuda-crabgrass mixture (slope unknown)	Cropland runoff	4.3-5.3	P(total)	26
					N(total)	50

In other studies, the effectiveness of vegetative filter strips in controlling nutrients in runoff was evaluated. Examples are given in table 1, illustrating the highly variable results. In general the fraction of nutrients trapped increased with filter length. However, nutrients are not trapped as effectively as sediment. Also, the very short filter strips were not highly effective in trapping soluble nutrients, and in fact sometimes became a source of N and P, as shown by the negative trapping efficiency of the studies by Magette et al. (1989) cited in table 1.

Due to the desire to prevent disruption of naturally developed channelized flow, the experimental studies of natural filter strips (Dillaha et al., 1986, 1988, 1989; Cooper et al., 1987; Lowrence et al., 1984, 1988) did not include monitoring of inflow to the filter strip. Rather, flow from an adjacent similar source plot was monitored and assumed to be the same as the flow onto the filter. Measurements from adjacent plots are frequently not representative of sediment flowing onto the filter being evaluated. Plot-to-plot variability of runoff, sediment, and chemical discharge can be very large (Barfield et al., 1984), even when attempts are made to have "identical plots". Using this adjacent-plot data can lead to erroneous conclusions concerning trapping efficiency. In addition, failing to develop an accurate measure of inflow results in insufficient information to partition trapped chemicals among infiltrated mass, and mass adsorbed in the surface layer. Such a partitioning is necessary to understanding the trapping processes occurring in the filter and hopefully allow for projection to different sites. For example, in our experimental studies infiltration rates were very high explaining a large percent of the trapping of chemicals. Projection of these results to a soil with low infiltration rates would require modification to account for the differences in infiltration. Such a modification would only be possible if the actual fraction trapped by infiltration were known.

To augment information from previous studies, our project had as its objective the development of a data base on trapping of sediment and chemicals in natural grass riparian vegetation where inflows and outflows were carefully measured. In addition, we estimated the partitioning of trapped chemicals among those adsorbed and those infiltrated. Studies were conducted in an area of karst geology with very high infiltration rates.

EXPERIMENTAL PROCEDURES

Grass filter strips for this study were selected in 1990 on an undisturbed area in a karst watershed with a naturally occurring mixture of bluegrass and fescue sod. A pair of naturally occurring filter strips were utilized for each strip length of 4.57, 9.14, and 13.72 m. These filter strips were located immediately downslope from standard erosion plots (4.57 m wide × 22.1 m long on a 9% slope) which had been established in 1989. The erosion plots consisted of three conventional-tillage plots and three no-tillage plots, which gave a variable sediment load to the filter strips. One of the pair of filter strips received runoff from conventional-tilled erosion plots and one from no-till plots. A schematic of the plot and filter strip layout is given in figure 1 and plot details are given in table 2. All of the erosion plots and the filter strips were located on the Kentucky Agricultural Experimental Station Spindletop Research Farm in a well-drained Maury silt loam soil (fine, mixed, mesic *Typic Palendalfs*) with an average slope of approximately 9%. These karst soils are highly

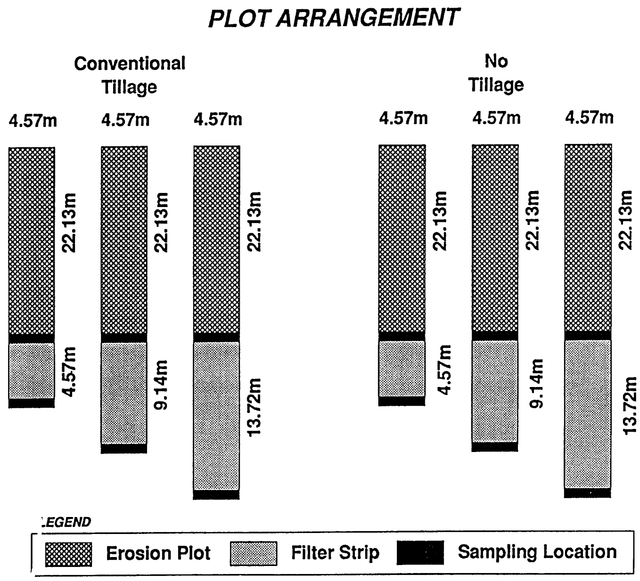

Figure 1–Schematic of erosion plot and filter strip arrangement.

structured with numerous macropores and are underlain with limestone with numerous solution channels.

Metal borders were placed on the two sides and the uphill end of the erosion plots in order to direct the flow to the filter strip. The lower end of the erosion plot had a narrow (approximately 14 cm) excavated trench across the width of the plot. A combination wood and metal abutment was fixed against the upslope face of the trench to prevent subsurface flow from entering the trench. A 10 cm gutter was placed on the downslope side of the wood abutment to facilitate sampling. A metal sampling device with 10 controllable openings was placed over the trench. The openings were normally closed, diverting flow directly onto the filter. When opened, the flow moved directly into the gutter for measuring flow rate and collecting flow samples for sediment and nutrient concentration measurements. Details of the sampler are given in Fogle et al. (1993).

The Kentucky Rainfall Simulator (Moore et al., 1983) was used to deliver 6.35 cm/h of simulated rainfall for 2 h on the erosion plots to simulate a 10-year storm on an intensity basis. This rainfall event was repeated once on each plot after a period of approximately three weeks. Each test on a given filter strip took about three days to set up and conduct. Dates for each test are given in table 3. Tests such as these take several days per plot. Obviously not all plots were run on one day. The time between tests was as close as possible to three weeks, considering weather conditions, etc. Each plot was treated with the same sequence of events prior to testing, and all plots were brought to saturation conditions prior to testing; therefore, the timing of the first test should not be significant.

Immediately prior to run 1 on each plot, chemicals typical of those applied for weed control and fertilization of corn were broadcast applied to the erosion plot at rates shown in table 2.

We desired to have a conservative estimate of the impact of filter strips on trapping in karst areas. To this end, we brought the filter strips to near saturation prior to allowing chemical-laden runoff to enter the filter. To accomplish the state of near saturation, the erosion plots were covered with plastic after chemical application, and rainfall applied in order to generate a high rate of runoff onto the filter strips. This process was continued until flow moved all the way through the filter strips. The plastic was then removed and the erosion plots were wet to the point of incipient runoff. At that point, the data collection began.

Table 2. Characteristics of filter strips

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Filter length (m)	9.14	9.14	13.72	4.57	4.57	13.72
Tillage on source plot	CT*	NT†	NT	CT	NT	CT

Chemicals applied to erosion plots†
- 170 kg N/ha as granular ammonium nitrate
- 44 kg P_2O_5 /ha as triple super phosphate
- 2.24 kg atrazine/ha

Slope = 9%
Soil type - Maury silt loam
Simulated rainfall intensity
Event 1 - 63.5 mm/h - 2 h
Event 2 - 63.5 mm/h - 2 h
(approx. 3 wks after Event 1)

* CT - Conventional Tillage.
† No Tillage
‡ Chemicals applied only prior to first event. No chemicals prior to second event.

Rainfall was not applied to the filter strip itself. While this might have been desirable, the simulator did not have sufficient size to cover the erosion plot and filter strip. Rainfall on the strip would have diluted the flow and likely made the effluent from the strip less concentrated. Theoretically, rainfall on the filter strip would have affected trapping efficiency, distribution of mass trapped between that infiltrated and adsorbed, and concentration ratio, which are all dependent on rainfall rate. Thus, the conclusions from a study with rainfall on the filter strip would only apply for the specific rainfall rate used. A simple analysis can be made, showing how the outflow concentration, mass infiltrated, etc., are affected by rainfall. This analysis can be used to make first order conjectures as to how the mass infiltrated, outflow concentration and outflow mass would respond to rainfall on the filter strips. The analysis procedure is presented in Appendix A along with an illustrative example.

Runoff from both the erosion plots and the filter strips was sampled periodically through each run. Runoff from the erosion plots onto the filters was measured and sampled for 10 s at 5 min intervals using the apparatus described by Fogle et al. (1993). Flow rates were measured volumetrically, and separate samples were taken for laboratory determination of sediment and chemical concentrations. One-liter samples were taken for sediment analysis and 0.5 L samples for chemical analyses. Samples taken for chemical analysis were stored at 8°C to prevent degradation. Sediment analyses were conducted gravimetrically. Soluble nitrate (NO_3) and ammonium (NH_4) analysis were conducted with a Technicon Auto Analyzer System II. Soluble phosphorus (P) was measured with an automated microplate reader, model EL 311 with a colorimetric method. Soluble atrazine was measured with an immunoassay method. Further details are given in Madison (1992).

DATA ANALYSIS PROCEDURES

This analysis considers only the impact of the filter strip on sediment and dissolved solids. We did not consider trapping of chemicals on the exchange phase of the deposited sediment.

TRAPPING EFFICIENCY

A simple analysis that can be made is determination of trapping efficiency,

$$T_E = \frac{M_i - M_o}{M_i} \qquad (1)$$

where M_i is the total mass flowing onto the filter and M_o is the total mass flow off the filter. M_i and M_o are given by

$$M_i = \int_o^T q_i C_i \, dt \qquad (2)$$

and

$$M_o = \int_o^T q_o C_o \, dt \qquad (3)$$

where C_i and C_o are inflow and outflow concentrations, q_i and q_o are inflow and outflow rates and T is the duration of the test.

Dissolved solids and sediment are trapped by several mechanisms as illustrated in figure 2 or:

- Infiltration of mass into and through the soil matrix, carried there by the infiltrating water.
- Adsorption onto vegetation and the soil surface layer plus storage in the soil water in the surface layer. This will be referred to as mass adsorbed.

Rather than simply predicting the trapping efficiency, trapped mass was divided into fraction infiltrated and fraction adsorbed. The surface layer includes the residue present. This division allowed us to separate the impact of infiltration from that of adsorption. The mass balance being used is shown conceptually in figure 2. In a typical analysis of overland flow, exchange with the surface layer is assumed to be by diffusion. The analysis in this article is different in that mass flow is assumed to move into and out of the surface layer. This movement, obviously, is not in accordance with potential flow that would be predicted by a flow net or potential flow theory, but is a result of macropore flow and flow through the surface residue. In the karst area being studied, the soils are highly structured and contain numerous macropores. When the surface layer becomes saturated, these macropores can return flow to the surface if the slopes are sufficiently steep. We have observed that to happen on slopes near 9%. The flow into and out of the surface layer is assumed to be a result of the presence of macropores and flow through the residue. This figure is used to show, conceptually, our hypothesis of flow in the filter strip. Whether or not exchange with the surface layer occurs by diffusion or mass flow would not affect the analysis that follows.

Using the mass balance shown in figure 2,

$$M_i - M_o = M_{inf} + M_{as} \qquad (4)$$

where M_{inf} is infiltration mass and M_{as} is mass adsorbed and stored in the surface layer. The mass stored would likely be stored in the water in the soil matrix. Mass adsorbed would be adsorbed on both the soil matrix in the surface layer, and on the vegetation. Infiltrated water, on the other hand, is that which moves into the soil matrix and does not return to the surface layer.

To be able to calculate mass infiltrated, the infiltrated volume must be known. This is calculated as the difference between inflow and outflow volume of runoff. Knowing the infiltrated volume, $\forall_{inf}$, the mass infiltrated into the soil matrix becomes

$$M_{inf} = \forall_{inf} C_{avg} \qquad (5)$$

where C_{avg} is the average concentration over the filter estimated as

$$C_{avg} = \frac{\overline{C}_i + \overline{C}_o}{2} \qquad (6)$$

where $\overline{C}_i$ is the average inflow concentration and $\overline{C}_o$ is the average outflow concentration, both volume averaged over the duration of the test.

Knowing M_{inf}, M_i, and M_o, then M_{as} can be calculated as a residual, or

$$M_{as} = M_i - M_o - M_{inf} \qquad (7)$$

Equations 5 through 7 can be used to make a first partition of the chemicals among the various components.

RESULTS

Data on runoff, sediment, and chemical yield exiting the erosion plots and filter strips is given in table 3. Although we attempted to use erosion plots and filter strips with similar characteristics, the plot to plot variability is evident. This variability is due to a number of factors including cover, residue, and timing of the test. Further description of the results of the runoff and yield from erosion plots is given in Madison (1992) where the variability is discussed.

TRAPPING EFFICIENCY

Using the concentrations and flow rates measured at the end of the erosion plot and filter, the inflow and outflow mass were calculated and utilized to determine the trapping efficiency for sediment and dissolved solids as well as the mass of water infiltrated. These values are summarized in tables 3 and 4. The trapping efficiencies for sediment and chemicals were generally higher than those observed by other researchers for similar sized plots. This is not surprising, since our plots were in an area of karst geology, characterized by well structured soils with rapid infiltration rates. Although the vegetative plots were saturated prior to

Table 3. Mass of sediment and chemicals in runoff from erosion plots and filter strips

Filter Strip Length and No.			Runoff (kg)		Atraz (mg)		Phosph (mg)		NO_3-N (mg)		NH_4-N (mg)		SED (kg)	
			EP	FS	EP	FS	EP	FS	EP	FS	EP	FS	EP	FS
4.57 m - CT	Event 1	07/03/91	6,073	713	288	23.2	10,140	1,270	5,232	574	21,840	2,678	103	2.62
	Event 2	07/26/91	9,268	942	197	15.8	1,710	203	11,300	539	23,670	1,814	258	8.44
4.57 m - NT	Event 1	07/11/91	9,230	470	2,049	23.2	34,850	2,513	117,300	1,970	120,000	2,974	55.7	0.18
	Event 2	07/30/91	9,009	720	292	13.5	6,658	387	20,840	466	22,320	1,750	67.4	4.13
9.14 m - CT	Event 1	06/25/91	3,223	27.7	49.8	0.007	11,940	45.0	7,570	8.24	23,220	49.3	26.6	0.0188
	Event 2	07/18/91	6,982	617	361	0.534	298,900	21,110	304,000	23,060	307,300	21,540	212	1.10
9.14 m - NT	Event 1	06/27/91	4,306	*	15.5	*	1,446	*	1,506	*	3,852	*	19.6	*
	Event 2	07/22/91	473	11.6	40.6	0.252	1,377	1.3	10,220	7.10	10,470	6.80	21.5	0.00105
13.72 m - CT	Event 1	07/15/91	8,859	623	3,529	78.6	40,640	1,713	63,770	3,274	114,400	5,936	28.4	2.09
	Event 2	08/01/91	11,634	706	456	17.9	2,982	232	15,220	326	42,210	2,149	361	2.06
13.72 m - NT	Event 1	07/01/91	609	*	46.8	*	452	*	591	*	1,337	*	.98	*
	Event 2	07/24/91	4,932	478	111.3	0.405	1,300	30.0	1,350	48.7	9,973	33.8	10.3	0.00244

EP - Mass discharged from erosion plot; FS - Mass discharged from filter strip; CT - Erosion plot treated with conventional tillage; NT - Erosion plot treated with no tillage;

* No discharge from the filter strip.

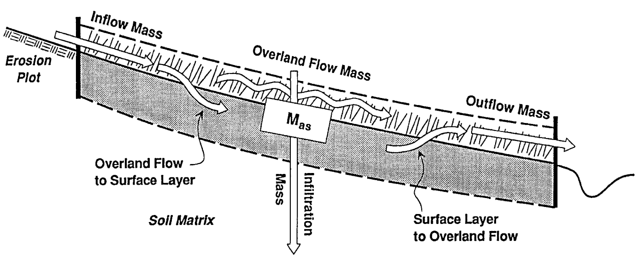

Figure 2–Illustration of the mass balance for a given dissolved solid on the filter strip.

Table 4. Trapping efficiencies for sediment and chemicals

Plot Length	% Runoff Infil	Trapping Efficiencies*				
		ATRAZ	PHOS	NO_3-N	NH_4-N	SED
4.57 m length						
Event 1	91.6	93.6	90.1	93.7	92.6	98.6
Event 2	90.9	93.7	91.2	96.5	92.2	95.3
Average	91.3	93.6	90.6	95.1	92.4	96.9
9.14 m length						
Event 1	99.6	100.0	99.8	99.9	99.9	100.0
Event 2	94.4	99.6	96.4	96.2	96.5	99.7
Average	97.0	99.8	98.1	98.1	98.2	99.9
13.72 m length						
Event 1	96.5	98.9	97.9	97.4	97.4	99.6
Event 2	92.1	97.9	95.0	97.1	97.3	99.7
Average	94.3	98.4	96.4	97.3	97.3	99.7

* Average of no-till and conventional tillage.
ATRAZ - Atrazin; PHOS - Phosphorus; NO_3-N - Nitrate Nitrogen; NH_4-N - Ammonia Nitrogen; SED - Sediment.

the test to the point of flow through to the outlet, infiltration rates were still extremely high, as evidenced by the high fraction of runoff which infiltrated in the filter strip (see table 4). Figure 3 Shows that trapping efficiency increases dramatically as the percentage of runoff infiltrated increases. One would anticipate that much of the trapping was a result of infiltration into the soil matrix. This will be evaluated in the following section.

An attempt to evaluate the impact of different length filter strips on trapping efficiency was also made by plotting the ratio of trapping efficiency to the percentage of runoff infiltrated against filter length. Both infiltration and filter length will affect trapping efficiency. In order to evaluate the impact of filter length on trapping efficiency, the impact of runoff infiltration must be separated from trapping efficiency by dividing by the percentage of runoff infiltrated. Figure 4 shows that trapping efficiency generally increases with increased filter length. The improvement in trapping efficiency is not significant when

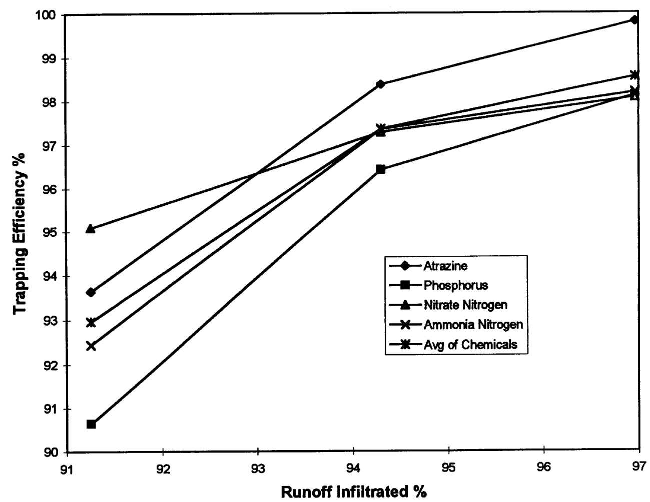

Figure 3–Trapping efficiency vs runoff infiltrated.

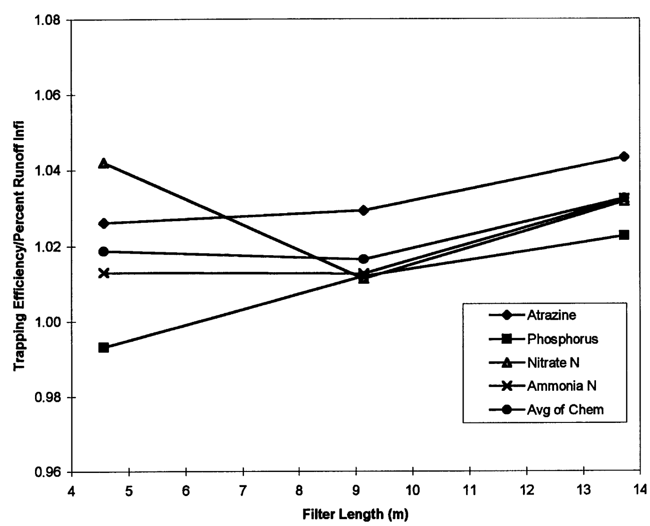

Figure 4–Impact of filter length on trapping efficiency.

the filter length was increased from 4.57 to 9.14 m. However, the better performance of the 13.72 m filters over 9.14 m filters is evident. The increase in trapping efficiency with filter length results from an increased opportunity for runoff infiltration and for chemical adsorption when the length of filter strip increases.

Table 5. Analysis of variance

Variable	Degrees of Freedom	Calculated F Value	F_{crit}*	P_{value}
Trapping efficiency				
Chemical	4	1.22	2.76	0.236
Plot length	2	24.52	3.35	< 0.001
Infiltrated mass				
Chemical	3	1.76	2.82	0.168
Plot length	2	10.05	3.20	< 0.001
Chemical adsorbed				
Chemical	3	1.75	2.82	0.170
Plot length	2	10.83	3.20	< 0.001
Peak outflow/inflow concentration				
Chemical	3, 44	4.84	2.81	0.005
Plot length	2, 45	2.04	3.20	0.142
Avg. outflow/inflow concentration				
Chemical	3, 44	4.15	2.81	0.011
Plot length	2, 45	1.06	3.24	0.355

* Alpha level of 0.05.

An analysis of variance (ANOVA) was conducted on chemicals and plot length to determine if a significant difference existed with an alpha level of 0.05. The results, in table 5, show that the evidence is not sufficient to reject the null hypothesis of no difference between chemicals, but overwhelmingly supports rejection of the null hypothesis of no difference between plot lengths. Thus, plot length effects on trapping efficiency are significant.

Partitioning of Fraction Trapped: Infiltration and Adsorption

The infiltrated mass, M_{inf}, and mass adsorbed, M_{as}, were determined by equations 5 and 7 for dissolved solids and normalized by the total mass flowing off the erosion plots (inflow mass to the filter strips). These values are plotted in figures 5 and 6 along with a best fit polynomial equation for no till and conventional till runoff plots. Since sediment is deposited and infiltrated differentially by size fractions, this analysis was not made for sediment.

The results show that the fraction adsorbed generally increases with plot length while the fraction infiltrated decreases. This is consistent with what would be expected; that is, the opportunity for adsorption increases with increasing length, causing a decrease in average concentration. Infiltrated mass is equal to infiltrated volume times average concentration over the filter. At the lower end of the filter, concentration decreases, making the average concentration smaller. Apparently, the decreased concentration more than offsets the increased infiltration.

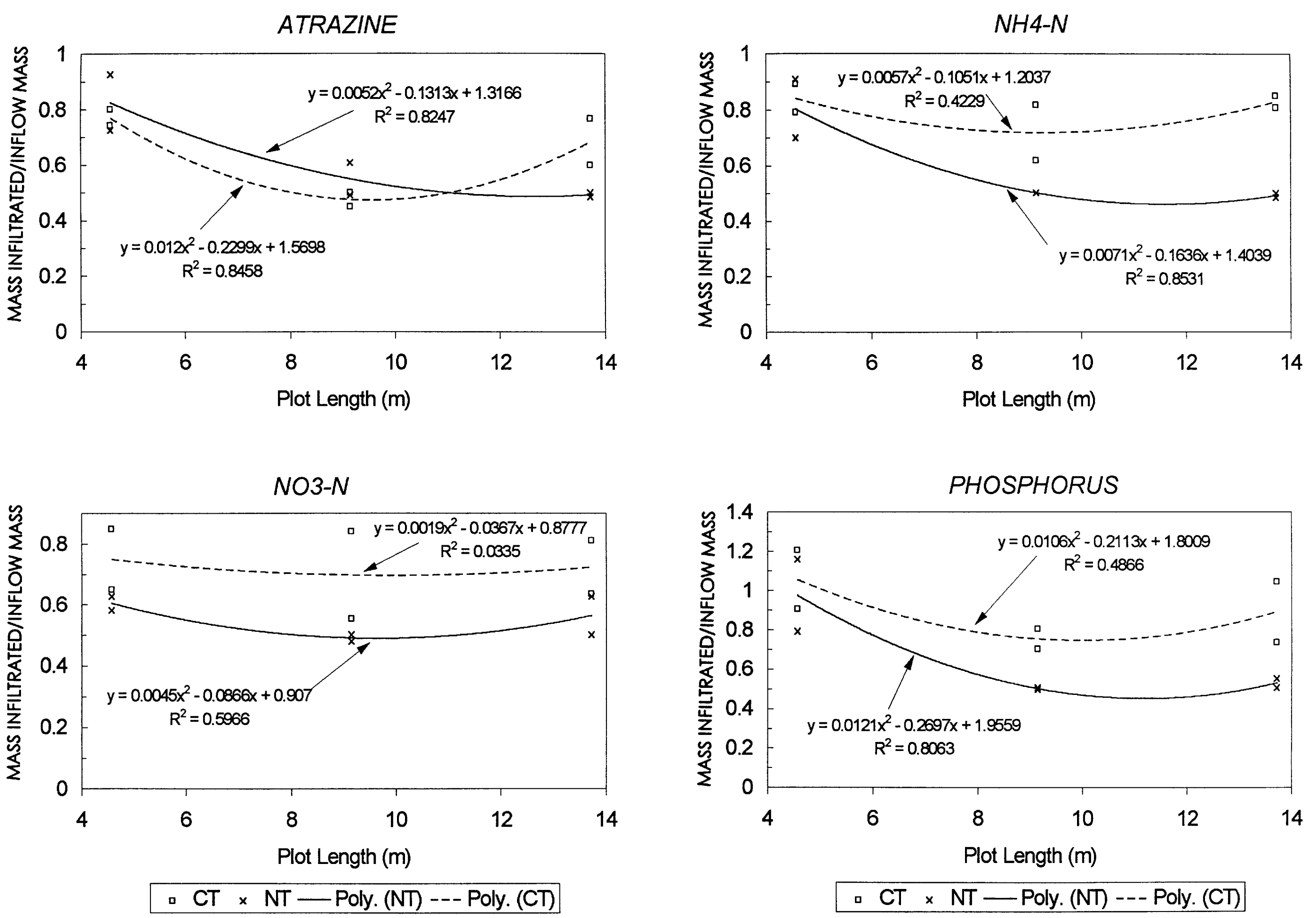

Figure 5–Infiltrated mass for all chemicals, plot lengths, and tillage treatments.

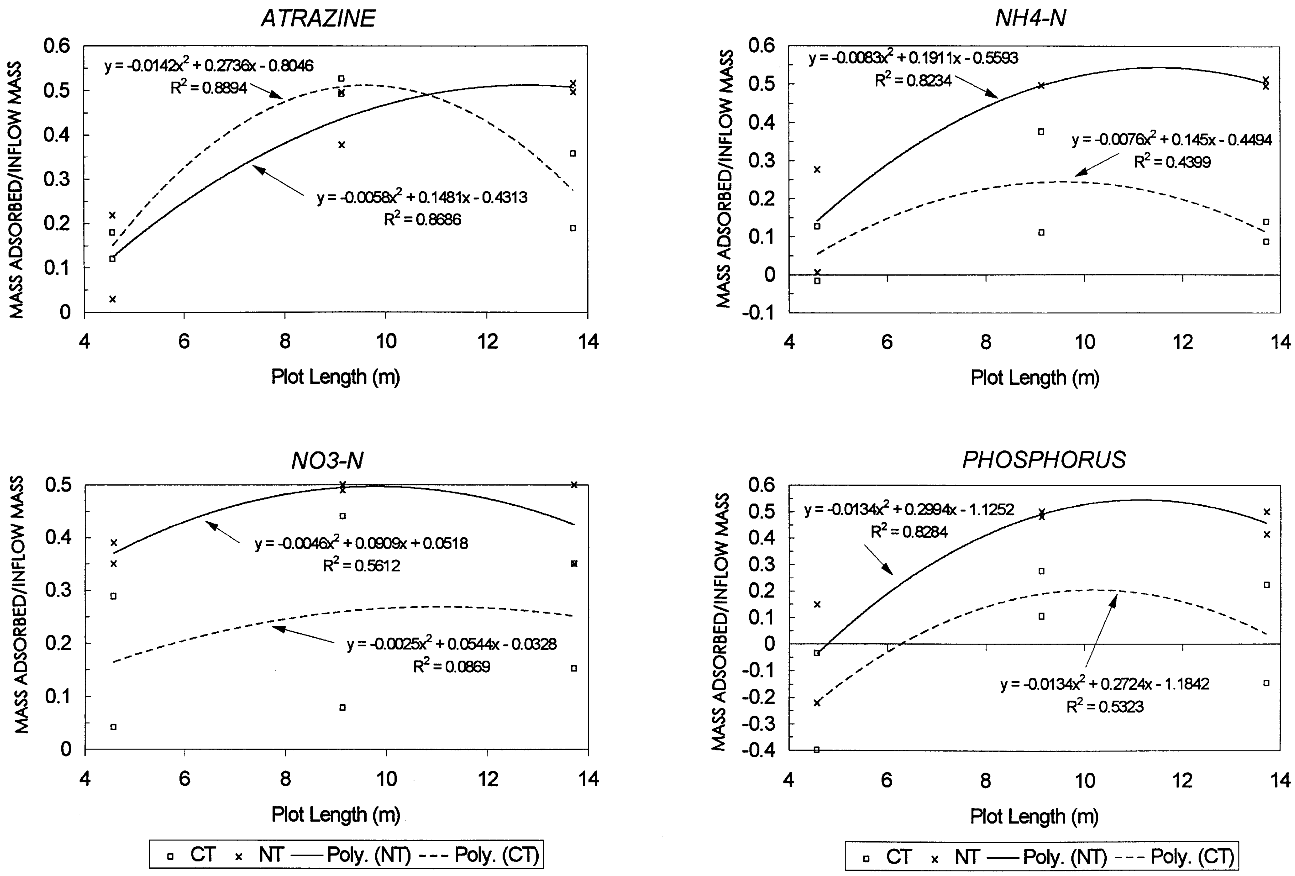

Figure 6–Adsorbed and stored mass for all chemicals, plot lengths, and tillage treatments.

This would correspond to a decrease in the fraction infiltrated.

By partitioning these results as shown, one can get some indication of the potential impact of a filter strip in areas where infiltration is minimal. In that case, it would be anticipated that the fraction trapped would be adsorbed in the surface layer. The results in figure 6 indicate that this fraction could range from near zero for phosphorous on the 4.57 m strip to near 50% on longer strips.

The negative values for adsorption of phosphorous indicate phosphorous is being generated on the filter strip. During the tests, some phosphorous was transported off the plots in granular form and as chemical adsorbed on the active phase of the sediment and would not have contributed to the mass of dissolved phosphorous calculated by equation 2. This was typically deposited in the delta that formed at the inlet to the filter strip. For the very short filter strips, this delta covered much of the strip length, providing a source of dissolved phosphorous for the outflow measurement. These measurements are consistent with results presented by Dillaha (1989) who indicated that effluent concentrations of phosphorous were sometimes greater than inflows.

A single factor ANOVA with an alpha level of 0.05 was conducted on infiltration as well as adsorbed mass, evaluating the impact of chemical type and plot length. The results, summarized in table 5, show that there is insufficient evidence to reject the null hypothesis of no impact of chemical type on either infiltration mass or adsorbed mass, but sufficient evidence does exist to reject the null hypothesis of no impact of filter strip length on both. Thus, filter strip length effects on infiltration mass and adsorbed mass are significant.

INFLOW AND OUTFLOW CONCENTRATIONS

Peak Concentrations. An important evaluation is the impact of riparian vegetative filter strips on peak concentration in runoff. A decrease in peak concentration would result in a lower peak discharge in the receiving

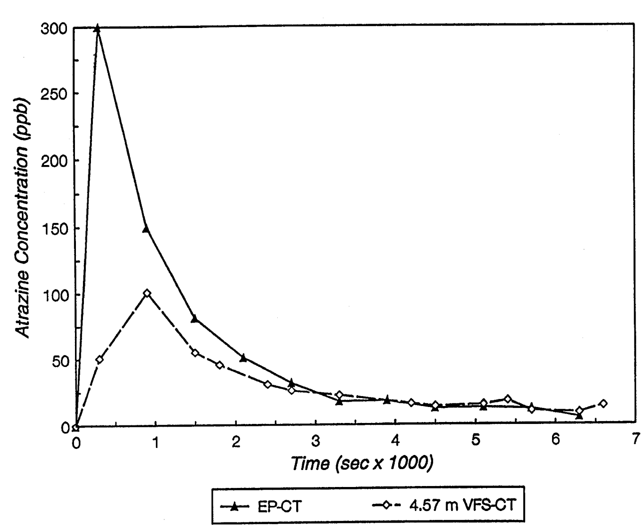

Figure 7–Inflow and outflow concentrations for Atrazine on the 4.57 m plot.

stream and, possibly, a lower impact. An example of the impact of the riparian grass vegetation on the concentrations of atrazine for the 4.56 m filter strips in our study is given in figure 7. The results show a greatly reduced peak discharge concentration. The ratio of peak outflow to peak inflow concentration was evaluated for all tests in this study and is presented graphically in figure 8. Based only on peak concentrations, it is obvious that the filter strips had a significant impact on water quality for all chemicals except phosphorus. The 4.57 m plots had higher ratios than the two longer plots, except for phosphorus. This is consistent with results from Magette et al. (1989) as shown in table 1. The reason for the high value for phosphorus is that the phosphorus fertilizer used was granular and would wash onto the plots to become a source later in the tests.

Average Concentrations. Much of the reduction in peak concentration shown in figure 8 is a result of early infiltration of high concentration runoff from the erosion plot. There is a time delay between the start of runoff onto the filter and the time when discharge begins to occur from the filter. During this time, nearly all of the water and accompanying high concentration chemicals flowing onto the filter are infiltrated. With passing time, the concentration of chemicals in the inflow from the erosion plot approaches a pseudo-steady value and the reduction in concentration is likely due to dilution from interchange with the surface layer and storage. An indication of this impact in reducing the concentration in the runoff can be seen in the ratio of concentrations for time periods after discharge occurs from the filter. The ratio of average concentration from the filter to that from the erosion plots for this later time period is given in figure 9. With the exception of P, the average concentration ratios are generally less than one, indicating some filtering of chemicals. Phosphorous concentration ratios are generally greater than 1, indicating that the filter is a source of phosphorus after the inflows and outflows reach some quasi-equilibrium. This also consistent with results from Magette et al. (1989) as shown in table 1.

A single variable ANOVA with an alpha level of 0.05 was conducted on peak concentration ratio and average concentration ratio, evaluating the impact of chemical type and plot length. The results are shown in table 5. Both peak and average concentrations results clearly indicate that the null hypothesis of no difference between chemicals can be rejected but the null hypothesis of no difference between plot lengths cannot be rejected. Thus, chemical type had a significant impact on concentration ratio, but plot length did not.

IMPACT OF CONVENTIONAL VERSUS NO TILL

It was not the intent of this study to evaluate the impact of no-till and conventional-tillage on trapping, but to simply have plots that had high and low sediment loads and runoff potentials. The plots that we used had no-till or conventional-tillage treatments the year before the studies reported in this article were conducted. During the studies reported in this document, no crop was grown. Therefore it would be misleading to evaluate the impact as being from

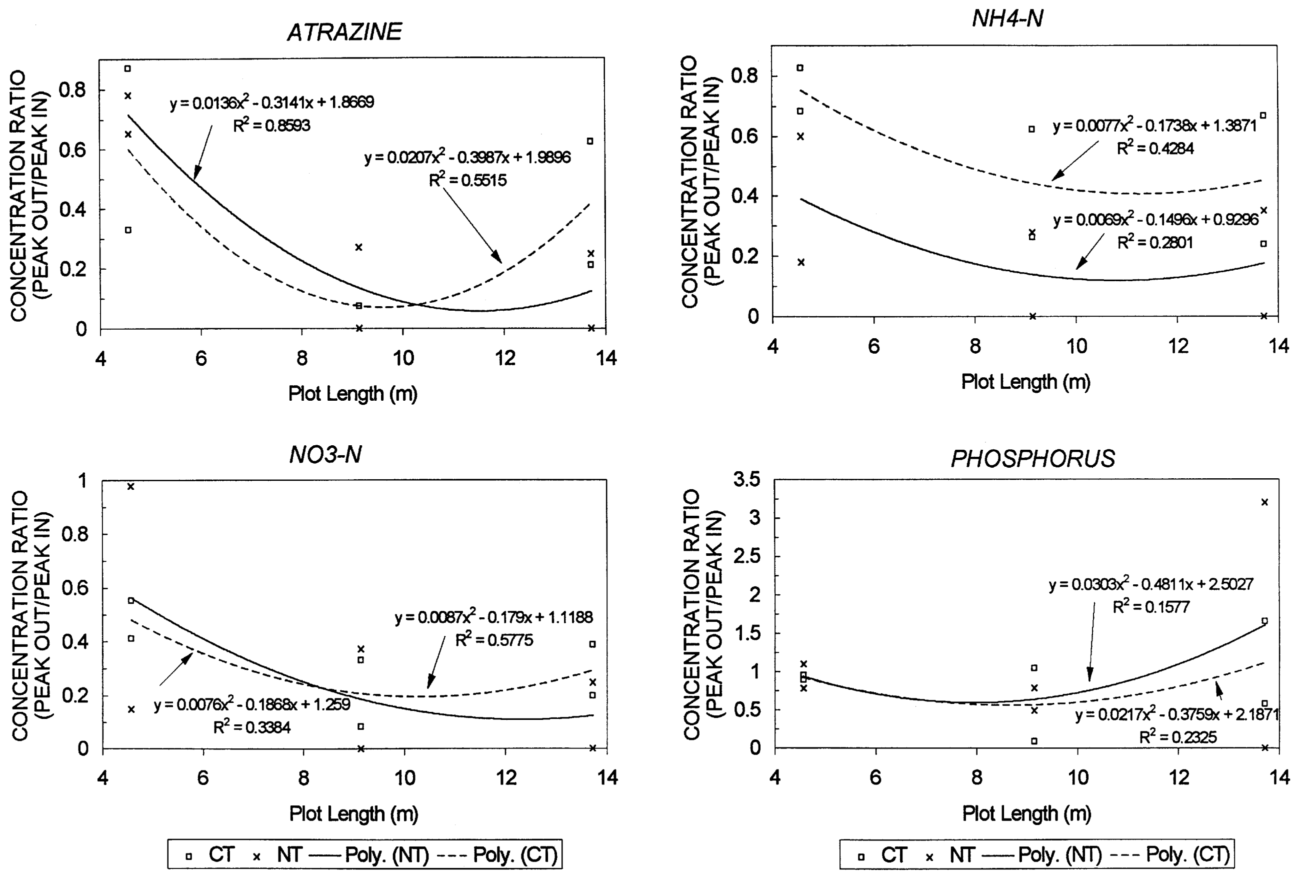

Figure 8–Ratio of peak outflow to inflow concentrations.

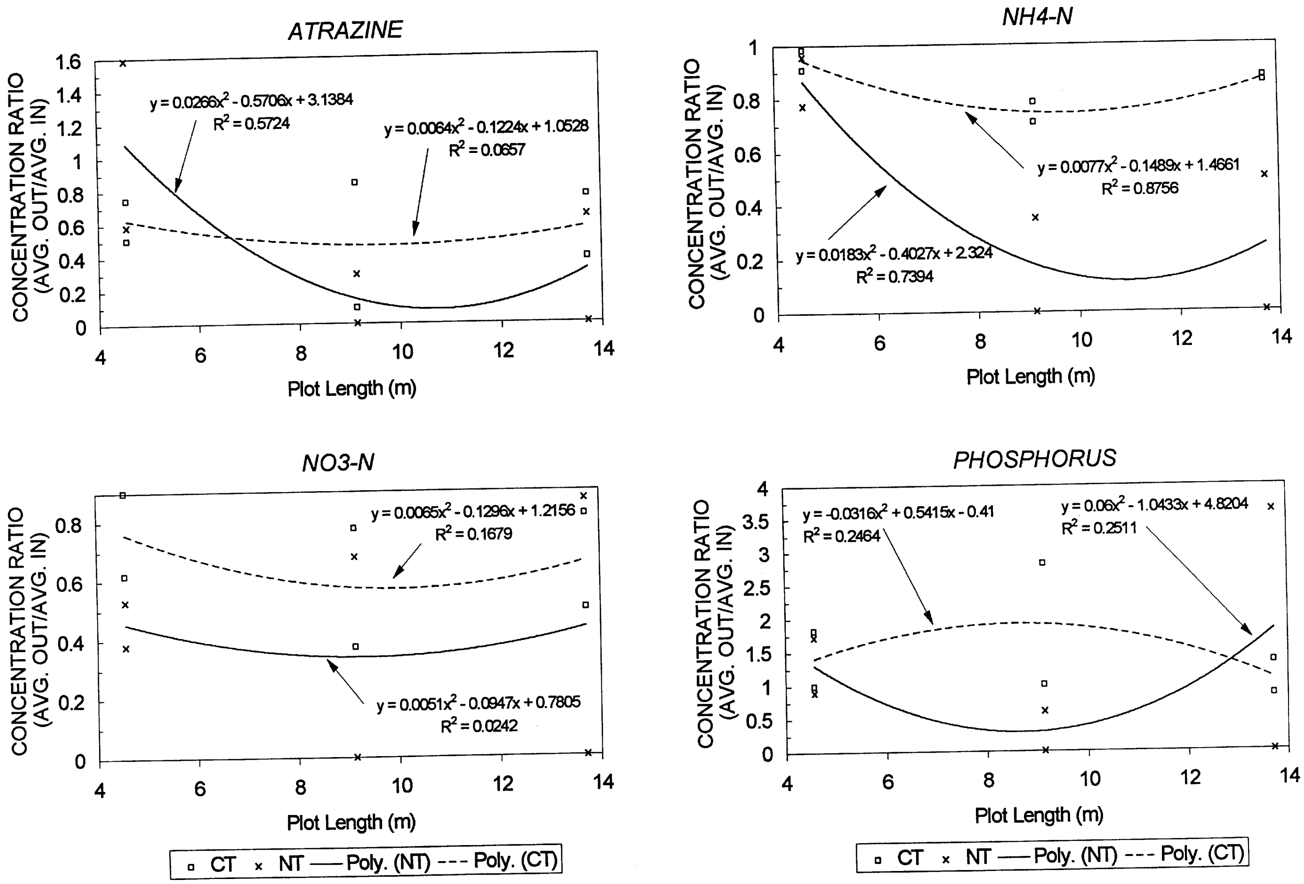

Figure 9–Ratio of average outflow to average inflow concentration after flow-through begins.

no-till and conventional-tillage treatments. The use of these erosion plots did, however, give a wide range of sediment loads and runoff rates. In spite of these cautions, the analysis that was made in this study differentiated between the conventional tillage and no-till plots. The results can be seen in figures 5-8.

The results are inconclusive. For mass infiltrated, peak concentration ratio, and average concentration ratio, the values for conventional-tillage are near or higher than no-till. For mass adsorbed and stored, the values for conventional-tillage were near or lower than no-till. The reason for these results are not clear.

Summary

Studies were conducted on the impact of the natural fescue filter strips on discharge of water, sediment, and agricultural chemicals. Filter strips of naturally occurring fescue of lengths from 4.57, 9.14, and 13.72 m were utilized downslope from standard erosion plots to trap sediment and chemicals. All plots were located in a karst watershed. The erosion plots were treated with atrazine, nitrogen, and phosphorus. Rainfall was applied to the plots with the Kentucky Rainfall Simulator. Runoff from the erosion plots was directed onto the filter and measurements made of flow into the filter and off the filter. The results showed that the filters trapped over 90% of sediment and chemicals. Trapping efficiency is generally improved when the length of filter strips increases. Estimates were made of the distribution of trapping between infiltration mass and storage and adsorption on the soil surface layer. It was determined that the major trapping mechanism was by infiltration, followed by adsorption in the surface layer.

Acknowledgments. The authors thank the Kentucky Agricultural Experiment Station, the Oklahoma Agricultural Experiment Station, and the USDA-CSREES President's Water Quality Initiative for support of this work.

References

Barfield, B. J., R. I. Barnhisel, J. L. Powell, M. C. Hirschi, and I. D. Moore. 1984. Erodibilities and eroded size distribution of Western Kentucky mine spoil and reconstructed topsoil. ASAE Paper No. 84-2539. St. Joseph, Mich.: ASAE.

Barfield, B. J., and S. A. Albrecht. 1982. Field evaluation of the effectiveness of vegetative filters for controlling sediment from strip mines. In *Proc. 1982 Nat. Symp. Surface Mine Hydrology, Sedimentology, and Reclamation*. Lexington, Ky.: College of Engineering, University of Kentucky.

Cooper, J. R., J. W. Gilliam, R. B. Daniels, and W. P. Robarge. 1987. Riparian areas as filters for agricultural sediment. *J. Soil Sci. Society of America* 51(2):416-420.

Dillaha, T. A., J. H. Sherrard, and D. Lee. 1986. Long-term effectiveness and maintenance of vegetative filter strips. VPI-VWRRC-BULL 153. Blacksburg, Va.: Virginia Polytechnic Institute and State University.

Dillaha, T. A., S. H. Sherrard, D. Lee, S. Mostaghimi, and V. O. Shanoltz. 1988. Evaluation of vegetative filter strips as best management practices for feedlots. *J. Water Pollution Control Fed.* 60(7):1231-1238.

Dillaha, T. A., R. B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. *Transactions of the ASAE* 32(2):491-496.
Doyle, R. C., G. C. Stanton, and D. C. Wolfe. 1977. Effectiveness of forest and grass buffer filters in improving the water quality of manure polluted runoff. ASAE Paper No. 77-2501. St. Joseph, Mich.: ASAE.
Fogle, A. W., and B. J. Barfield. 1993. A low head loss sampling device for monitoring inflow to natural vegetated filter strips. *Transactions of the ASAE* 36(3):791-793.
Hayes, J. C., B. J. Barfield, and R. I. Barnhisel. 1984. Performance of grass filters under laboratory and field conditions. *Transactions of the ASAE* 27(5):1321-1331.
Hayes, J. C., and J. Harriston. 1983. Modeling the long term effectiveness of vegetative filter strips as onsite sediment control. ASAE Paper No. 83-2081. St. Joseph, Mich.: ASAE.
Lowrance, R. R., S. McIntyre, and C. L. Lance. 1988. Erosion and deposition in a field/forest system estimated using cesium-137 activity. *J. Soil and Water Conserv.* 43(2):195-199.
Lowrance, R. R., R. L. Todd, and L. E. Asmussen. 1984. Nutrient cycling in an agricultural watershed: II. Streamflow and artificial drainage. *J. Environ. Qual.* 13(1):27-32.
Madison, C. E. 1992. Tillage and grass filter strip effects on sediment and chemical losses. M.S. thesis. Lexington, Ky.: Department of Agronomy, University of Kentucky.
Magette, W. L., R. B. Brinsfield, R. E. Palmer, and J. D. Wood. 1989. Nutrient and sediment removal by vegetated filter strips. *Transactions of the ASAE* 32(2):663-667.
Moore, I. D., M. C. Hirschi, and B. J. Barfield. 1983. Kentucky rainfall simulator. *Transactions of the ASAE* 26(4):1085-1089.
Neibling, W. H., and E. E. Alberts. 1979. Composition and yield of soil particles transported through sod strips. ASAE Paper No.79-2065. St. Joseph, Mich.: ASAE.
Parsons, J. E., R. B. Daniel, J. W. Gilliam, and T. A. Dillaha. 1991. The effect of vegetation filter strips on sediment and nutrient removal from agricultural runoff. In *Proc. Environmentally Sound Agricultural Conf.*, Orlando, Fla.
Thompson, D. B., T. L. London, and B. Garish. 1978. Winter and spring runoff from manure application plots. ASAE Paper No. 78-2032. St. Joseph, Mich.: ASAE.
Wilson, L. G. 1967. Sediment removal from flood water by grass filtration. *Transactions of the ASAE* 19(1):35-37.
Young, R. A., T. Handwrites, and W. Anderson. 1980. Effectiveness of vegetative buffer strips in controlling pollution from feedlot runoff. *J. Environ. Qual.* 9(3):483-487.

APPENDIX A — IMPACT OF RAINFALL ON FILTER STRIP

For the tests conducted, the filter strips were near saturation at the start of test. During tests, water was ponded over most of the filter strips, hence infiltration rates would not be changed by rainfall. If one assumes that the infiltration rate is unchanged by rainfall, then

$$\mathcal{V}_{or} = \mathcal{V}_{o} + \mathcal{V}_{rain} \qquad \text{(A1)}$$

where $\mathcal{V}_{or}$ is the outflow volume with rain on the filter strip, $\mathcal{V}_{o}$ is outflow volume without rain on the filter strip, and $\mathcal{V}_{rain}$ is the volume of rain falling on the filter strip. From equations 5 and 6, modified for the condition of rainfall on the filter strip

$$M_{infr} = \left[\frac{\overline{C}_i}{2} + \frac{\overline{C}_{or}}{2} \right] \mathcal{V}_{inf} \qquad \text{(A2)}$$

where M_{infr} refers to mass infiltrated when filter strip plots are given a rain treatment, $\overline{C}_{or}$ is outflow concentration when rainfall is occurring and other terms as defined earlier in the body of the text. But

$$\overline{C}_{or} = \frac{M_{or}}{\mathcal{V}_{or}} = \frac{M_i - M_{infr} - M_{as}}{\mathcal{V}_o + \mathcal{V}_{rain}} \qquad \text{(A3)}$$

where M_{or} is the mass outflow during rain. Using equation A-3 in equation A-2,

$$M_{infr} = \left[\frac{\overline{C}_i}{2} + \frac{M_i - M_{infr} - M_{as}}{2\left(\mathcal{V}_o + \mathcal{V}_{rain}\right)} \right] \mathcal{V}_{inf} \qquad \text{(A4)}$$

Simplifying

$$M_{infr} = \left[\frac{\overline{C}_i}{2} + \frac{M_i - M_{as}}{2\left(\mathcal{V}_o + \mathcal{V}_{rain}\right)} \right] \left[\frac{\mathcal{V}_{inf}}{1 + \dfrac{\mathcal{V}_{inf}}{2\left(\mathcal{V}_o + \mathcal{V}_{rain}\right)}} \right] \qquad \text{(A5)}$$

If it is assumed that M_{as} remains unchanged with rainfall, then equation A-5 can be used to show the impact of rain on the filter strip and how outflow conditions depend on the amount of rain.

IMPACT OF RAINFALL ON FILTER STRIP - ILLUSTRATIVE EXAMPLE

The above procedure to evaluate the impact of rainfall on the filter strip is illustrated with the data selected from table 3. Using the Atrazine data from Event 1 for the 13.72 m - CT plot taken on 07/15/91, varying levels of rainfall on the plot were assumed and outflow concentrations, mass infiltrated, and mass discharged were determined. In the determination, equation A-5 was used to estimate mass

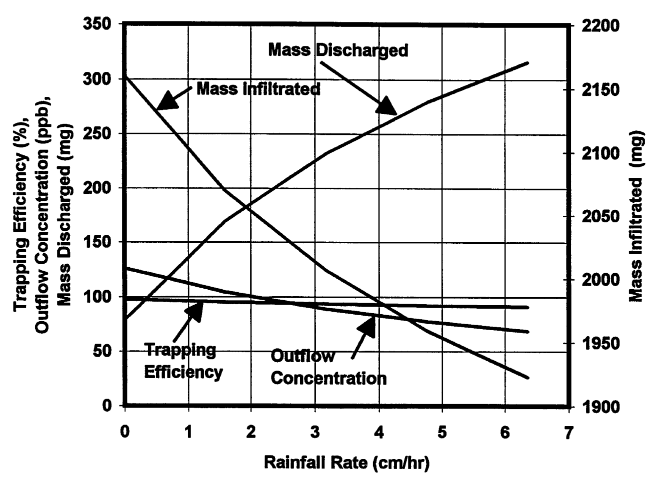

Figure A1–Illustration of impact of filter strip rainfall rate on trapping efficiency, outflow concentration, and mass discharged.

infiltrated, M_{infr}. Knowing M_{infr}, the mass outflow, M_{or}, could be calculated, based on the assumption that M_{as} is constant. Knowing M_{or}, and V_{or} determined from equation A-1, the outflow concentration, C_{or} , could be determined. The results are plotted in figure A1.

The results of this theoretical evaluation show that the outflow concentration should decrease due to the dilution effect of rainfall. This in turn leads to a decrease in mass infiltrated and trapping efficiency and an increase in mass discharged. Since mass infiltrated is proportional to the average of inflow and outflow concentration and the outflow concentration is decreasing, one would expect the mass infiltrated to decrease. This would correspond to an increase in mass discharged and a decrease in trapping efficiency as shown. The measured trapping efficiency value for zero rainfall was 97.7%. The predicted trapping efficiency for 6.25 cm of rain was 91.1%, a significant decrease.

It should be pointed out that the assumption was made that the mass adsorbed remained constant. Since the dilution effect of rainfall along the filter would likely result in a decrease in the mass adsorbed, it is possible that the effect of rainfall would be a further decrease in trapping efficiency. Unfortunately, there is no way to evaluate such an impact with this simple analysis.

These results point to a need to develop more sophisticated models of the distribution of chemicals trapped in vegetative filter strips and to collect data to validate the models.