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Effectiveness of Vegetative Filter Strips in Controlling Losses of Surface-Applied Poultry Litter Constituents

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EFFECTIVENESS OF VEGETATIVE FILTER STRIPS IN CONTROLLING LOSSES OF SURFACE-APPLIED POULTRY LITTER CONSTITUENTS


ABSTRACT. Vegetative filter strips (VFS) have been shown to have high potential for reducing nonpoint source pollution from cultivated agricultural source areas, but information from uncultivated source areas amended with poultry litter is limited. Simulated rainfall was used in analyzing effects of VFS length (0, 3.1, 6.1, 9.2, 15.2, and 21.4 m) on quality of runoff from fescue (Festuca arundinacea Schreb.) plots (1.5 x 24.4 m) amended with poultry litter (5 Mg/ha). The VFS reduced mass transport of ammonia-nitrogen (NH₃-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (PO₄-P), total phosphorus (TP), chemical oxygen demand (COD), and total suspended solids (TSS). Mass transport of TKN, NH₃-N, TP, and PO₄-P were reduced by averages of 39, 47, 40, and 39%, respectively, by 3.1 m VFS and by 81, 98, 91, and 90%, respectively, by 21.4 m VFS. Effectiveness of VFS in terms of mass transport reduction was unchanged, however, beyond 3.1 m length for TSS and COD and averaged 35 and 51%, respectively. The VFS were ineffective in removing nitrate-nitrogen from the incoming runoff. Removal of litter constituents was described very well (r² = 0.70 to 0.94) by a first-order relationship between constituent removal and VFS length. Keywords. Runoff, Water quality, Animal manure, Poultry litter.

L and application of animal manure is generally regarded as an economic means of making beneficial use of manure constituents. Runoff from land application sites, however, is a potentially significant source of pollution, since it can contain undesirable concentrations of sediment, organic matter, nutrients, and microorganisms. The increasing size and concentration of animal production facilities in some regions have made land application of manure a topic of high public interest.

Use of vegetative filter strips (VFS) has received considerable attention for removing impurities in runoff from cropland and areas of livestock activity. Vegetative filter strips (also referred to as grass filters, vegetative buffer strips, filter strips, or buffer strips) consist of grass or other cover and are emplaced down slope of pollutant sources to remove sediment, nutrients, and other materials from the incoming runoff. While VFS can occur naturally, the term generally (and in this article) denotes a man-made nonpoint source pollution management practice. Vegetative filter strips can purify entering runoff by promoting infiltration of soluble pollutants, deposition of sediment and sediment-bound pollutants, and adsorption of pollutants onto soil and plant surfaces (Dillaha et al., 1989). Several studies have been conducted to investigate the use of VFS for nonpoint source pollution control, but there are currently no generally accepted methods for VFS design with respect to pollutant removal that fully account for the many different mechanisms that govern VFS performance. Consequently, VFS can be installed in areas and under conditions in which they are either ineffective or perhaps overdesigned.

Field studies involving runoff from cattle feedlots/barnyards (e.g., Westerman and Overcash, 1980; Young et al., 1980; Dickey and Vanderholm, 1981; Edwards et al., 1983; Dillaha et al., 1988; Schellinger and Clausen, 1992), cropland runoff (e.g., Dillaha et al., 1989; Magette et al., 1989; Michelson and Baker, 1993), and runoff from vegetated areas receiving various treatments (e.g., Doyle et al., 1975, 1977; Thompson et al., 1978; Paterson et al., 1980; Bingham et al., 1980; Overman and Schanze, 1985; Schwer and Clausen, 1989) indicate that VFS can be very effective in removing various constituents from incoming runoff. Depending on factors such as runoff rate, nature and length of the VFS, and pollutant source area characteristics, VFS can remove in excess of 90% of runoff constituents such as total Kjeldahl nitrogen (TKN), total phosphorus (TP), fecal coliforms, and total suspended solids (TSS). The nature of incoming flow is also reported to have a significant effect on VFS effectiveness; Dillaha
et al. (1986) reported that VFS effectiveness decreased markedly following the development of concentrated flow within the VFS.

Several scientists have successfully described the capability of VFS to remove materials in incoming runoff through use of mathematical simulation models (Barfield et al., 1979; Kao and Barfield, 1978; Toller et al., 1976, 1977; Hayes et al., 1979; Hayes and Hairston, 1983). One of the more recent modeling developments was reported by Lee et al. (1989), who developed an event-based model to simulate phosphorus transport in VFS.

The objective of this study was to test the effectiveness of VFS for the removal of sediment, nutrients, and organic matter from land areas amended with poultry litter. This work complements previous studies by examining poultry litter 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 studies have addressed use of VFS just beneath row-cropped land or feed lots; this work addresses VFS effectiveness just beneath pasture/range land.

**MATERIALS AND METHODS**

Three plots with dimensions of $1.5 \times 24.4$ m (long axes oriented down slope) were constructed on a Captina silt loam (fine-silty, mixed mesic, Typic Fragiudult) at the main Agricultural Experiment Station in Fayetteville, Arkansas (approximately 36°N Lat). Each plot was graded to a uniform 3% slope and bordered with rust-proofed metal to isolate runoff. A cover of fescue was established in spring 1992 by seeding at approximately 500 kg/ha. Wooden gutters were installed across each plot, with tops at ground surface level, at 3.1, 6.1, 9.2, 12.2, 18.3, and 24.4 m down slope of the top to enable collection of runoff at those locations (fig. 1). Each gutter had inside dimensions of $1.5 \times 0.1$ m and was fitted with a removable, water-tight cover that prevented water entry into the gutter during the nonsampling times.

Poultry litter was manually applied in May 1993 (approximately 13 months after seeding the plots) at 5 Mg/ha to the upper 3.1 m of each plot. The grass height was approximately 10 cm at the time of litter application, and the proportion of soil surface covered by the grass was essentially 100%. Prior to litter application, soil samples (0 to 2.5 cm depth) were collected from each plot and analyzed by the University of Arkansas Agricultural Services Laboratory. The results of the soil analyses are given in table 1. The composition of the poultry litter and application rates of selected litter constituents appear in tables 1 and 2, respectively. The litter 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.

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 two days following litter application. The plots received no natural rainfall between litter application and the simulated rainfall. The municipal water that was used as the simulated rainfall source was sampled and analyzed for various constituents (table 3). The duration of simulated rainfall was 1 h after the beginning of runoff. Runoff samples were manually collected from the gutters approximately every 0.17 h. All runoff samples for a given sampling time were collected sequentially beginning with the gutter most distant from the source area. The times required to collect the samples were measured to enable computation of runoff rates and volumes.

Aliquots of the samples were filtered (0.45 μm pore diameter) for ortho-phosphorus (PO$_4$-P) and nitrate-nitrogen (NO$_3$-N) analysis. The runoff samples were then refrigerated (4° C) and analyzed using standard methods (Greenberg et al., 1992) by the Arkansas Water Resources Center Water Quality Laboratory for TKN, ammonia-nitrogen (NH$_3$-N), NO$_3$-N, TP, PO$_4$-P, chemical oxygen demand (COD), and TSS. The macro-Kjeldahl method was used for TKN analysis. Ammonia was determined by the ammonia-selective electrode method. Ion chromatography

![Figure 1-Schematic of experimental field plot (not to scale).](image)
was used in analyses of NO₃-N and PO₄-P. Total P was analyzed by the ascorbic acid colorimetric method. The closed reflux, colorimetric method was used for COD analyzed by the ascorbic acid colorimetric method was used in analyses of NO₃-N and PO₄-P. Total P was analyzed by the ascorbic acid colorimetric method. The closed reflux, colorimetric method was used for COD determinations.

The runoff amount and poultry litter constituent concentration data were used to compute mass losses of TKN, NH₃-N, NO₃-N, TP, PO₄-P, COD, and TSS occurring at various VFS lengths. Analyses of variance were performed to determine the effects of VFS length on average concentration, average mass loss, and average proportion of mass loss reduction for the litter constituents studied. Least significant difference (LSD) testing was performed to determine significant differences in VFS length performance when analyses of variance indicated a significant overall VFS length treatment effect. All tests of significance were conducted at the \( p = 0.05 \) level.

**RESULTS AND DISCUSSION**

**VFS LENGTH EFFECTS ON LITTER CONSTITUENT MASS TRANSPORT**

Data on mean mass transport measured at each VFS length are given in table 5. Except for the case of NO₃-N, VFS length treatment had an overall significant effect on the mass transport of all poultry litter constituents investigated. Means separation according to VFS length treatment level, however, indicated variation in the VFS lengths beyond which no further mass transport reduction occurred. Mass transport of TKN, NH₃-N, and PO₄-P significantly decreased up to a VFS length of approximately 9.2 m. Mass transport of TP decreased up to a VFS length of 6.1 m, while mass transport of COD and TSS decreased only up to a VFS length of 3.1 m. Mass transport of NO₃-N tended to increase (although not significantly) with VFS length and averaged 0.82 kg/ha. It is likely that the predominant source of NO₃-N in the runoff was the simulated rainfall itself (table 3), the soil, and/or the grass, since (a) the NO₃-N content of the poultry litter was low, and (b) the short time and dry conditions between litter application and rainfall would not have promoted NO₃-N formation. A reduction in runoff NO₃-N transport might have been observed if the simulated rainfall NO₃-N concentration had been low relative to that of the litter. Mass transport data for the other constituents, however, indicate that mass is being removed as the runoff travels down slope. Except for the case of NO₃-N, then, the data of table 5 indicate that decreasing concentrations of constituents shown in table 4 are due to filtration mechanisms (i.e., infiltration and trapping/adsorption to grass and/or debris) as well as to dilution.

Infiltration appears to be the mechanism most responsible for mass removal of P. Although some P was associated with the solids in runoff, most (64%, table 4) was in the soluble PO₄-P form, in which case a deposition mechanism would not have been applicable. Infiltration might also be responsible for the majority of N removed by the VFS in the incoming runoff, since there is evidence that the organic N in poultry litter (which, in this case, accounted for 85% of the total N) is comprised primarily of soluble uric acid (e.g., Schefferle, 1965) and would presumably not be subject to physical filtration or deposition. Experiments that include partitioning incoming

**Table 3. Municipal water composition**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Concentration* (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TKN</td>
<td>0.476 (0.01†)</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>0.003 (0.31)</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>0.550 (0.00)</td>
</tr>
<tr>
<td>TP</td>
<td>0.050 (0.01)</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>0.003 (0.03)</td>
</tr>
</tbody>
</table>

* Mean of three replications.
† Standard deviation.

**Table 4. Mean* poultry litter constituent concentration as a function of VFS length**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>VFS Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>(mg/L)</td>
<td></td>
</tr>
<tr>
<td>TKN</td>
<td>26.5</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>7.15</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>0.67</td>
</tr>
<tr>
<td>TP</td>
<td>6.72</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>4.29</td>
</tr>
<tr>
<td>TSS</td>
<td>61.60</td>
</tr>
<tr>
<td>COD</td>
<td>170.68</td>
</tr>
</tbody>
</table>

* Mean of three replications.
† Within-row means followed by the same letter are not significantly different by LSD test.

**Table 5. Mean* poultry litter constituent mass transport as a function of VFS length**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>VFS Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>(kg/ha source area)</td>
<td></td>
</tr>
<tr>
<td>NO₃-N</td>
<td>0.4a</td>
</tr>
<tr>
<td>TKN</td>
<td>15.5a</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>4.2a</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>4.0a</td>
</tr>
<tr>
<td>TP</td>
<td>2.5a</td>
</tr>
<tr>
<td>TSS</td>
<td>35.9a</td>
</tr>
<tr>
<td>COD</td>
<td>101.4a</td>
</tr>
</tbody>
</table>

* Mean of three replications.
† Within-row means followed by the same letter are not significantly different by LSD test.
poultry litter constituents into solid and soluble phases will be necessary to better assess the relative importance of infiltration and other mechanisms in terms of VFS effectiveness.

A first-order equation was used to describe the relationship between mass transport of litter constituents and VFS length. The equation used was:

\[ M_{i,L} = M_{i,0} e^{k_i L} \]  

(1)

where

- \( M_{i,L} \) = mass transport (kg/ha) of constituent I transported past VFS length L (m)
- \( M_{i,0} \) = mass transport (kg/ha) of constituent I initially entering the VFS
- \( k_i \) = rate coefficient (1/m) for constituent I

The parameters \( k_i \) were determined from linear regressions of natural logarithms of mass transport data against VFS length. The values of \( k_i \) are given in table 6. No data for TSS and NO3-N are shown, because the coefficient of determination for TSS was insignificant, and NO3-N transport was unaffected by VFS length.

Figure 2 demonstrates the relationship between mean observed and regression (first-order) mass transport of NH3-N, TP, and PO4-P. In all cases, regression mass transport values were comparable to the observed values (table 5 and fig. 2).

VFS LENGTH EFFECTS ON PROPORTIONS OF MASS TRANSPORT REDUCTION

VFS length effectiveness was computed for each poultry litter constituent from:

\[ E_{i,j} = 100 \left( \frac{M_{i,j}}{M_{i,0,j}} \right) \]  

(2)

where

- \( E_{i,j} \) = effectiveness (%) of VFS length I for constituent j
- \( M_{i,j} \) = mass of constituent j transported past VFS length I
- \( M_{i,0,j} \) = mass of constituent 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 poultry litter constituents are indicated in table 7. No values are shown for NO3-N since, as discussed earlier, mass transport of this constituent was independent of VFS length. Furthermore, no data for TSS or COD are given in table 7, because the VFS effectiveness with regard to these constituents did not vary with VFS length for lengths of from 3.1 to 21.4 m. The average effectiveness (computed for all lengths and replications) of the VFS for TSS was 34.5%, whereas the VFS were 50.7% effective in reducing incoming COD transport.

Results in table 7 indicate that a 21.4-m VFS length was from 80.5 to 98.0% effective in reducing incoming mass transport of TKN, NH3-N, TP, and PO4-P. The LSD testing of the mean effectiveness values, however, indicates that the effectiveness in terms of TKN and TP removal was constant for VFS lengths of 9.2 m and greater. Effectiveness of NH3-N and PO4-P removal increased up to a VFS length of 15.2 m.

CONTEXT AND APPLICABILITY OF RESULTS

This study focused on only the first runoff event following poultry litter application to the VFS source area; thus, it was not a "long-term" study. In the context of this particular VFS application, however, the results are nonetheless useful. The emphasis on the first post-litter-application runoff event is justifiable because it has been demonstrated to be far worse in terms of quality of treated area runoff than succeeding runoff events (McLeod and Hegg, 1984; Edwards and Daniel, 1994). Edwards and Daniel (1994), for example, found that 80% of all solids

<table>
<thead>
<tr>
<th>Constituent</th>
<th>k_i (m⁻¹)</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>TKN</td>
<td>-0.084</td>
<td>0.791</td>
</tr>
<tr>
<td>NH3-N</td>
<td>-0.174</td>
<td>0.995</td>
</tr>
<tr>
<td>TP</td>
<td>-0.123</td>
<td>0.932</td>
</tr>
<tr>
<td>PO4-P</td>
<td>-0.113</td>
<td>0.942</td>
</tr>
<tr>
<td>COD</td>
<td>-0.064</td>
<td>0.698</td>
</tr>
</tbody>
</table>

* k is rate coefficient, and r² is coefficient of determination.

Table 6. Results of linear regression analysis for determination of rate coefficients of the first-order kinetic equation (\( M_{i,L} = M_{i,0} e^{k_i L} \))

<table>
<thead>
<tr>
<th>Constituent</th>
<th>3.1% (m)</th>
<th>6.1% (m)</th>
<th>9.2% (m)</th>
<th>15.2% (m)</th>
<th>21.4% (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TKN</td>
<td>39.2c†</td>
<td>53.5bc</td>
<td>66.6ab</td>
<td>75.7a</td>
<td>80.5a</td>
</tr>
<tr>
<td>NH3-N</td>
<td>46.6c</td>
<td>69.8b</td>
<td>77.6b</td>
<td>94.1a</td>
<td>98.0a</td>
</tr>
<tr>
<td>TP</td>
<td>39.6c</td>
<td>58.4bc</td>
<td>74.0ab</td>
<td>86.8a</td>
<td>91.2a</td>
</tr>
<tr>
<td>PO4-P</td>
<td>38.8d</td>
<td>55.1cd</td>
<td>70.5bc</td>
<td>84.9ab</td>
<td>89.5a</td>
</tr>
</tbody>
</table>

* Mean of three replications.
† Within-row means followed by the same letter are not significantly different by LSD test.

Figure 2—Predicted (first-order) and observed mass transport of NH3-N, TP, and PO4-P as functions of VFS length.
losses occurring during four rainfall events occurred during the first runoff event following poultry litter application to fescue. Minimizing first post-application runoff losses of poultry litter constituents is therefore critical to minimizing total constituent losses.

The long-term effectiveness of VFS would be an issue of concern in a use of VFS below pasture if there were evidence of accumulation of nutrients, sediment, or other litter constituents. Investigations of runoff losses of poultry constituents applied to fescue, however, have consistently demonstrated that nutrient losses are typically quite low (only a few percent of amounts applied) (Edwards and Daniel, 1993; 1994). It is therefore more likely that incoming nutrients in runoff from amended pasture will be insufficient to maintain optimal grass density within the VFS than that nutrients will accumulate within the VFS. Available information also suggests that when VFS are used below pasture, effectiveness will not be appreciably degraded due to a build-up of solids within the VFS. Reported solids losses from fescue pasture treated with poultry litter are relatively low in comparison to those that are characteristic of cropland or feedlots (Edwards and Daniel, 1993; 1994). In addition, most (by far) of the solids transported from litter-treated fescue consist of litter particles (as opposed to soil) that can decompose rather rapidly (Edwards et al., 1994). In view of the preceding discussion, it appears likely that VFS used to remove pollutants transported from pasture will not experience some of the same processes that significantly diminish long-term effectiveness of VFS installed down slope of cropland, feedlots, or other sources that provide a relatively high and constant pollutant input.

It was recognized that the litter-treated “source area” was small in comparison to the VFS. A longer litter-treated source area, as would be more typical in actual practice, would have increased hydraulic and pollutant loadings to the VFS and thus altered some VFS performance measures. The focus of this study, however, was on characterizing VFS effectiveness as a function of VFS length rather than hydraulic and pollutant loadings. More comprehensive studies that eventually address all major factors that influence VFS performance are needed, because the effects of those factors and their interactions will ultimately be necessary to best implement VFS technology in situations outside the reported collective database.

SUMMARY AND CONCLUSIONS

Poultry litter was applied at 5 Mg/ha to the upper 3.1 m of 24.4 m long grassed (fescue) plots. The remainder of the plots acted as a VFS for the runoff produced by simulated rainfall (50 mm/h). Runoff was sampled at selected down slope distances, analyzed, and used to compute concentrations of poultry litter constituents, mass transport of the constituents past the sampling points, and effectiveness of the various VFS lengths in reducing constituent mass transport.

The VFS removed significant quantities of TKN, NH$_3$-N, TP, PO$_4$-P, TSS, and COD from incoming runoff. Removal of NH$_3$-N and PO$_4$-P increased up to a VFS length of 15.2 m. Increases in TKN and TP removal were observed up to a VFS length of 9.2 m, while TSS and COD removal did not increase beyond a VFS length of 3.1 m. The VFS appeared to be ineffective in removing NO$_3$-N from incoming runoff, but their effectiveness could have been masked by the relatively high NO$_3$-N concentration of the simulated rainfall.

Fescue VFS appear to hold promise for improving quality of runoff from source areas treated with poultry litter, if considerations mentioned in the introductory portion of this article are followed. Additional work is needed to determine the effect of source area to filter area ratio on VFS effectiveness and to quantify impacts of other variables such as type of vegetation and incoming flow rate on VFS performance.

REFERENCES


