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Assessment of Effectiveness of Buffer Zones in Removing Impurites in Runoff from Areas Treated with Poultry Litter

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ASSESSMENT OF EFFECTIVENESS OF BUFFER ZONES IN REMOVING IMPUITIES IN RUNOFF FROM AREAS TREATED WITH POULTRY LITTER

Technical Completion Report Research Project G-1549-03

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ABSTRACT

EFFECTIVENESS OF VEGETATIVE FILTER STRIPS IN RETAINING SURFACE-APPLIED POULTRY LITTER AND SWINE MANURE CONSTITUENTS

Land application of animal manures (e.g. poultry litter, poultry manure, and swine manure) to pasture and range can lead to runoff quality degradation during storms that occur soon after application. Vegetative filter strips (VFS) have been shown to reduce pollution in runoff from row-cropped areas but have not been extensively studied in pasture and range settings. This research involved characterizing performance of fescue VFS in improving quality of runoff from pasture land areas treated with poultry litter and swine manure. The VFS were found to be quite effective in reducing off-site transport of ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (PO_4-P), total phosphorus (TP), and fecal coliform (FC) for simulated storms occurring 2-5 days following poultry litter and swine manure application. The VFS were from 81 to 99% effective (at a VFS length of 21.4 m) in reducing incoming mass transport of NH_3-N, TKN, PO_4-P, TP, and FC in runoff from poultry litter-treated plots. Similar performance was observed for the VFS installed below plots treated with swine manure. Transport of suspended solids and chemical oxygen demand was also reduced by the VFS, but generally not to the extent of other litter and manure constituents. Transport of poultry litter and swine manure constituents were well-described by first-order kinetics.

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Completion Report to the U.S. Department of the Interior, Geological Survey, Reston, VA, March, 1994.

Keywords - Vegetative Filter Strips/Animal Manures/Nonpoint Source Pollution/Pasture

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INTRODUCTION

Land disposal of animal manure is widely recognized as an economic means of productively using manure constituents as well as an effective disposal technique. Runoff from land application sites, however, is a potentially significant source of pollution. Runoff from these areas may contain undesirable quantities of sediment, organic residue, nutrients and potentially pathogenic organisms. Past research has demonstrated potential runoff quality impacts of poultry litter and swine manure application to pasture/range areas (Westerman et al., 1983; McLeod and Hegg, 1984; Edwards and Daniel, 1992, 1993). Concerns about the impact of surface-applied poultry litter and swine manure on water quality are increasing in areas where production is heavily concentrated. As the production of poultry and swine continues to expand, in terms of both number of facilities and the area covered, anxieties regarding the environmental implications will be shared by an increasing number of citizens, local governments, service agencies, and regulatory agencies.

While much progress has been made toward the control of agricultural non-point source (NPS) pollution through the use of best management practices (BMPs), the role of BMPs in rectifying problems associated with broiler litter and swine manure disposal is currently limited by both practical and technical problems. The practical problems stem from the fact that the user of the litter or manure may not be able to implement all BMPs due to economic considerations and/or characteristics of the receiving fields. The technical problems are associated with a lack of theoretical and experimental investigations to precisely identify the levels at which BMPs should be implemented (e.g., manure application rates) as a function of physical and biological variables.

One practice that is receiving attention for removing sediment and nutrients from the runoff from crop land and areas of livestock activity is vegetative filter strips (VFS). Vegetative filter strips (also referred to as grass filters, vegetative buffer strips, filter strips or buffer strips) are vegetated regions emplaced down slope of pollutant source areas to remove impurities from incoming runoff.

Vegetative filter strips purify incoming runoff by allowing increased opportunity for infiltration of soluble pollutants, deposition of sediment and sediment-bound pollutants, and adsorption onto plant surfaces and soil particles. There are very limited methods for VFS design with respect for removal of nutrients, organic matter, and microbes. Consequently, VFS can easily be installed in areas and under conditions in which they are ineffective or overdesigned for removal of such pollutants.

Infiltration is perhaps the most significant removal mechanism affecting VFS performance under pasture/range settings. In general, infiltration rate depends on soil physical properties, vegetative cover, antecedent soil moisture condition, rainfall intensity, and the slope of the infiltrating surface. Soils protected by vegetative cover tend to have higher infiltration rates than bare soils. Many pollutants associated with runoff from enter the soil profile as the infiltration takes place. Once in the soil profile, most of these pollutants are removed by a combination of physical, chemical, and biological processes.

Infiltration is also important because it decreases the amount of runoff, which reduces the ability of runoff to transport pollutants.

Vegetative filter strips can also purify runoff through the process of deposition. If the VFS is relatively resistant to overland flow in comparison to the pollutant source area, then the velocity (and thus sediment transport capacity) of runoff will decrease upon entering the VFS. If the VFS sufficently decreases the sediment transport capacity of the runoff, then some deposition of suspended solids will occur within the VFS, usually at or near the top of the VFS. Sediment-bound pollutants will presumably be removed from the runoff during deposition of the solids.

OBJECTIVES

The objective of this study was to assess the effectiveness of fescue VFS for the removal of sediment, nutrients, chemical oxygen demand, and bacteria from poultry litter and swine manure surface-applied to fescue pasture.

This work complements previous studies by examining poultry litter and swine manure as the animal manure source as opposed to livestock manures, which have often been used in studies of this nature. The study also adds to prior work in that most previous studies have addressed use of VFS just beneath row-cropped land or feed lots; this work addressed assessing VFS effectiveness just beneath pasture/range land. Another distinguishing characteristic of this study was the use of only one plot per replication to examine differing VFS lengths, whereas previous studies have generally required one plot per replication per VFS length to be examined.

RELATED RESEARCH

Sediment Transport in VFS

Neibling and Alberts (1979) found that VFS lengths of up to 4.9 m reduced incoming sediment load from a bare 6.1 m plot by more than 90%. The majority of sediment was deposited during the upper 0.6 m of the VFS. No equations were presented to estimate the influence of grass filter parameters on sediment yield.

Scientists at the University of Kentucky developed design equations to relate to VFS performance to selected parameters. Tollner et al. (1976, 1977) described sediment deposition in simulated VFS to the mean flow velocity, flow depth, particle fall velocity, filter length, and the spacing hydraulic radius of the simulated medium. They also developed steady-state equations to predict the rate of advance of a sediment deposition front in a grass filter.

Barfield et al. (1977, 1979) developed a steady-state model to estimate VFS performance as a function of characteristics of incoming sediment, runoff, and the VFS. Model simulations indicated that sediment concentration in runoff exiting the VFS is most sensitive to channel slope and spacing, but the expected useful life of the VFS (the time required to essentially saturate it with sediment) is primarily a function of incoming sediment load. Hayes et al. (1979) modified the model to predict VFS behavior for non-uniform particle sizes and time varying inflows. Hayes and Hairston (1983) used field data to evaluate the Kentucky model for multiple storm events.

Kao et al. (1975) suggested that VFS be alternated with bare areas to help avoid VFS saturation with sediment since, with the appropriate arrangement of bare and VFS areas, most sediment incoming to the VFS could be deposited just before entering the VFS. This strategy would enable the deposited sediment to be removed as needed from the bare areas without damaging the VFS. However, these findings have not been validated under field conditions with actual grasses.

Nutrient Transport in VFS

Several scientists have studied the effectiveness of VFS with respect to nutrient removal. Similar to sediment, however, generally accepted procedures are lacking to size VFS to achieve desired effectiveness of nutrient removal.

Doyle et al. (1975, 1977) applied dairy manure upslope of both fescue (*Festuca arundinacea* Schreb) and forest buffers and found that filter lengths of only 3.7 to 4.6 m were very effective in removing soluble and suspended nutrients from runoff. Thompson et al. (1978) applied dairy manure to frozen or snow-covered orchardgrass (*Dactylis glomerata*) plots on sandy loam soil and found that a 12 m orchardgrass filter removed 55, 46, 41, and 45% of incoming total P, NO_3-N, TKN, and total N, respectively. Increasing the filter length to 36 m increased removal of total P, NO_3-N, TKN, and total N to 61, 62, 57, and 69%, respectively.

After applying dairy waste for one year to a fescue plot on silt loam soil, Patterson et al. (1980) found that a 35 m fescue VFS reduced incoming concentrations of biochemical oxygen demand (BOD), NH_4-N, PO_4-P, and TSS by 42, 38, 7, and 71%, respectively. Observed losses of NO_3-N from the VFS were greater than the loading, which was attributed to formation of NO_3-N from organic N and NH_3-N in the filter. Citing problems with maintaining grass cover on the VFS, the authors recommended that alternative VFS areas be established and used in rotation.

Young et al. (1980) reported on the ability of a 27.4 m long VFS to remove pollutants from feedlot runoff. Significant reductions in incoming pollutant mass (79% total solids, 84% TN, and 83% TP) were achieved in the buffer strips. Incoming NH_3-N, and PO_4-P were similarly reduced. Schwer and Clausen (1989) reported that a 26 m long VFS retained 95% of incoming solids, 89% of incoming TP, and 92% of incoming TKN (mass basis) from dairy milkhouse waste water.

Bingham et al. (1980) applied caged layer poultry manure to grass area and measured fescue VFS effectiveness at various distances. The authors observed concentration reductions even at buffer area length to waste area length ratios of 0.5 and 0.75, but they concluded that buffer lengths in 1:1 ratio to land application areas were necessary to achieve background levels of pollution in filters below manure application sites.

Dickey and Vanderholm (1981) measured the effectiveness of VFS in removing sediment and nutrients from feedlot runoff. After settling the runoff for partial solids removal, they applied the runoff directly to the filters. They found total reductions in incoming nutrients and solids of over 80% on a concentration basis and over 90% on a mass basis for filter lengths ranging from 91 to 262 m. They recommended settling to be used to remove solids from feedlot runoff before application to filter areas to prevent damage to vegetation and reduced filter effectiveness.

Edwards et al. (1983) used two 30.5 m fescue VFS in series to purify incoming storm runoff from a paved feedlot after passage through a settling basin. The first VFS removed approximately 50% of incoming total P and total N with similar proportions removed by the second VFS.

Overman and Schanze (1985) studied the runoff quality from "coastal" bermudagrass after it was irrigated with waste water from a municipal waste water plant. They detained the water in a holding pond before applying in the field and found that with the exception of TP, the field served as an excellent polishing unit for the treatment plant. The detention pond reduced concentrations of BOD, TSS, and TKN by 91, 75, and 82%, respectively, while the bermudagrass reduced incoming concentrations by 78, 81, and 65%, respectively. The overall reduction in TP concentration was found to be 25% by the detention pond and 39% by the bermudagrass filter.

Researchers at Virginia evaluated the effectiveness of VFS for the removal of sediment, N, and P from cropland runoff with field plots and observation of VFS on farms in Virginia (Dillaha, 1989; Dillaha et al., 1985, 1986a, 1986b,1988, 1989; Lee et al.,1989). Under uniform flow conditions, 9.1 and 4.6 m VFS removed 91 and 81% of the incoming sediment, 69 and 58% of the incoming P, and 74 and 64% of incoming N, respectively, from feedlot runoff. Dillaha et al. (1989) found in a similar study with cropland runoff that 9.1 and 4.6 m VFS removed an average of 84 and 70% of incoming suspended solids, 79 and 61% of the incoming P, and 73 and 54% of the incoming N, respectively. Magette et al. (1986, 1989) observed similar results, noting that VFS effectiveness decreased with increasing time and with decreasing VFS to source area ratio.

Michelson and Baker (1993) studied effectiveness of 4.6 and 9.1 m VFS on herbicide runoff losses from conventional and no-tillage crop land.

Reductions in the mass transport of sediment and atrazine were observed to be 72.2 and 37.1% by 4.6 m VFS, and 75.7 and 55.4% by 9.1 m VFS, respectively.

Dillaha et al. (1986b) conducted a study to evaluate the long-term effectiveness and operational problems associated with vegetative filter strips by observing them on 33 farms in the Chesapeake Bay and Chowan River Basins. The most significant factor affecting VFS performance was the flow regime of runoff. The strips were highly effective for shallow runoff that was uniformly distributed across the VFS. Under concentrated flow conditions, however, VFS effectiveness was greatly reduced. They suggested that cost-shared VFS be limited to fields with fairly uniform slopes and poorly developed drainage patterns, excluding the sites in which more than 40 to 50% of the runoff crosses the VFS as concentrated flow. They also recommended mowing to control weeds and to promote thicker grass growth.

Recently, several researchers (Flanagan et al., 1989; Williams and Nicks, 1988) have attempted to evaluate the effectiveness of VFS for erosion control with the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980). Williams and Nicks (1988) applied CREAMS to a 1.6-ha watershed in Oklahoma. The authors concluded that CREAMS was a useful tool for evaluating VFS effectiveness in reducing sediment yield. This model, like the Kentucky model, does not consider the long-term effectiveness of VFS in that CREAMS also does not account for long-term sediment accumulations within the VFS. Consequently, CREAMS would be expected to overestimate long-term sediment trapping. The model also does not account for concentrated flow effects.

CREAMS does have a nutrient transport component, but the applicability for use with VFS has not been substantiated.

Flanagan et al. (1989) developed a simplified procedure from CREAMS simulations to calculate the effectiveness of filter strips for removing sediment from shallow overland flow. Predictions of sediment delivery ratios using the simple equations were close to those predicted using the complete CREAMS model. They used these simplified equations to select the minimum width of filter strip to trap a desired level of sediment when the strip was composed of dense grass and was located at the base of a slope having minimal flow concentrations.

Lee et al.(1989) developed an event-based model to simulate P transport in VFS by incorporating chemical transport submodels into SEDIMOT II, a storm water and sediment transport model originally developed for strip mine reclamation. The model considers advection, infiltration, biological uptake, adsorption, phosphorus desorption processes from land surface to runoff, and changes in sediment size distribution on P transport. The model simulates time-varying infiltration, runoff discharge, sediment yield, particle size distribution, and dissolved and sediment-bound P discharge along with sediment and P trapping efficiencies in VFS.

Munoz-Carpena et al. (1992) developed a single-event model to simulate hydrology and sediment filtration in VFS. They linked three submodels: a modified Green-Ampt infiltration routine, a finite element kinematic wave overland flow algorithm, and the University of Kentucky sediment filtration model. Major inputs to the model were VFS properties (length, slope, hydraulic roughness, grass spacing, media height), soil infiltration parameters, sediment and water inflow from the adjacent agricultural field and sediment properties. Major outputs of the model were runoff from the filter, infiltration rate, total infiltration, sediment outflow, sediment deposition, and filter trapping efficiency. The model predictions, however, applied to an ideal situation, since only sheet flow over a uniform, dense stand of vegetation was considered.

MATERIALS AND METHODS

Description of Experimental Plots

Six plots with dimensions of 1.5 m by 24.4 m (long axes oriented up and down slope) were constructed for the study at the Main Agricultural Experiment Station in Fayetteville, Arkansas. The soil is Captina silt loam (fine-silty, mixed mesic, Typic Fragiudult). Each plot was graded to a uniform 3% slope along the main axis and was bordered with wood (0.1 m below and 0.1 m above ground) to isolate runoff. A stand of fescue grass was established on the plots in spring, 1992 by seeding at approximately 500 kg/ha. Wooden gutters were installed across each plot at 3.1, 6.1, 9.2, 12.2, 18.3, and 24.4 m down slope to enable collection of runoff at those lengths down the plot. Each gutter was fitted with a removable, water-tight cover that was capable of preventing water entry into the gutter. Each gutter cover was constructed of sheet metal and fitted with a gasket to seal the gutter/cover interface. Three wing nuts with gaskets and washers were used to hold the cover tightly to the gutter. The covers were removed to collect runoff samples whenever desired.

Thirty soil samples (0-2.5 cm depth) were collected from each plot on the dates of poultry litter and swine manure application. The samples were mixed together, and 3 composite samples from each plot were analyzed by the University of Arkansas Agricultural Services Laboratory using standard methods of analysis (Page et al., 1982). The results of the soil analyses are given in Table 1.

Poultry Litter and Swine Manure Collection, Analysis, and Application

Poultry litter was collected from a broiler house in mid April, 1993. Three samples were collected and analyzed for moisture content

Table 1. Chemical characterization of the soil receiving poultry litter and swine manure.

	Concentration[1]			
Constituent	Poultry Litter[2]		Swine Manure[3]	
		%		
H_2O	22.5	(1.2[4])	23.4	(1.5)
Organic matter	0.7	(0)	0.7	(0.3)
		pH units		
pH	5.3	(0.2)	5.7	(0.1)
		μmhos/cm		
EC	17.7	(0.5)	20.0	(2.0)
		mg/kg		
TKN	557.7	(25.8)	732.0	(86.6)
NH_3-N	1.6	(1.5)	8.5	(8.6)
NO_3-N	1.5	(1.5)	3.3	(2.9)
P	75.7	(4.9)	76.8	(9.3)
K	36.5	(19.9)	68.7	(18.9)
Fe	129.2	(7.6)	140.5	(6.6)
Cu	6.5	(1.3)	0.7	(0.3)

[1] Mean of three replications; "as is" basis.

[2] Plots subsequently treated with poultry litter.

[3] Plots subsequently treated with swine manure.

[4] Figures in the parentheses show standard deviations.

(MC), total N, NH_3-N, NO_3-N, TP, K, Fe, Cu, pH, and electrical conductivity (EC) by the University of Arkansas Agricultural Services Laboratory. Moisture content was determined gravimetrically 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. The litter was refrigerated (4°C) for 1 d prior to application to the plots.

Liquid swine manure was pumped from an unagitated pit beneath a production facility into a metal container two days before the experiment in mid May. Two samples of the manure slurry were collected from the stirred container and analyzed for MC, total N, NH_3-N, NO_3-N, TP, K, Fe, Cu, pH, and EC by the University of Arkansas Agricultural Services Laboratory. Moisture content was determined gravimetrically by weighing a sample of the slurry before and after drying at 104°C for 24 h. Total N was determined by digestion with H_2SO_4 and H_2O_2 followed by distillation. Inorganic N fractions were determined by distillation without digestion. Amounts of TP, K, Fe, and Cu in the slurry were determined by digestion with HNO_3 and analysis by the inductively coupled plasma method (Thermo Jarrel Ash Model 300) (Donohue and Aho, 1991). Analyses of pH and EC

Table 2. Poultry litter and swine manure composition.

	Concentration			
Constituent	Poultry Litter[1]		Swine Manure[2]	
	%			
H_2O	24.6	(1.0[3])	94.4	(0.04)
	pH units			
pH	8.5	(0.0)	7.6	(0.2)
	µmhos/cm			
EC	6,000	(0.0)	6,500	(707)
	mg/kg		mg/L	
Total N	33,100	(6686)	2,491	(301)
NH_3-N	4,516	(390)	1,846	(13)
NO_3-N	176	(25)	53.2	(5.4)
Total P	15,833	(462)	1,725	(348)
K	20,633	(4697)	966	(97)
Fe	101	(30)	634	(336)
Cu	467	(12)	15	(2.5)

[1] Mean of three samples; "as is" basis.

[2] Mean of two samples; "as is" basis.

[3] Figures in the parentheses show standard deviations.

followd standard methods of analysis (Greenberg et al., 1989). The composition of the swine manure is shown in Table 2.

The poultry litter and swine manure were manually-applied at rates of 186 and 203 kg N/ha, respectively, to the upper 3.1 of each plot with careful attention to the uniformity of application. Three plots were treated with poultry litter and three with swine manure. Application rates of selected poultry litter and swine manure constituents appear in Table 3. The grass height was approximately 0.1 m at the time of poultry litter and swine manure application. The litter and manure application to the upper 3.1 m of the plots and the placement of the runoff collection gutters enabled assessment of effectiveness of VFS lengths of 0, 3.1, 6.1, 9.2, 15.2, and 21.4 m.

Runoff Sampling and Analysis

Simulated rainfall was intiated 2 d following poultry litter application and 5 d following swine manure application. Four rainfall simulators (Edwards et al., 1992), altogether capable of applying rainfall to one complete plot, were used to supply rainfall at an intensity of 50 mm/h. The plots received no natural rainfall between litter/manure application and the simulated rainfall. The municipal water that was used as the simulated rainfall source was sampled and analyzed (Table 4). The simulated rainfall was maintained until 1 h of runoff had occurred on each plot. The elapsed time between the beginning of rainfall and the beginning of runoff was noted for each plot. Seven runoff samples were manually-collected from the gutters on approximately a 0.17 h sampling interval, starting 0.08 h after start of runoff. All runoff samples at a given sampling time were collected sequentially beginning with the

Table 3. Application rates of selected poultry litter and swine manure constituents.

	Application Rate	
Constituent	Poultry Litter	Swine Manure
	kg/ha	
Total N	185.9	203.0
NH_3-N	25.4	150.4
NO_3-N	1.0	4.3
Total P	88.9	140.6

Table 4. Municipal water composition.

Constituent	Concentration[1]
	mg/L
NO_3-N	0.550 (0.01[2])
TKN	0.476 (0.31)
NH_3-N	0.003 (0.0)
PO_4-P	0.003 (0.01)
Total P	0.050 (0.03)

[1] Mean of three replications.

[2] Figures in the parentheses show standard deviations.

bottom gutter. The times required to collect the samples were measured to enable computation of runoff rates and volumes.

Analytical Analyses of the Runoff Samples

Aliquots of the runoff samples were filtered (0.45 μm pore diameter) immediately after collection for PO_4-P and NO_3-N analysis. The runoff samples were then analyzed by Arkansas Water Resources Center Water Quality Laboratory for TKN, NH_3-N, NO_3-N, TP, PO_4-P, chemical oxygen demand (COD), FC, and total suspended solids (TSS) using standard methods of analysis (Greenberg et at., 1992). The macro-Kjeldahl method was used for TKN analysis. Ammonia was determined by the ammonia-selective electrode method. An ion chromatograph was used in analysis of NO_3-N and PO_4-P. Total P was determined by the ascorbic acid colorimetric method following H_2SO_4-HNO_3 acid digestion. The closed reflux, colorimetric method was used for COD analysis. Fecal coliform concentration was measured using the membrane-filter technique.

Statistical Analyses

The runoff amounts and poultry litter and swine manure constituent concentration data were used to compute flow-weighted concentrations and mass transport of TKN, NH_3-N, NO_3-N, TP, PO_4-P, COD, FC, and TSS past various VFS lengths. One-way analysis of variance tests were performed to determine the effects of VFS length on average concentration, average mass transport, and average proportion of mass transport reduction for different litter and manure constituents. Least significant difference (LSD) testing used to separate treatment means when analysis of variance indicated a significant VFS length treatment effect.

RESULTS

Effects of VFS Length on Runoff Concentrations of Litter and Manure Constituents

Flow-weighted mean runoff concentrations, averaged across all replications, for all the investigated water quality parameters for poultry litter and swine manure are shown in Tables 5 and 6, respectively. All parameters were significantly ($p<0.05$) affected by VFS length, although concentrations of TSS, COD, and FC in runoff from poultry litter-treated plots and TP, TSS, COD, and FC in runoff from swine manure-treated plots did not decrease significantly ($p<0.05$) after a VFS length of 3.1 m. The data generally indicate the influences of filtration by the grass, dilution by the simulated rainfall, and infiltration of soluble parameters. However, decreasing concentrations were expected, since dilution must occur if the simulated rainfall is relatively pure in comparison to the oncoming runoff, and if the VFS topsoil is relatively pure in comparison to the manure-treated topsoil.

Effects of VFS Length on Mass Transport of Litter and Manure Constituents

Effects of VFS length on masses of poultry litter and swine manure constituents transported past the runoff collection troughs at the various VFS lengths are summarized in Tables 7 and 8, respectively. Mass transport of all parameters except NO_3-N was significantly affected ($p<0.05$) by VFS length treatment. Mass transport of NO_3-N tended to increase (although not significantly) with VFS length and averaged 0.82 kg/ha poultry litter-treated area and 0.32 kg/ha swine manure-treated area. It is likely that the predominant source of NO_3-N in the runoff was

Table 5. Mean[1] runoff concentrations of selected poultry litter constituents as a function of VFS length.

VFS length	Constituent							
	NO_3-N	NH_3-N	TKN	PO_4-P	TP	TSS	COD	FC
—m—	mg/L							cfu/100mL
0	0.67a[2]	7.15a	26.50a	4.29a	6.72a	61.60a	170.68a	75354a
3.1	0.62b	2.02b	6.88b	1.38b	2.22b	22.26b	53.11b	13090b
6.1	0.56c	0.9bc	4.68bc	0.75bc	1.04bc	16.78b	37.25b	7057b
9.2	0.55c	0.64bc	3.03bc	0.44bc	0.59bc	19.10b	32.94b	2629b
15.2	0.52cd	0.12c	1.85c	0.20c	0.28c	11.05b	19.49b	773b
21.4	0.50d	0.05c	1.67c	0.17c	0.22c	12.52b	19.54b	332b

[1] Mean of three replications.

[2] Within-column means followed by the same letter are not significantly (p=0.05) different by LSD test.

Table 6. Mean[1] runoff concentrations of selected swine manure constituents as a function of VFS length.

VFS length	Constituent							
	NO_3-N	NH_3-N	TKN	PO_4-P	TP	TSS	COD	FC
m	mg/L							cfu/100mL
0	0.56a[2]	11.51a	18.47a	9.79a	11.07a	61.73a	126.55a	1149000a
3.1	0.5b	2.05b	3.97b	2.01b	2.11b	12.09b	35.21b	75000b
6.1	0.48bc	0.8bc	2.18bc	1.07bc	1.18b	11.42b	27.46b	217000b
9.2	0.48bc	0.18c	0.89c	0.46c	0.57b	8.68b	22.78b	126000b
15.2	0.43c	0.06c	1.08c	0.29c	0.4b	9.48b	42.83b	115000b
21.4	0.44bc	0.04c	1.00c	0.24c	0.34b	5.3b	19.38b	152000b

[1] Mean of three replications.

[2] Within-column means followed by the same letter are not significantly (p=0.05) different by LSD test.

Table 7. Mean[1] mass transport of selected poultry litter constituents as a function of VFS length.

VFS length	Constituent						
	NH_3-N	TKN	PO_4-P	TP	TSS	COD	FC
—m—	kg/ha						cfu/ha
0	4.2a[2]	15.5a	2.5a	4.0a	35.9a	101.4a	436402 E+6a
3.1	2.2b	9.2b	1.5b	2.3b	22.7ab	56.3b	135964 E+6b
6.1	1.3bc	7.1bc	1.1bc	1.5bc	23.8ab	54.9b	97278 E+6b
9.2	1.0cd	5.1bc	0.7cd	0.9c	29.8ab	50.1b	40246 E+6b
15.2	0.3cd	4.2c	0.4d	0.6c	20.2b	37.2b	14613 E+6b
21.4	0.1d	3.4c	0.3d	0.4c	18.6b	31.1b	10014 E+6b

[1] Mean of three replications.

[2] Within-column means followed by the same letter are not significantly ($p<0.05$) different by LSD test.

Table 8. Mean[1] mass transport of selected swine manure constituents as a function of VFS length.

VFS length	Constituent				
	NH_3-N	TKN	PO_4-P	TP	TSS
—m—	kg/ha				
0	3.62a	5.81a	3.10a	3.49a	19.61a
3.1	1.03b	1.99b	1.01b	1.07b	6.06b
6.1	0.60c	1.77b	0.86bc	0.97bc	9.15b
9.2	0.13d	0.65c	0.34cd	0.43bcd	6.62b
15.2	0.04d	0.83c	0.23d	0.32cd	7.31b
21.4	0.03d	0.76c	0.18d	0.26d	4.45b

[1] Mean of three replications.

[2] Within-column means followed by the same letter are not significantly ($p<0.05$) different by LSD test.

the simulated rainfall itself, the soil, and/or the grass, since (a) the NO_3-N contents of the litter and manure were small, and (b) the short time and dry conditions between poultry litter and swine manure application and simulated rainfall would not have promoted NO_3-N formation. A reduction in NO_3-N transport might have been observed if the simulated rainfall NO_3-N concentration had been low relative to those of the litter and manure. Mass transport values for COD and FC are not shown in Table 8, because VFS length had no effect on the mass transport of these parameters. The average mass transport (computed for all VFS lengths and replications) was 22.32 kg/ha manure-treated area for COD and 1.64 X 10^{12} cfu/ha manure-treated area for FC, respectively. Mass transport data for the other parameters, however, indicate that mass is being removed as the runoff travels down slope. Decreases in concentrations of all the parameters except for NO_3-N in runoff from poultry litter-treated plots (Table 7), and NO_3-N, COD, and FC in runoff from swine manure-treated plots (Table 8) can thus be attributed to filtration mechanisms (i.e., infiltration and trapping/adsorption to grass and/or debris) as well as to dilution.

For the plots treated with poultry litter, significant ($p<0.05$) mass transport reductions occurred up to a VFS length of 9.2 m in the case of NH_3-N and PO_4-P. Mass transport did not significantly ($p<0.05$) change beyond a VFS length of 6.1 m for TKN and TP, and 3.1 m for TSS, COD, and FC.

For the swine manure-treated plots, mass transport did not decrease significantly ($p<0.5$) after a VFS length of 9.2 m for NH_3-N, TKN, PO_4-P, and TP, and 3.1 m in the case of TSS.

First order kinetics was used to describe the relationship between mass transport of poultry litter and swine manure constituents and VFS length. The equation used was

$$M_{i,L} = M_{i,0}\ e^{k_i L} \tag{1}$$

where $M_{i,L}$ is the mass transport (kg/ha treated area) of constituent i transported past VFS length L, $M_{i,o}$ is the mass transport (kg/ha treated area) of constituent i initially entering the VFS, k_i is the rate coefficient (1/m) of constituent i, and L is VFS length (m). The parameter k_i was determined from linear regression of natural logarithms of mass transport data against VFS length. The regression lines were forced through initial values of incoming mass transport. The values of k_i are given in Table 9.

Figures 1, 2, and 3 demonstrate the relationship between actual and predicted (first-order) mass transport of NH_3-N, TP, and PO_4-P for different VFS lengths for the poultry litter-treated plots. Relationships between actual and predicted (first-order) mass transport past different VFS lengths of these nutrients for the swine manure treated plots are shown in Figures 4, 5, and 6. In all cases, predicted mass transport values were very similar to the observed values.

Proportions of Reduction of Initial Mass Transport

Vegetated filter strip effectiveness was computed for each poultry litter and swine manure constituent from

$$E_{i,j} = 100\ [(M_{o,j} - M_{i,j})/M_{o,j}] \tag{2}$$

Table 9. Rate coefficients for first-order model of mass transport.

	Poultry Litter		Swine Manure	
Parameter	k[1]	C.V.[2]	k	C.V.
	—m^{-1}—	—%—	—m^{-1}—	—%—
TKN	-0.084	37	-0.26	22
NH_3-N	-0.174	41	-0.13	22
TP	-0.123	45	-0.15	35
PO_4-P	-0.113	33	-0.16	34
COD	-0.064	36	-0.08	45
TSS	-0.035	32	-0.06	47

[1] k is rate coefficient.

[2] C.V. is the coefficient of variation.

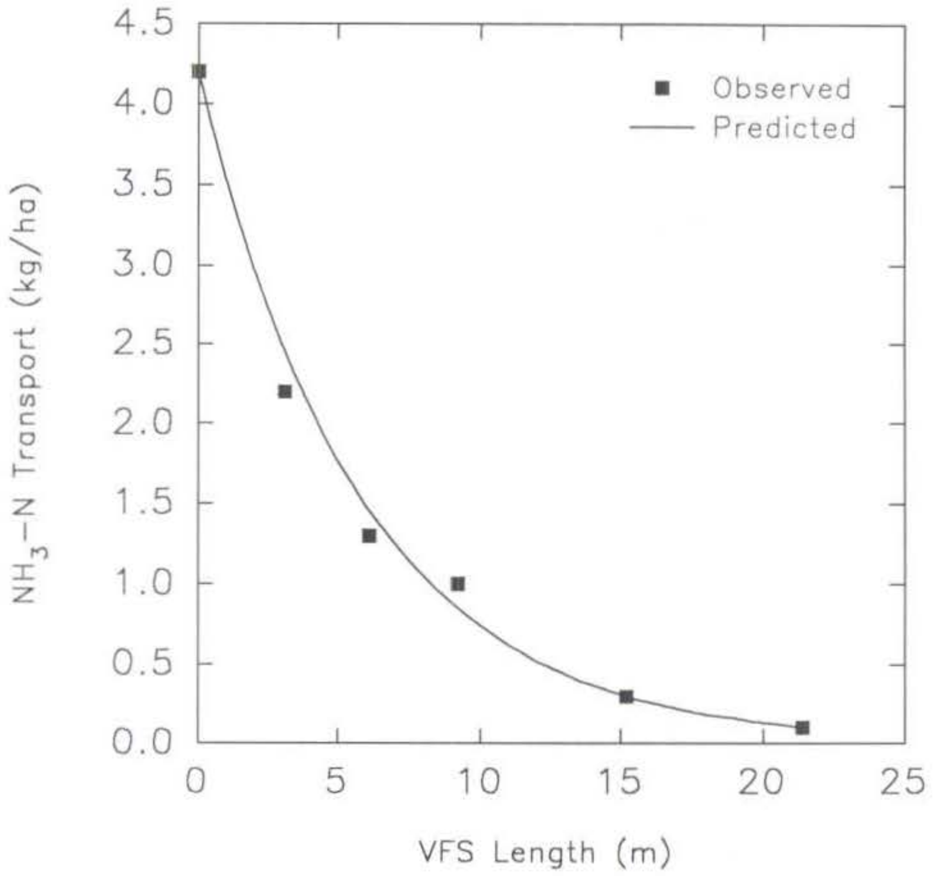

Figure 1. Observed and predicted (first-order) mass transport of NH_3-N from the plots treated with poultry litter as a function of VFS length.

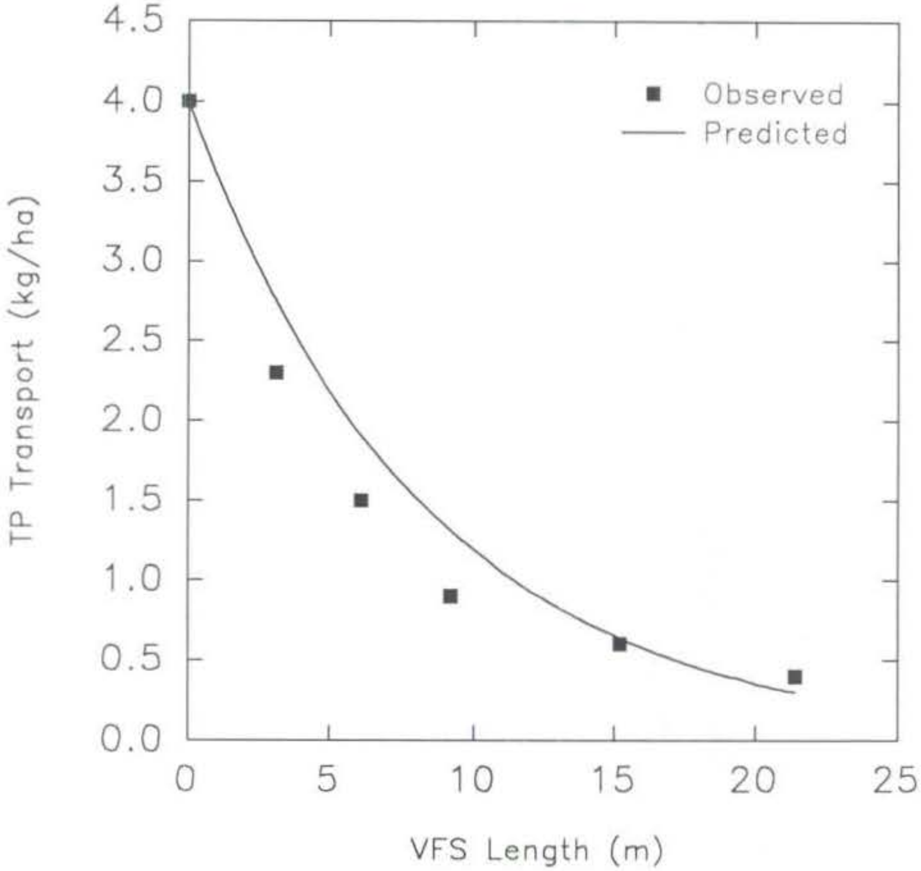

Figure 2. Observed and predicted (first-order) mass transport of TP from the plots treated with poultry litter as a function of VFS length.

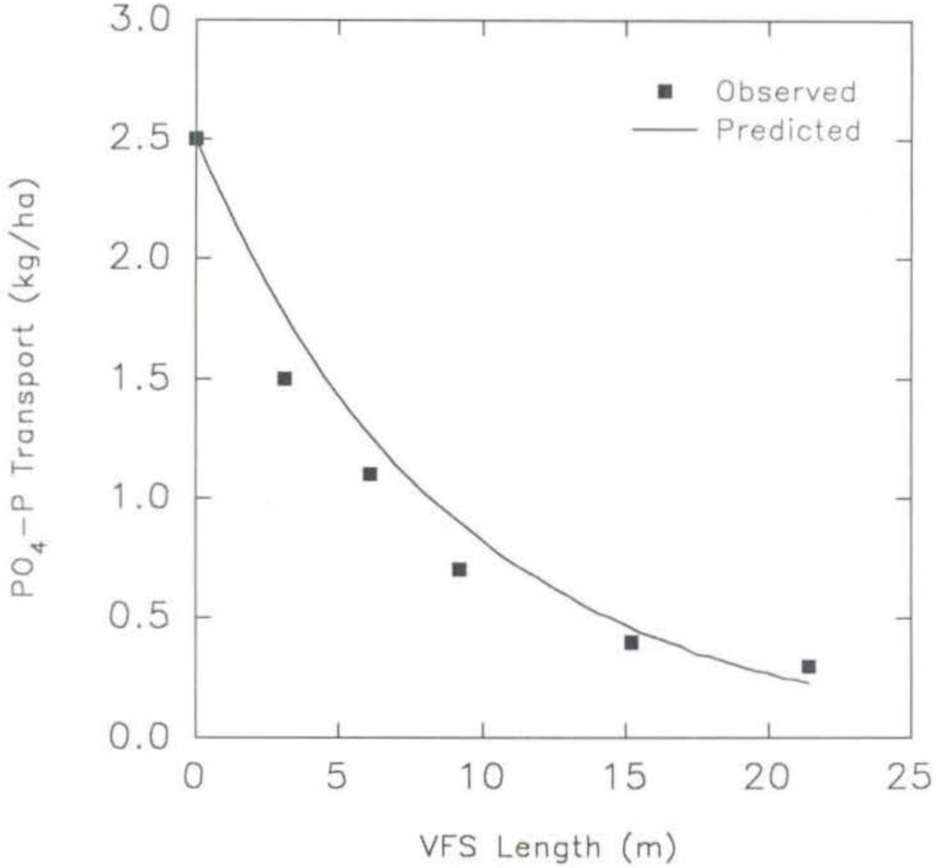

Figure 3. Observed and predicted (first-order) mass transport of PO_4-P from the plots treated with poultry litter as a function of VFS length.

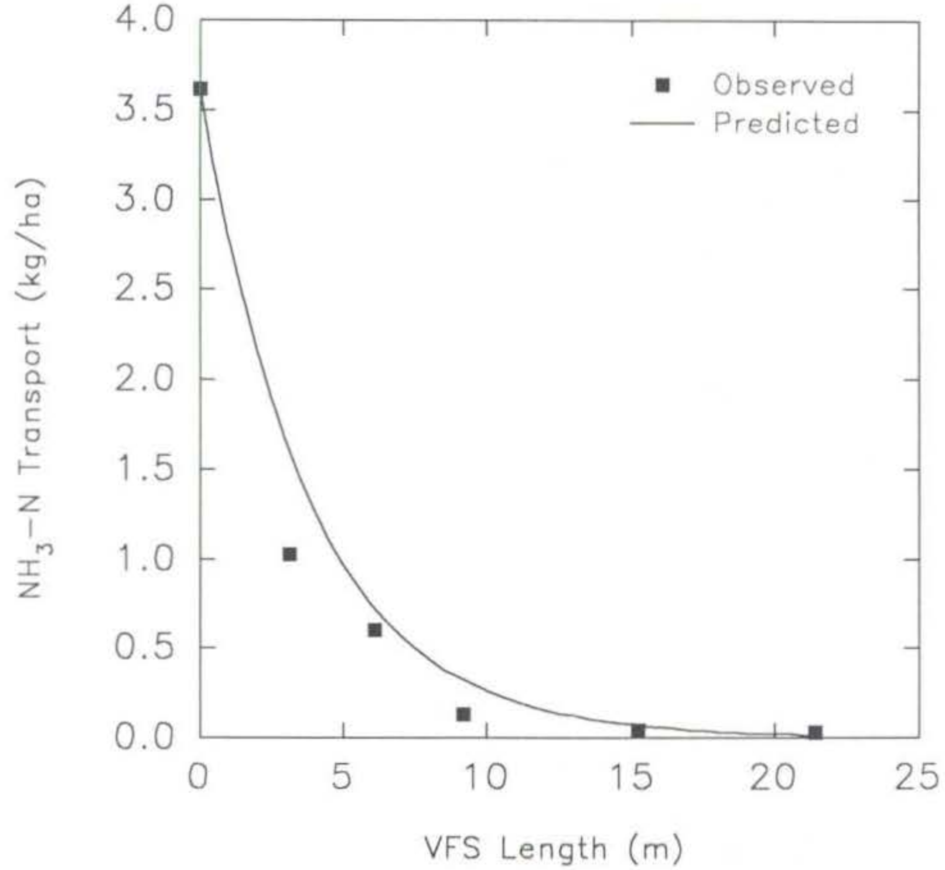

Figure 4. Observed and predicted (first-order) mass transport of NH_3-N from the plots treated with swine manure as a function of VFS length.

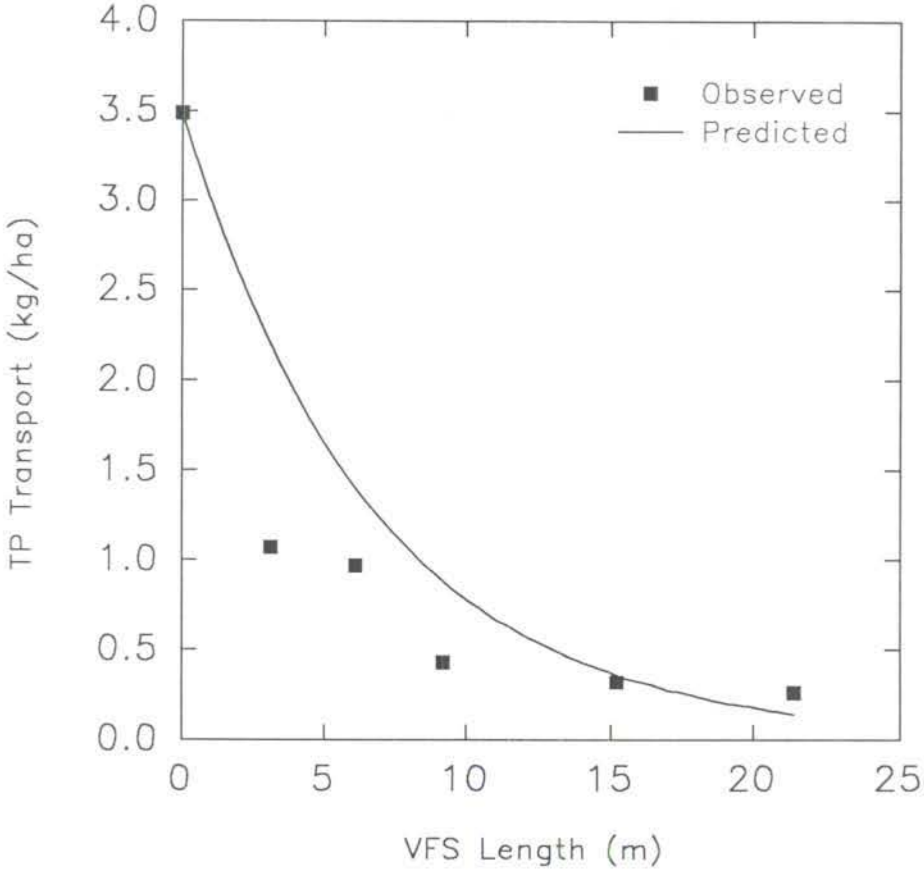

Figure 5. Observed and predicted (first-order) mass transport of TP from the plots treated with swine manure as a function of VFS length.

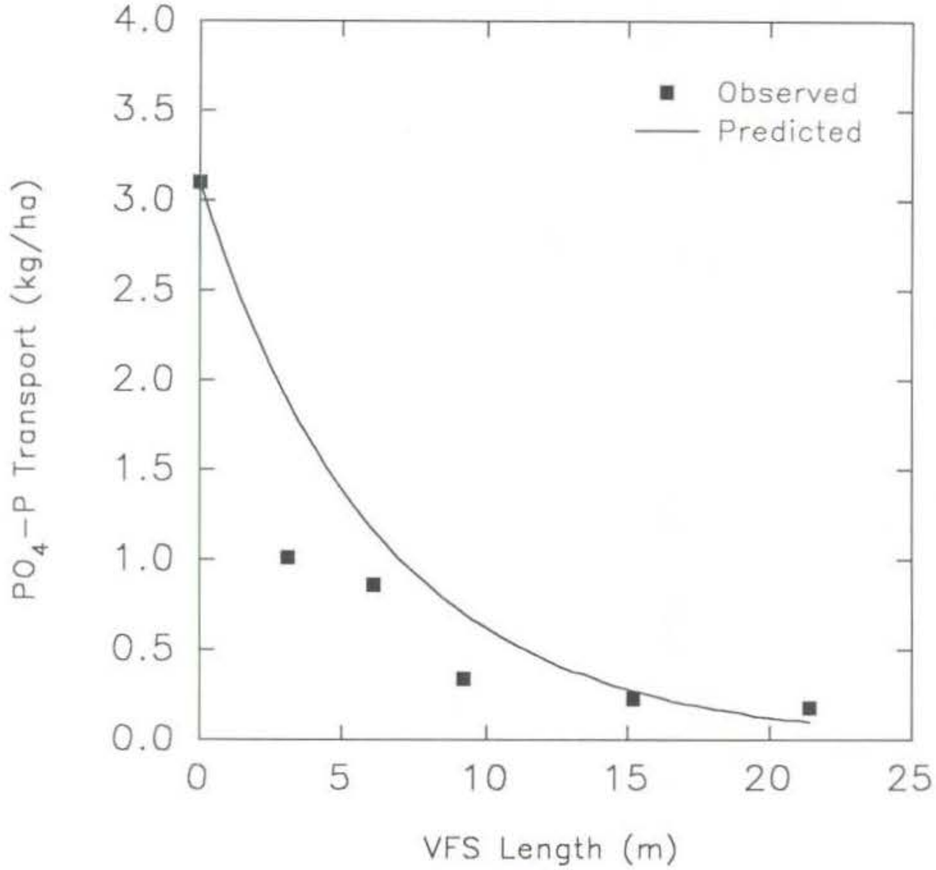

Figure 6: Observed and predicted (first-order) mass transport of PO_4-P (from the plots treated with swine manure) as a function of VFS length.

where $E_{i.j}$ is the effectiveness (%) of VFS length i for parameter j, $M_{i.j}$ is the mass of parameter j transported past VFS length i, and $M_{o.j}$ is the mass of parameter j transported past the zero VFS length (i.e., initially entering the VFS). The effectiveness values of the various VFS lengths with respect to the runoff analysis parameters from the plots treated with poultry litter and swine manure are indicated in Tables 10 and 11, respectively. No values are shown for NO_3-N since, as discussed earlier, mass transport of this parameter was independent of VFS length. Furthermore, no data for TSS or COD are given in Table 10, and for TSS, COD, and FC in Table 11, because the effectiveness of these parameters did not vary with VFS length for lengths between 3.1 and 21.4 m. The average effectiveness (computed for all lengths and replications) of the VFS for the poultry litter-treated plots for COD and TSS was 34.5 and 50.7%, respectively. The average VFS effectiveness (computed for all lengths and replications) was 61.4, 49.5, and 58.8% for TSS, COD, and FC, respectively, for the swine manure-treated plots.

Table 10 indicates that the 21.4 m VFS length was from 80.5 to 99.0% effective in reducing incoming mass transport of TKN, NH_3-N, TP, PO_4-P, and FC. The LSD testing of the mean effectiveness values, however, indicated that VFS effectiveness in terms of TKN, TP, and FC removal did not increase significantly ($p<0.05$) beyond VFS lengths of 9.2 m. Vegetative filter strip effectiveness with respect to NH_3-N and PO_4-P removal increased up to 15.2 m.

Maximum effectiveness (at 21.4 m VFS length) varied from 87.3 to 99.2% for reducing incoming mass transport of TKN, NH_3-N, TP, and PO_4-P from the plots treated with swine manure (Table 11). LSD testing of the

Table 10. Mean[1] VFS effectiveness for selected poultry litter constituents.

VFS Length	Constituent				
	NH_3-N	TKN	PO_4-P	TP	FC
—m—	%				
3.1	46.6c[2]	39.2c	38.8d	39.6c	62.2c
6.1	69.8b	53.5bc	55.1cd	58.4bc	77.2b
9.2	77.6b	66.6ab	70.5bc	74.0ab	89.9a
15.2	94.1a	75.7a	84.9ab	86.8a	97.2a
21.4	98.0a	80.5a	89.5a	91.2a	98.9a

[1] Mean of three replications.

[2] Within-column means followed by the same letter are not significantly ($p<0.05$) different by LSD test.

Table 11. Mean[1] VFS effectiveness for selected swine manure constituents.

VFS Length	Constituent			
	NH_3-N	TKN	PO_4-P	TP
—m—	%			
3.1	70.9c[2]	64.9b	65.4b	67.0b
6.1	82.9b	69.1b	71.3b	70.9b
9.2	96.4a	88.7a	88.7a	87.2ab
15.2	98.8a	86.2a	92.9a	91.1a
21.4	99.2a	87.3a	94.3a	92.4a

[1] Mean of three replications.

[2] Within-column means followed by the same letter are not significantly ($p<0.05$) different by LSD test.

mean effectiveness values, however, indicated that the effectiveness in terms of NH_3-N, TKN, PO_4-P, and TP mass transport reduction did not increase significantly ($p<0.5$) beyond a VFS length of 9.2 m.

CONCLUSIONS

The fescue VFS removed significant ($p<0.05$) quantities of TKN, NH_3-N, TP, PO_4-P, TSS, and COD from incoming runoff that originated from a 3.1 m long source area treated with poultry litter. The VFS also were effective in reducing significant quantities of TKN, NH_3-N, PO_4-P, TP, and TSS from incoming runoff that originated from swine manure-treated area. The effectiveness of the VFS depended on the particular poultry litter/swine manure constituent as well as the VFS length.

The VFS were ineffective in removing NO_3-N from the incoming runoff from the poultry litter-treated area and NO_3-N, FC, and COD from swine manure-treated area, although this might have been due to the relatively high NO_3-N concentration of the water used to provide simulated rainfall.

Effectiveness of VFS did not significantly ($p<0.05$) increase beyond 3.1 m for TSS and COD, 9.2 m for TKN and TP, and 15.2 m for NH_3-N and PO_4-P, respectively, for poultry litter-treated plots. There was no significant increase in the effectiveness of VFS beyond 3.1 m for TSS, and 9.2 m for NH_3-N, TKN, PO_4-P, and TP, respectively, for the plots treated with swine manure.

Fescue VFS appear to be effective in improving the quality of runoff from source areas treated with poultry litter and swine manure, if considerations mentioned earlier are followed. Further research is needed to determine the impact of source area to buffer area ratio on VFS performance and to quantify the effects of other variables such as type of vegetation, and rate and nature of incoming flow (diffuse vs. concentrated) on VFS performance.

Given the relatively straight forward nature of the results of this experiment and past success in modeling VFS performance, it seems likely that accurate estimation of VFS performance under a variety of circumstances will be possible in the future. It will then be the task of appropriate governmental agencies to define goals with regard to VFS effectiveness or even to establish something similar to discharge limitations in order for VFS (or similar management options) to be most effectively and rationally implemented.

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