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ASSESSMENT OF EFFECTIVENESS OF BUFFER ZONES IN REMOVING IMPURITIES IN RUNOFF FROM AREAS TREATED WITH POULTRY LITTER.
PART II: SOURCE AREA TO BUFFER AREA RATIO EFFECTS

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ABSTRACT

ASSESSMENT OF EFFECTIVENESS OF BUFFER ZONES IN REMOVING IMPURITIES IN RUNOFF FROM AREAS TREATED WITH POULTRY LITTER. PART II: SOURCE AREA TO BUFFER AREA RATIO EFFECTS

Vegetative filter strips (VFS) are known to reduce runoff losses of nutrients, solids, and other materials from land areas treated with fertilizers. Although VFS effectiveness is known to depend partially on the relative lengths of filter and pollutant source areas, there is little experimental evidence available to quantify this dependence. This is particularly the case when VFS are implemented down-slope of pasture areas treated with animal manures such as poultry litter. This study assessed the influences of pollutant source area (treated with poultry litter) and VFS lengths on VFS removal of total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), total phosphorus (TP), total organic carbon (TOC), total suspended solids (TSS), and fecal coliform (FC) from incoming runoff for a silt loam soil with fescue cover. Litter-treated lengths of 6.1, 12.2, and 18.3 m with corresponding VFS lengths of up to 18.3 m, 12.2 m, and 6.1 m, respectively, were examined. Runoff was produced from simulated rainfall applied at 50 mm/h for 1 h of runoff. Concentrations of the parameters analyzed were unaffected by litter-treated length but demonstrated a first-order decrease with increasing VFS length except in the cases of TSS and FC. Mass transport of TKN, NH_3-N, PO_4-P, and TP increased with increasing litter-treated length (due to increased runoff) and decreased (approximately first-order) with increasing VFS length. Effectiveness of the VFS in terms of TKN, NH_3-N, PO_4-P, and TP removal from runoff ranged from 6.5 to 96.3% depending on the particular parameter, litter-treated length, and VFS length. The data collected during this study can be helpful in developing and testing simulation models of VFS performance and can thus aid in design of VFS for pasture areas treated with poultry litter.

P. Srivastava, D.R. Edwards, and T.C. Daniel

Completion Report to the U.S. Department of the Interior, Geological Survey, Reston, VA, March, 1995.

Keywords - Non-point Source Pollution/Vegetative Filter Strips/Poultry Litter

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INTRODUCTION

Land application of manures associated with concentrated animal production increases the fertility of the receiving soils. Manure application, however, can lead to diminished quality of downstream waters due to off-site losses of manure constituents such as carbon (C), nitrogen (N), and phosphorus (P) in storm runoff as found, for example, by Westerman et al. (1983, 1985, 1987) and Edwards and Daniel (1993).

Vegetative filter strips (VFS) have been investigated as a management option for retaining potential pollutants at or near their origin and thus minimizing their entry into downstream waters. Vegetative filter strips consist of grassed (or other vegetation) areas installed down-slope of potential pollutant source areas. Due to their low installation and maintenance costs and perceived effectiveness in removing pollutants, conservation and regulatory agencies are encouraging VFS use beneath pollutant sources such as cropland, feed lots, and manure-treated areas (Dillaha et al., 1989).

Vegetative filter strips can improve the quality of incoming runoff by enabling deposition of pollutants associated with solids, adsorption of pollutants by plant material, and infiltration of soluble pollutants. The effectiveness of these mechanisms is governed by parameters such as the nature of the vegetation, VFS length, infiltration characteristics of the VFS, and the incoming pollutant load. Several studies, to be described later in this report, have investigated effects of VFS length and vegetation on VFS effectiveness. There are comparatively few reports that directly address the role of incoming pollutant load relative to VFS effectiveness; i.e., how the performance of a particular VFS (of fixed length and other characteristics) is influenced by the amounts and concentrations of incoming pollutants (i.e., the hydraulic loadings of the pollutants). The hydraulic loading of a particular pollutant, is in turn, a function of the length of the pollutant source area up-slope of the VFS. In addition, most reported studies have investigated the effectiveness of VFS from the perspective of improving runoff from crop land and cattle feed lots, with relatively little attention given to runoff from pasture areas. As a result, the base of experimental information available for designing VFS to function down-slope of pasture areas is more limited than for other potential pollutant source areas.

OBJECTIVES

The objective of this study was to assess the performance of grassed VFS in removing nutrients, solids, and bacteria from runoff originating from grassed areas treated with poultry litter (a combination of manure and bedding material). Both different VFS lengths and litter-treated lengths were investigated to better determine the relationship between these two parameters and VFS effectiveness. The result can aid in identifying VFS lengths that strike the balance between adequate VFS performance and minimum VFS length requirement.

RELATED RESEARCH

Manure-Treated Pollutant Source Areas

Doyle et al. (1975) applied dairy manure (69% moisture) at 90 Mg/ha to a 0.19 ha Chester gravelly silt loam (Typic Hapludult; fine loamy, mixed, mesic) plot having a slope of 4% and planted in alfalfa (*Medicago sativa*). Runoff samples were collected from four natural rainfall events after an initial application of manure. A second 90 Mg/ha of manure was spread, and runoff samples from three subsequent rainfall events were collected. Fecal coliform (FC), fecal streptococci (FS), total N (TN), and soluble P (P) losses were reduced on average by 92, 99.8, 83, and 91% respectively by a 30.5 m forest buffer strip. These scientists also concluded that the concentrations of nutrients in runoff were a function of the number of rainfall events previously leaching the manure but independent of total rainfall and the amount of runoff collected.

Bingham et al. (1980) applied caged-layer poultry manure to 13 m long fescue (*Festuca arundinacea* Schreb.) grass plots on an eroded Cecil clay loam (clayey, kaolinitic, thermic Typic Hapludult) with 6-8% slopes and reported that a VFS length to manure-treated area length ratio of about 1.0 resulted in runoff of near background concentrations of pollutants. Total P (TP), total Kjeldahl N (TKN), nitrate N (NO_3-N) and TN losses were reduced by 25, 6, 28, and 28% respectively.

Cattle Feedlot Pollutant Source Areas

Young et al. (1980) used a rainfall simulator to study runoff originating from an active feedlot for two years. Vegetative filter strip plots having a slope of 4% with 13.72 m within the feedlot and the lower 27.43 m below the feedlot and planted in either corn (*Zea mays* L.), orchard grass (*Dactylis glomerata* L.) oats (*Avena sativa* L., 'Frocker') or a mixture of sorghum (*Sorghum vulgare* L.) and sudangrass (*Sorghum sudanense* L.), were studied. Total runoff, sediment, TP, and TN losses were reduced by from 61 to 87% by the various vegetations. Total coliform, FC, and FS in runoff were reduced by averages of 69, 69, and 70%, respectively.

Dickey and Vanderholm (1981) studied the effectiveness of VFS for channelized and overland flow originating from a feedlot. After settling for partial solids removal, runoff was applied directly to the filters and allowed to flow from the inlet to the outlet section. The VFS removed as much as 95% of incoming nutrients and oxygen-demanding materials from the applied runoff on a weight basis, and 80% on a concentration basis. Channelized flow required greater contact time or flow distance than shallow overland flow to achieve the same level of treatment. The researchers proposed that to prevent damage to vegetation and reduced VFS effectiveness, settling should be used to remove solids from feedlot runoff before application to VFS areas.

Edwards et al. (1983) found in their three-year study on runoff originating from a paved feedlot and passing through a shallow settling basin and two consecutive 30 m long by 4.5 m wide sod VFS that runoff, total solids, TP, and TN were reduced by -2, 50, 49, and 48%, respectively, after passing through the first VFS and by an additional -6, 45, 52, and 49%, after passing through the second VFS. The authors remarked that removal efficiency would have been higher if the settling basin located upslope of the VFS had not removed 54, 41, and 35% of the total solids, TP, and TN, respectively.

Dairy Barnyard Pollutant Source Areas

Schellinger and Clausen (1992) evaluated the performance of VFS used to improve the quality of dairy barnyard runoff. Runoff from a concrete-surfaced barnyard that flowed through a detention pond then onto a 22.9 m VFS planted in red and Kentucky tall fescue, annual and perennial ryegrass, and Kentucky blue grass (*Poa spp.*) on a 2% slope was monitored for one and one-half years. These VFS did not significantly reduce solids, P, N, or bacteria concentrations in the runoff. Over the study period, mass retention was highest during the growing season and poorest during snow-melt periods. It was concluded that the poor performance of the VFS was due to an excessive hydraulic loading rate resulting in detention times that were inadequate for proper treatment.

Cropland Pollutant Source Areas

Researchers at Virginia evaluated the effectiveness of VFS for controlling sediment and nutrient losses from cropland on farms at Virginia (Dillaha et al., 1985, 1986, 1987, 1989). Experimental plots were constructed on an eroded Groseclose silt loam (clayey, mixed, mesic Typic Hapludult) soil. The 4.6 and 9.1 m filter strips reduced TSS by 81% and 91% from shallow uniform flow and 31% and 58%, respectively, from concentrated flow. Vegetative filter strip effectiveness for total suspended solids (TSS) removal decreased with time as sediment accumulated in the filter. On the average, VFS effectiveness decreased by approximately 9% with respect to sediment removal between the first and second set of experiments. The 9.1 and 4.6 m filters removed 69 and 58% of applied P and 74 and 64% of the incoming N, respectively, from the runoff that occurred as diffuse overland flow. The VFS that had runoff occurring as concentrated flow were 40 to 60%, 70 to 95%, and 61 to 70% less effective with respect to TSS, P, and N removal, respectively, than were the plots that had diffuse flow. The authors concluded that VFS are much less effective in case of concentrated flow than in case of diffuse flow. In their later study with cropland runoff, Dillaha et al. (1989) found that 9.1 and 4.6 m VFS with shallow, diffuse flow removed an average of 84 and 70% of the incoming TSS, 79 and 61% of the incoming P, and 73 and 54% of the incoming N, respectively. The authors concluded that unless VFS can be installed so that concentrated flow is minimized, it is unlikely that they will be very effective for agricultural nonpoint source pollution.

Mickelson and Baker (1993) applied simulated rainfall at 66 mm/h to plots 4.6 and 9.1 m long planted with a mixture of smooth brome (*Bromus inermis*), Kentucky blue grass (*Poa partensis*), and Kentucky-31 tall fescue on 3-6% slope to assess the effectiveness of VFS in controlling atrazine loss from conventional tillage and no-tillage plots. The investigators found that sediment was reduced by 72.2, and 75.7% by 4.6 and 9.1 m buffer strips respectively. The VFS reduced atrazine losses by 31.7 and 55.4% by 4.6 and 9.1 m buffer strips respectively. Despite increasing the length by a factor of two, there was no significant increase in sediment removal.

MATERIALS AND METHODS

Nine plots having dimensions 1.5 m by 24.4 m (long axes oriented downslope) constructed on Captina silt loam (fine-silty, mixed, mesic, Typic Fragiudult) at the Main Agricultural Experiment Station of the University of Arkansas, Fayetteville were used for the experiment. Each plot was cross-leveled and had a uniform slope of 3% along the long axes. "Tall" fescue (*Festuca arundinacea* Schreb.) was the dominant grass cover. All plots were bordered to isolate the runoff. Wooden gutters were installed across each plot at every 3.1 m down-slope to collect runoff samples at those locations. The gutters were fitted with removable, water-tight sheet metal covers to prevent the entry of water when a runoff sample was not being collected.

Prior to poultry litter application, 32 soil samples (0-2.5 cm) were collected from each plot. The soil samples were mixed together to form a composite sample which was then analyzed for pH, moisture content, electrical conductivity (EC), organic matter content, P, potassium (K), iron (Fe), copper (Cu), ammonium N (NH_4-N), nitrate N (NO_3-N), and total Kjeldahl N (TKN) by the Agricultural Diagnostic Services Laboratory of the University of Arkansas using standard method of analysis (Page et al., 1992). The results of the soil analyses are given in Table 1. Poultry litter was surface-applied manually at 146.4 kg N/ha to the upper 6.1, 12.2, and 18.3 m on the plots with three replications of each litter-treated length. The litter was also

Table 1: Chemical characterization of the soil receiving poultry litter.

Constituent	Concentration*
	------ % ------
H_2O	20.4
Organic Matter	1.4
	--- pH units ---
pH	5.6
	--- mhos/cm ----
EC	20.0
	---- mg/kg -----
NH_3-N	3.9
NO_3-N	2.1
TKN	713.1
P	59.7
K	69.7
Fe	113.9
Cu	19.1

* Mean of nine samples; "as is" basis.

analyzed for pH, EC, moisture content, total N (TN), P, K, Fe, Cu, NH_4-N, and NO_3-N prior to application by the Agricultural Diagnostic Services Laboratory of University of Arkansas. Moisture content was determined using the gravimetric method by weighing a sample of the litter before and after drying at 104° C for 24 h. Total N was determined by the combustion method with a Leco FP 228 Nitrogen Determinator (Campbell, 1991). Inorganic N composition was determined by extraction with 2M KCl and distillation. Phosphorus, K, Fe, and Cu were determined by digestion with HNO_3 and analysis by the inductively coupled plasma method (Thermo Jarrell Ash Model 300) (Donohue and Aho, 1991) after preparation according to Campbell and Plank (1991). Water was added to the litter to obtain ratios of 1:1 (water/litter) and 2:1 for analyses of pH and EC, respectively. The composition of the poultry litter is shown in Table 2. Application rates of selected litter constituents are given in Table 3.

Simulated rainfall was applied to the plots immediately following litter application. The water used to provide the simulated rainfall was analyzed for various constituents using methods described later for the runoff samples (Table 4). A simulated rainfall intensity of 50 mm/h was used to facilitate comparison of results with similar studies (Chaubey et al., 1993). The simulated rainfall continued until 1 h after the start of runoff at the bottoms of the plots. Runoff was sampled manually (approximately 1 L sample size) at 2.5 min after runoff

Table 2: Poultry litter composition.

Constituent	Concentration*
	------ % ------
H_2O	24.9
	-- pH units ---
pH	7.2
	-- μmhos/cm ---
EC	7300
	---- mg/kg ----
Total N	26 100
NH_3-N	1 088
NO_3-N	78
P	10 750
K	19 315
Fe	116
Cu	417

* Mean of 20 samples; "as is" basis.

Table 3: Nutrient application rates.

Constituent	Application rate
	-- kg/ha --
Total N	146.4
NH_3-N	6.1
NO_3-N	0.5
Total P	60.3

Table 4: Municipal water composition.

Constituent	Concentration*
	--- mg/L ---
TKN	0.320
NH_3-N	0.020
NO_3-N	0.026
Total P	0.036
PO_4-P	0.021

* Mean of three samples.

began and at 10 min intervals thereafter at sampling locations. Runoff samples corresponding to a particular sampling time were collected by first collecting a sample from the bottom-most gutter of the plot and by then successively sampling gutters up the length of the plot. The times required to collect the samples were also recorded to enable computation of runoff rates and volumes. The runoff rate data were used to construct a single flow-weighted composite sample per sampling point from the associated seven discrete runoff samples.

Each flow-weighted composite runoff sample was analyzed in terms of quality. Aliquots of the samples were filtered (0.45 μm pore diam.) for PO_4-P and NO_3-N analysis. The runoff samples were then refrigerated (4° C) until analyzed. Standard methods of analyses (Greenberg et al., 1992) were used in analyzing the samples for TKN, ammonia N (NH_3-N), NO_3-N, TP, ortho-P (PO_4-P), total organic carbon (TOC), TSS, FC by Arkansas Water Resources Center Water Quality Laboratory. The micro-Kjeldahl method was used for TKN analysis, and the ammonia-selective electrode method was used for NH_3-N analysis. An ion chromatograph (Dionex DX-300 Gradient Chromatography System) was used to analyze NO_3-N and PO_4-P. Total P was determined by the ascorbic acid colorimetric method following digestion with sulfuric acid-nitric acid. Total organic carbon was determined by the combustion-infrared method. Fecal coliform concentrations were measured using the membrane filtration technique.

Runoff amounts and concentration data were used to compute mass transport of constituents past each sampling location. Two-way analysis of variance was performed to assess effects of length of pollutant source area and vegetative filter strip length on concentrations and mass transport of poultry litter constituents as well as on vegetative filter strip effectiveness with respect to the different constituents.

RESULTS AND DISCUSSION

Parameter Concentrations

Concentrations of the investigated runoff quality parameters were not significantly influenced by litter-treated length. This finding reflects similar runoff concentrations of parameters entering the VFS and within the litter-treated areas (Figs. 1-3). The insignificant effect of litter-treated length on parameter concentrations could be helpful in applying results of this study to more practical situations, because it suggests that runoff flow length within litter-treated areas might not be an important variable in estimating parameter concentrations entering the VFS.

All runoff quality parameters except TSS and FC were significantly ($p<0.01$) affected by VFS length (Table 5). The failure of TSS to decrease with increasing VFS length may have been due in part to a disproportionately large contribution from the soil and from the regions immediately adjacent to the runoff collection gutters. This seems particularly likely given that (a) poultry litter applied to similar plots has been observed to cause higher runoff TSS concentrations than observed for untreated plots (e.g., Edwards et al., 1994) and (b) abundant research, described earlier, exists that indicates VFS are effective in removing solids from incoming runoff. The reason why FC concentrations did not respond to VFS length are unclear but might

Table 5: Mean parameter concentration as a function of VFS length.

VFS length	Parameter					
	PO_4-P	TP	NO_3-N	NH_3-N	TKN	TOC
- m -	-- mg/L --					
0[1]	12.15	13.93	0.73	24.52	44.61	40.85
3.1[1]	7.54	8.08	0.45	14.38	26.30	22.06
6.1[1]	4.76	5.42	0.35	9.44	14.97	16.68
9.2[2]	2.49	3.23	0.26	4.43	8.96	13.98
12.2[2]	2.06	2.37	0.17	3.05	9.78	11.25
15.3[3]	1.00	1.10	0.15	1.01	3.13	9.12
18.3[3]	0.55	0.99	0.14	0.70	2.85	11.94

[1] Mean of 9 replications.
[2] Mean of 6 replications.
[3] Mean of 3 replications.

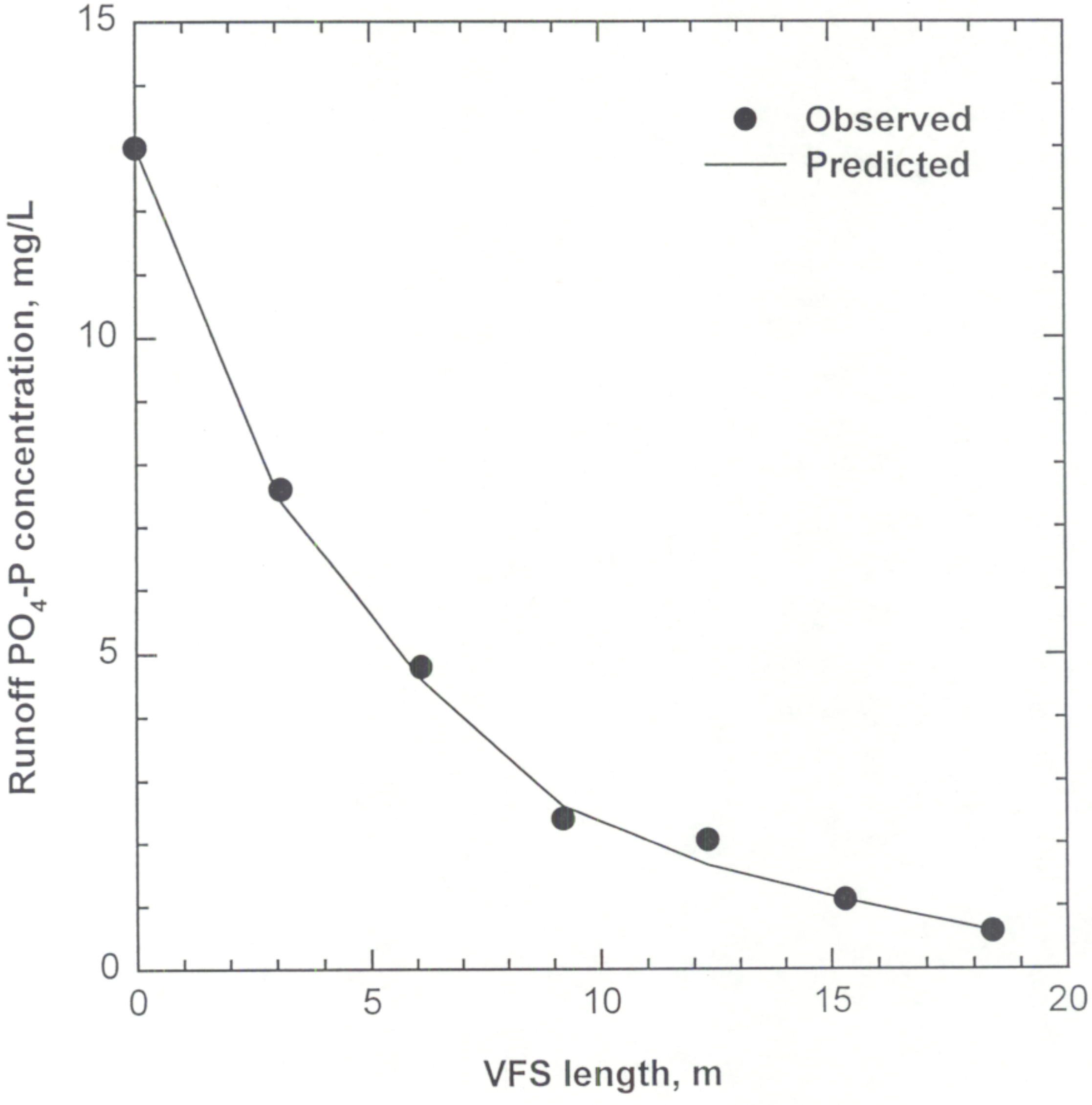

Figure 1. Observed and predicted (first-order) concentration of ortho-phosphorus (PO_4-P) as affected by vegetative filter strip (VFS) length.

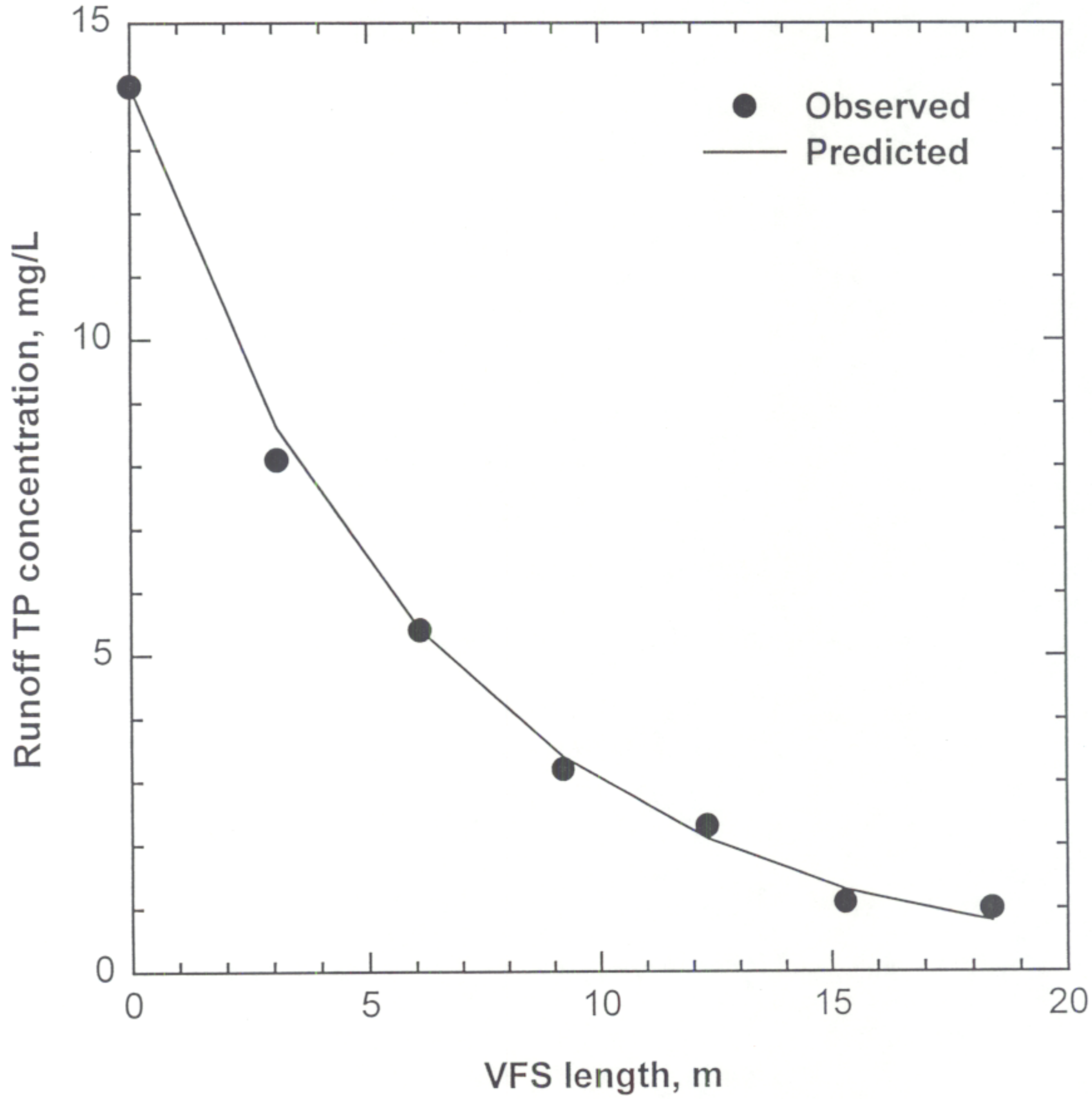

Figure 2. Observed and predicted (first-order) concentration of total phosphorus (TP) as affected by vegetative filter strip (VFS) length.

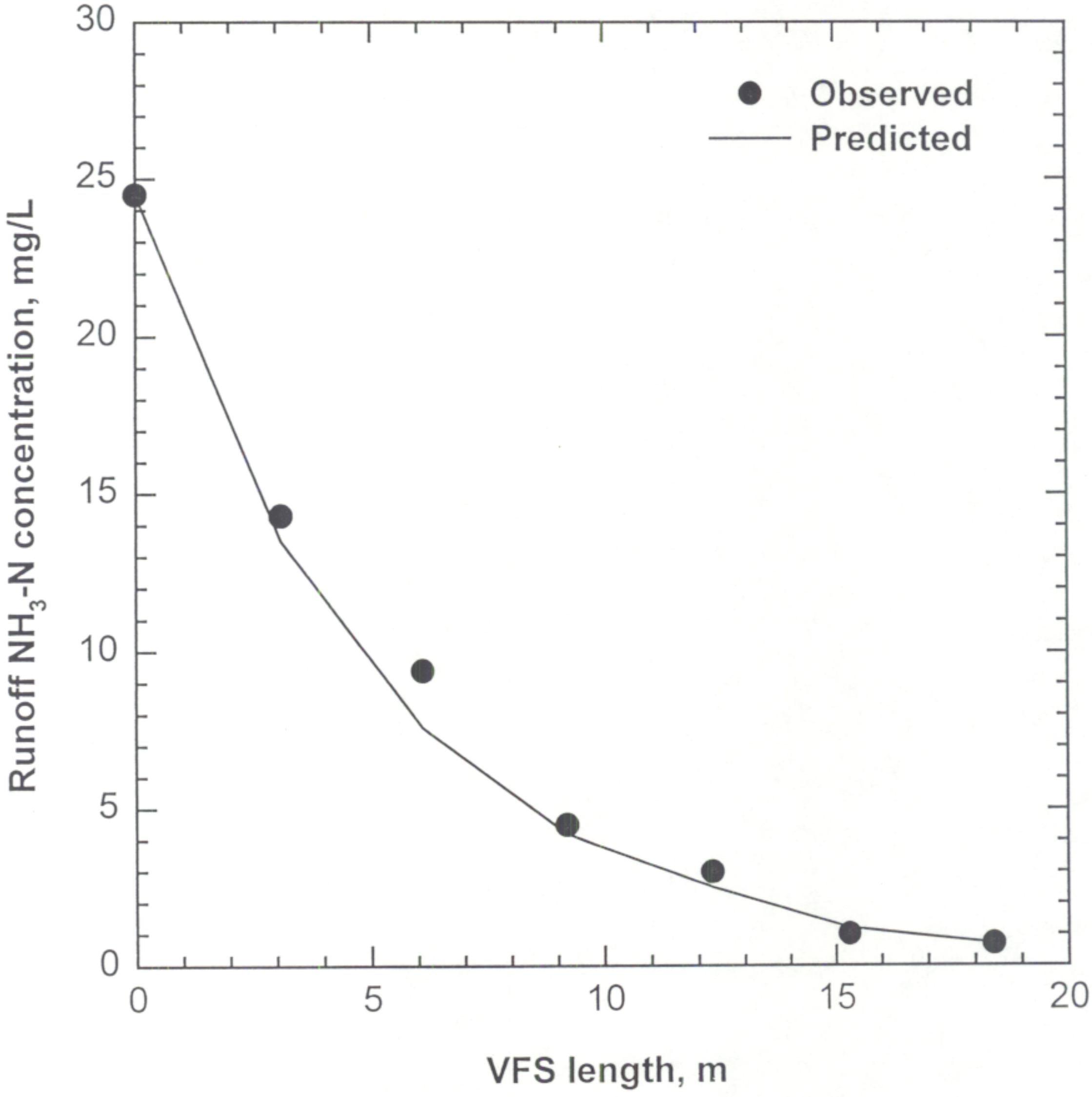

Figure 3. Observed and predicted (first-order) concentration of ammonia nitrogen (NH_3-N) as affected by vegetative filter strip (VFS) length.

involve FC transport mechanisms and/or the presence of high background FC concentrations within the VFS. The parameters that were influenced by VFS length (NO_3-N, NH_3-N, TKN, PO_4-P, TP, TOC) exhibited an approximately first-order declining response to increasing VFS length,which is consistent with modeling approaches used by Overcash et al. (1981) as well as others.

Parameter Mass Transport

Mass transport of NH_3-N, TKN, PO_4-P, and TP was significantly ($p<0.05$) influenced by both litter-treated length and VFS length (Figs. 4-6). Mass transport of TOC was significantly influenced by VFS length, while NO_3-N and TSS transport were unaffected by either variable. The findings with regard to NO_3-N suggest that the concentration declines accompanying increasing VFS lengths were offset by increased runoff volumes and the NO_3-N contribution from the simulated rainfall. Since TSS concentrations were independent of both litter-treated length and VFS length, as discussed earlier, TSS mass transport would have been expected to increase with both litter-treated and VFS lengths. However, there was greater variability in the TSS data than for other parameters. The relatively high variability in TSS concentrations combined with runoff variability was probably responsible in large measure for the lack of a TSS mass transport response to either of the experimental variables. Mass transport of NO_3-N, TOC, and TSS averaged (over all

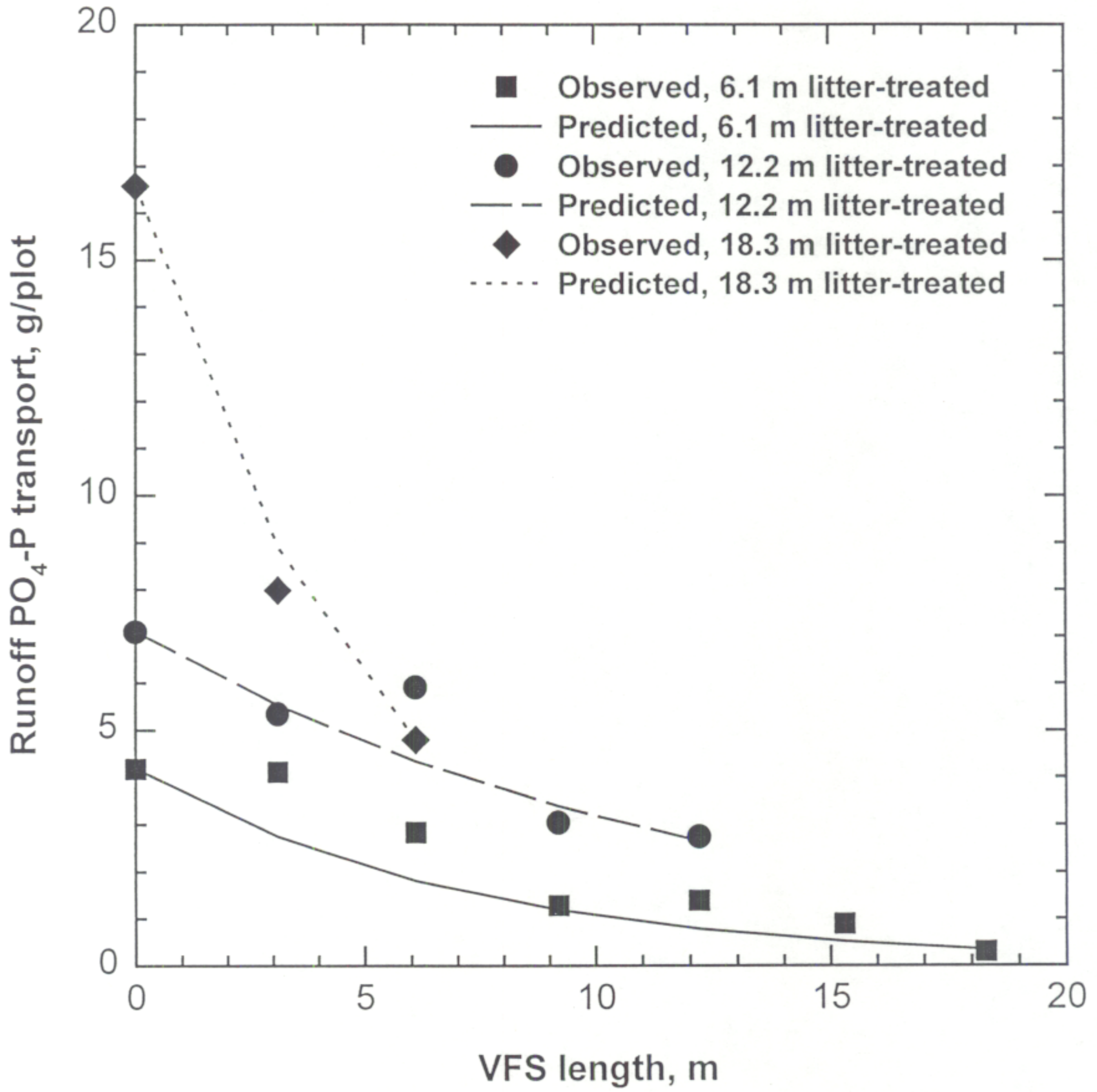

Figure 4. Observed and predicted (first-order) mass transport of orthophosphorus (PO_4-P) as affected by litter-treated and vegetative filter strip (VFS) lengths.

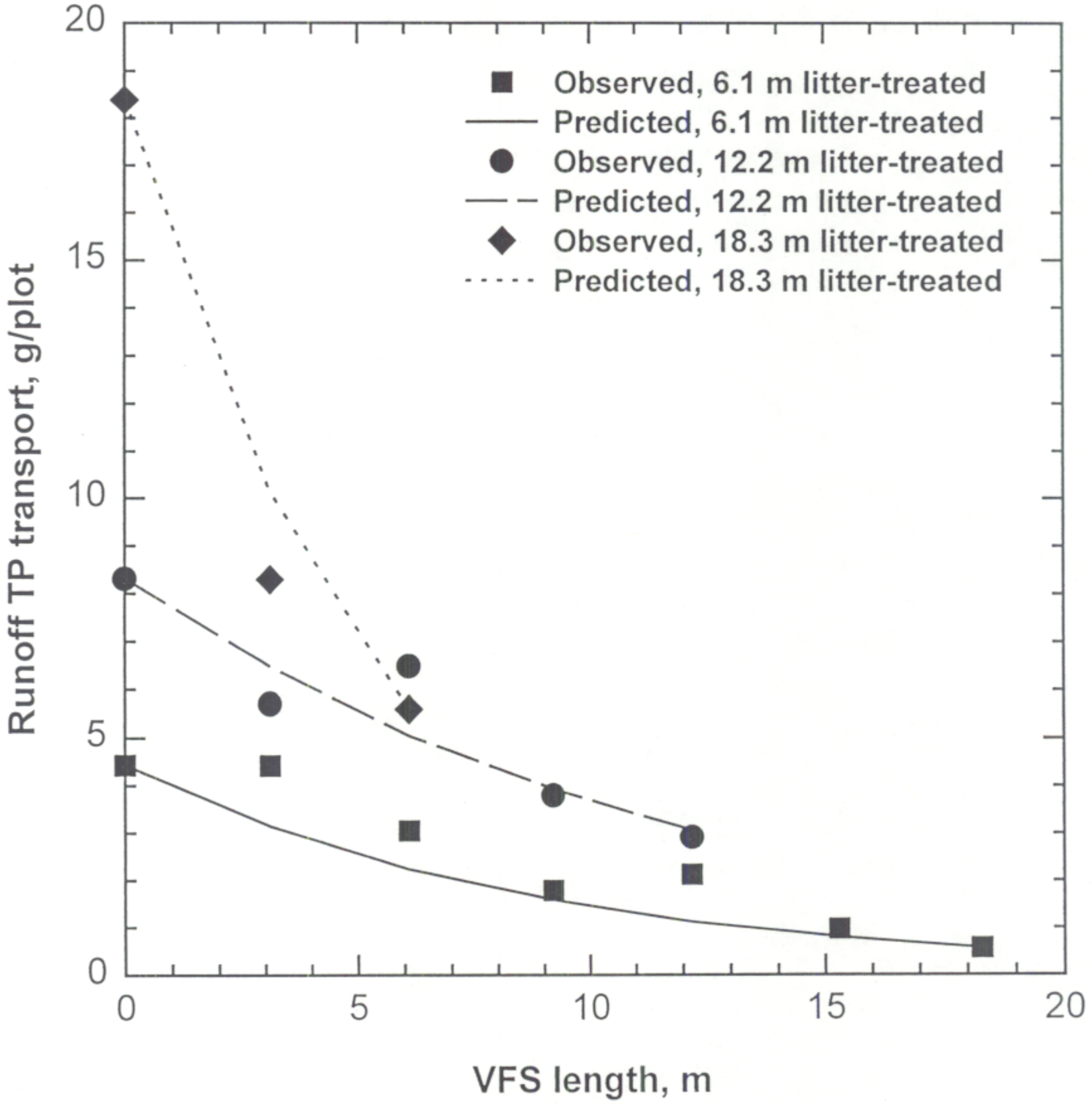

Figure 5. Observed and predicted (first-order) mass transport of total phosphorus (TP) as affected by litter-treated and vegetative filter strip (VFS) lengths.

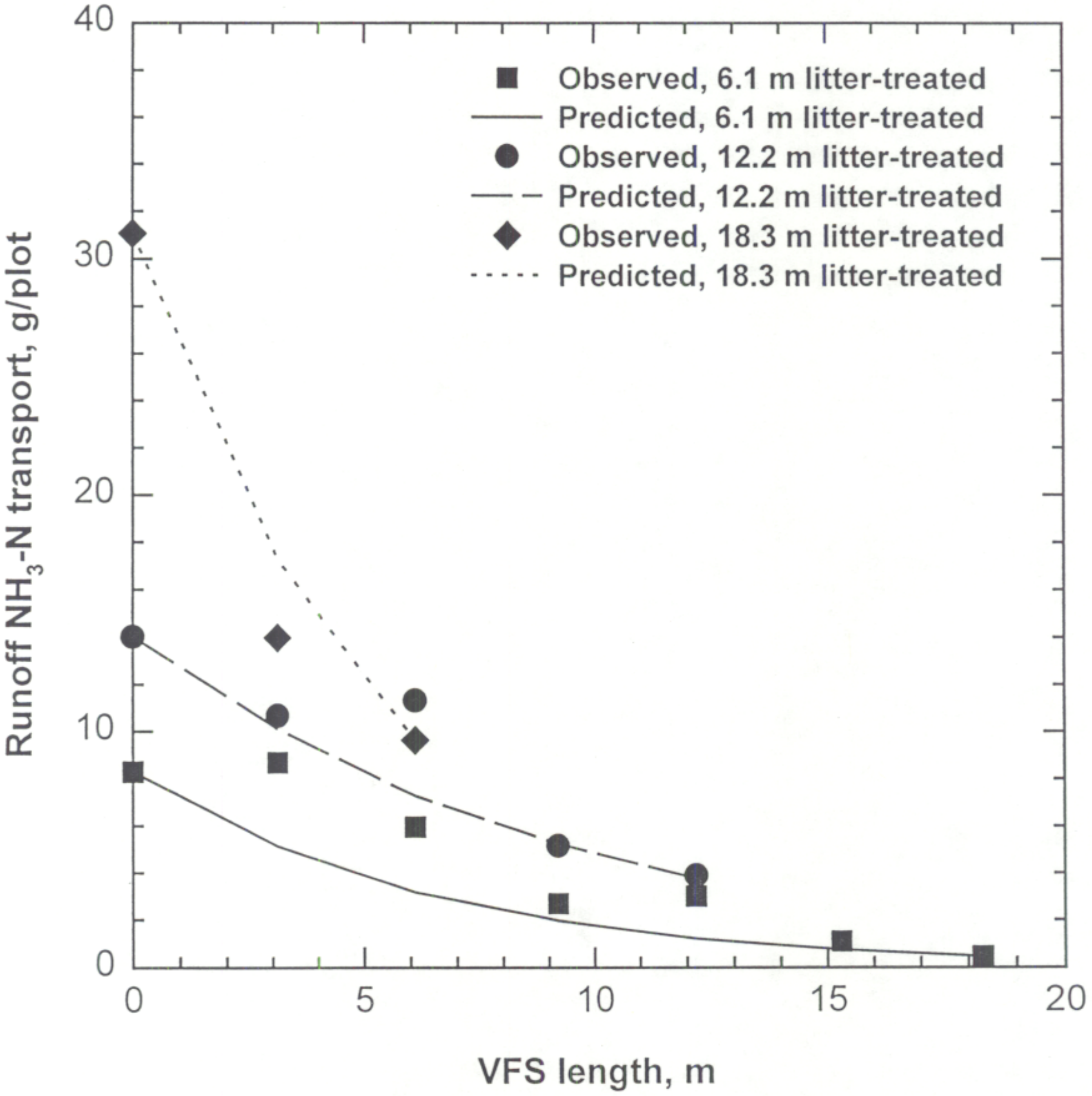

Figure 6. Observed and predicted (first-order) mass transport of ammonia nitrogen (NH_3-N) as affected by litter-treated and vegetative filter strip (VFS) lengths.

leng treatments and replications) 0.30, 15.70, and 55.05 g/plot, respectively.

For the parameters affected by litter-treated length and VFS length, masses entering the VFS increased with increasing litter treated area as a result of increased runoff volume (Table 6). Upon entering the VFS, mass transport of those parameters decreased, reflecting removal by infiltration, adsorption to grass, settling, and other mechanisms as discussed earlier. The responses of mass transport to VFS length for the affected parameters were again an approximately first-order decline.

Parameter Mass Transport Reduction

Vegetative filter strip effectiveness as a function of VFS length was computed for the parameters (NH_3-N, TKN, PO_4-P and TP) whose mass transport was affected by the experimental variables using the equation

$$E_{i,j} = 100\left(\frac{M_{i,o} - M_{i,j}}{M_{i,o}}\right) \qquad (1)$$

where $E_{i,j}$ is the effectiveness (%) of VFS length j for parameter i, $M_{i,j}$ is the mass of parameter i transported past VFS length j, and $M_{i,o}$ is the mass of parameter i transported past the zero VFS length (i.e., entering the VFS).

Table 6: Mean* parameter mass transport as a function of VFS length and length of pollutant source area.

VFS length	Parameter			
	PO_4-P	Total P	NH_3-N	TKN
- m -	-- g/plot --			
	6.1 m litter-treated length			
0	4.17	4.43	8.29	15.69
3.1	4.11	4.42	8.68	16.00
6.1	2.84	3.04	5.96	10.05
9.2	1.28	1.78	2.68	5.93
12.2	1.39	2.12	3.01	6.11
15.3	0.89	0.97	1.09	2.88
18.3	0.30	0.56	0.47	1.60
	12.2 m litter-treated length			
0	7.08	8.31	14.03	27.22
3.1	5.35	5.70	10.67	17.65
6.1	5.92	6.46	11.32	18.32
9.2	3.05	3.80	5.16	9.71
12.2	2.75	2.92	3.90	12.66
	18.3 m litter-treated length			
0	16.58	18.39	31.08	53.14
3.1	7.98	8.29	13.99	28.05
6.1	4.80	5.59	9.62	13.93

* Mean of three replications.

Effectiveness of the VFS was significantly ($p<0.05$) influenced by both litter-treated length and VFS length for NH_3-N, TKN, PO_4-P, and TP. Effectiveness in terms of these parameters generally increased with increasing VFS length (as expected), ranging from 6.50 to 96.27%, depending on the particular parameter and litter-treated and VFS lengths (Table 7). Interestingly, VFS effectiveness for a given VFS length was usually higher for higher litter-treated lengths (Table 7); this was especially the case for the 18.3 m litter-treated length treatment. Considering that concentrations of the affected parameters at a VFS length of 6.1 m were highest for the 18.3 m litter-treated length, it seems likely that the effectiveness results are due in part to different infiltration characteristics near the bottoms of the plots. In other words, relatively high infiltration near the bottoms of the plots could have caused a relatively high removal of analysis parameters in those areas.

Table 7: Mean* parameter mass transport effectiveness as a function of VFS length and length of pollutant source area.

VFS length	Parameter			
	PO_4-P	Total P	NH_3-N	TKN
- m -	-- % --			
	6.1 m litter-treated length			
3.1	6.50	19.08	21.29	15.2
6.1	32.81	43.43	43.42	32.6
9.2	75.07	65.59	76.95	57.1
12.2	54.27	60.47	75.35	52.9
15.3	79.07	81.75	91.41	79.5
18.3	92.00	88.44	96.27	83.7
	12.2 m litter-treated length			
3.1	22.35	29.95	20.48	28.9
6.1	12.42	19.64	13.91	26.6
9.2	57.62	54.44	64.21	64.6
12.2	62.69	65.49	73.57	47.0
	18.3 m litter-treated length			
3.1	57.06	58.29	58.57	50.6
6.1	74.79	72.81	73.11	75.0

* Mean of three replications.

SUMMARY AND CONCLUSIONS

This study assessed the combined influences of litter-treated length and VFS length on performance of VFS with regard to removing pollutants from runoff originating from grassed areas treated with poultry litter. Litter-treated lengths of 6.1, 12.2, and 18.3 m were used with corresponding VFS lengths of up to 18.3, 12.2, and 6.1 m, respectively. Simulated rainfall was applied at 50 mm/h for 1 h of runoff to generate runoff samples, which were subsequently analyzed for nutrients, solids, and bacteria. Analysis of the results of the experiment indicated that:

1. Analysis parameter concentrations in runoff were unaffected by litter-treated length; i.e., concentrations of parameters entering the VFS did not depend on the length of the contributing litter-treated area.

2. Concentrations of NO3-N, NH3-N, TKN, PO4-P, TP, and TOC decreased with increasing VFS length, while concentrations of TSS and FC were not significantly influenced by VFS length.

3. Mass transport of NH3-N, TKN, PO4-P, and TP increased with litter-treated length (due to higher runoff) and decreased with VFS length (due to removal of pollutants).

4. Effectiveness of VFS increased with VFS length and litter-treated length, although the findings with regard to litter-treated

length may have been due to relatively high infiltration near the bottoms of the plots.

The results with regard to VFS length effects on VFS performance complement those from other studies and indicate a potential for properly installed and maintained VFS to be very helpful in minimizing runoff losses of land-applied poultry litter. The finding that litter-treated length had no effects on concentrations of parameters entering the VFS might be helpful in simplifying VFS design, since it suggests that the length of the contributing area is not an important factor in estimating incoming pollutant concentrations.

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