Vegetative Filter Strip Removal of Metals in Runoff from Poultry Litter-Amended Fescuegrass Plots

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VEGETATIVE FILTER STRIP REMOVAL OF METALS IN RUNOFF FROM POULTRY LITTER-AMENDED FESCUEGRASS PLOTS

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ABSTRACT. *Runoff from land areas amended with poultry (Gallus gallus domesticus) manure can contain elevated concentrations of metals such as Cu, Fe, and Zn. Vegetative filter strips (VFS) can reduce runoff concentrations of animal manure components, but reported studies have typically focused on nutrients and solids rather than metals. This experiment assessed the impact of VFS length (0 to 12 m) on concentrations and mass losses of Cu, Fe, K, Na, Ni, and Zn in runoff from fescuegrass (Festuca arundinacea* Schreb.*) plots (1.5 m wide × 6 and 12 m long) treated with poultry litter. The runoff was produced from simulated rainfall applied at 50 mm h^{-1} until 1 h of runoff had occurred. Runoff Ni concentrations were below detection levels in all cases. Concentrations of Cu, Fe, K, Na, and Zn did not differ between litter-treated plot lengths but were significantly (p <0.001) affected by VFS length, decreasing in an approximately first-order fashion. Means separation indicated that concentrations of Cu, Fe, K, and Zn did not significantly decrease after a VFS length of 3 m, while Na concentrations decreased up to a VFS length of 6 m. Mass transport of only Cu significantly decreased with increasing VFS, suggesting that VFS removal mechanisms such as adsorption to clay particles might play a larger role with regard to Cu than to Fe, K, Na, and Zn.* **Keywords.** *Runoff, Metals, Manure.*

Poultry (*Gallus gallus domesticus*) litter is a by-product of broiler and other poultry production systems that consists of manure and bedding material (typically wood shavings, wheat straw, and/or rice hulls). On average, poultry litter consists of approximately 4.1% N, 1.4% P, and 2.1% K (Edwards and Daniel, 1992), but varies widely in nutrient content due to species differences and managerial factors. In southeastern poultry-producing states, poultry litter is commonly surface-applied to forage crops such as fescuegrass (*Festuca arundinacea* Schreb.) and bermudagrass [*Cynodon dactylon* L. (Pers.)]. Recent reports such as those of Huneycutt et al. (1988) and Lucero et al. (1995) have documented the yield benefits that can be realized when using poultry litter as a soil amendment.

Intense rainfall that occurs soon after poultry litter application can cause runoff losses of poultry litter components. While single-event losses of litter components are generally not great enough to be of agronomic significance (e.g., Edwards and Daniel, 1994), runoff concentrations of solids, organic matter, and nutrients can be appreciably higher than from unfertilized areas. Studies reported by Westerman et al. (1983), McLeod and Hegg (1984), Edwards and Daniel (1993, 1994), and Edwards et al. (1994) indicate that runoff concentrations and mass transport of various poultry litter components depends on variables such as rainfall intensity, poultry litter application rate, cover, number of rainfall events following application, and amount of time between litter application and rainfall. The majority of studies on runoff quality impacts of poultry litter application have emphasized the transport of solids, N, P, organic matter, and sometimes microorganisms (e.g., fecal coliforms). With the exception of recent work by Moore et al. (1996), runoff transport of metals has received scant attention.

Relatively high concentrations of metals such as Cu and Zn in poultry litter have been documented (Sims and Wolf, 1994; Moore et al., 1995b). Others (van der Watt et al., 1994; Kingery et al., 1994) have demonstrated accumulations, particularly near the surface, of such metals in soils receiving long-term applications of poultry manure. These findings indicate a potential for metals to be lost in runoff from land areas treated with poultry litter and to ultimately be transported into downstream waters.

Depending on the particular metal and its concentration, metals in streams and lakes can have detrimental impacts on aquatic plants and wildlife. For example, moderate Cu concentrations can be very toxic to algae (Manahan, 1991), and maximum concentrations of 0.02 mg L^{-1} are recommended to protect freshwater fish. Concentrations above 0.3 mg L^{-1} and 0.18 mg L^{-1} of Fe (NAS/NAE, 1972) and Zn (USEPA, 1980), respectively, are judged as potentially detrimental to freshwater fish. Combined Na and K concentrations of greater than 50 mg L^{-1} can cause foaming of water having suspended solids. Direct human health effects of these metals are generally not of great concern when present in approximately normal concentrations; none are included in the list of constituents for which primary U.S. drinking water standards exist (USEPA, 1986). There are secondary drinking water quality standards for Cu (1 mg L^{-1}), Fe (0.3 mg L^{-1}) and

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Zn (5.0 mg L^{-1}) (USEPA, 1986). These standards exist, however, primarily for aesthetic reasons (e.g., to enhance taste or to prevent staining of clothes). When ingested in concentrations greater than 20 mg L^{-1}, Na may cause some health difficulties in predisposed persons (Heath, 1982).

Vegetative filter strips (VFS), which can remove pollutants from incoming runoff, are a low-cost management option that have successfully been applied to cropland (Dillaha et al., 1989; Magette et al., 1989; Michelson and Baker, 1993), feed lots (Westerman and Overcash, 1980; Young et al., 1980; Dickey and Vanderholm, 1981; Edwards et al., 1983; Dillaha et al., 1988; Schellinger and Clausen, 1992), and grassed areas (Chaubey et al., 1994, 1995) to remove various substances from incoming runoff. The previously cited studies indicate that VFS can remove 90% or more of the incoming masses of various pollutants in runoff, depending on parameters such as vegetation characteristics, amount and characteristics of incoming pollutants, type of flow within the VFS (concentrated vs. diffuse), and VFS length.

The historical focus of research into VFS effectiveness and design has been on sediment, nutrients, bacteria, and pesticides. The effectiveness of VFS with regard to removal of incoming metals in runoff has not been adequately documented. The objective of this study was to determine the influence of fescuegrass VFS length on concentrations and mass transport of metals (Cu, Fe, K, Na, Ni, and Zn) in runoff from fescuegrass plots treated with poultry litter and to determine whether VFS performance is affected by the length of the contributing litter-treated area (i.e., characteristics of the pollutant source area).

MATERIALS AND METHODS

Six plots, located at the main Agricultural Experiment Station in Fayetteville, Arkansas, were used in the experiment. The soil is Captina silt loam (fine-silty, mixed mesic, Typic Fragiudult), covered by a stand of fescuegrass (essentially 100% cover). The plots were all 1.5 m wide, but lengths varied from between 18 and 24 m, as will be discussed later. Each plot was graded to a uniform 3% slope (along the major axis) and bordered (5 × 20 cm treated lumber) to isolate runoff.

Sloping wooden gutters were installed across each plot at 3 m intervals from the plot tops to enable collection of runoff samples at those locations. Each gutter had inside dimensions of 150 × 10 cm and was fitted with a removable, water-tight cover that prevented water entry into the gutter during the non-sampling periods. 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 held the cover tightly to the gutter when runoff sampling was not in progress. Runoff samples were collected by removing the gutter cover, whereupon the runoff would enter the gutter and exit through a 5 cm diameter PVC pipe that drained (with free outfall) into a sump. The experimental facilities and procedures have been used previously for similar work with good results (Chaubey et al., 1994, 1995).

Poultry litter was manually applied in July 1994 (approximately 2 years after seeding the plots) at 5 Mg ha^{-1} to the upper 6 m of three plots and to the upper 12 m of the remaining three plots (fig. 1). The grass height was approximately 10 cm at the time of litter application. 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 table 2.

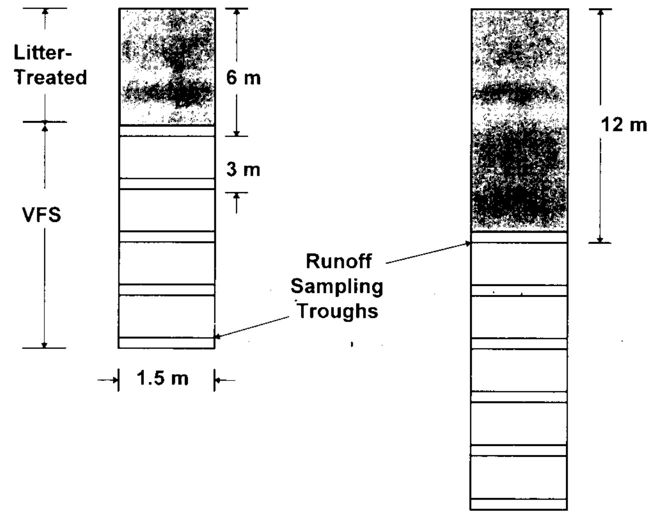


Figure 1–Schematic (not to scale) of plots.

Table 1. Soil composition

Parameter	Mean	C_v*
pH	5.5	0.04
	(μmhos cm^{-1})	
EC	20.0	0.09
	(%)	
OM	1.4	0.29
	(mg kg^{-1})	
Cu	19.1	0.86
Fe	113.9	0.33
K	69.7	0.13
Na	5.8	0.14
Zn	5.2	0.77

* Coefficient of variation.

Table 2. Poultry litter composition and application rates

Parameter	Mean	C_v*	Application Rate
pH	7.2	0.01	
	(μmhos cm^{-1})		
EC	7280	0.09	
	(mg kg^{-1})		
Cu	555	0.12	2.78
Fe	154	0.64	0.77
K	25700	0.05	129
Na	NT†	NT	34.1‡
Zn	647	0.06	3.24

* Coefficient of variation.
† Not tested.
‡ Assuming standard (ASAE, 1991) poultry litter Na content.

Rainfall simulators (Edwards et al., 1992) were used to apply water to the plots at an intensity of 50 mm h^{-1} immediately following litter application. Simulated rainfall continued until 1 h after the beginning of runoff. Runoff samples were manually collected approximately every 0.17 h in the gutters at distances of 0, 3, 6, 9, and 12 m down-slope of the litter-treated plot areas. All runoff samples for a given sampling time were collected sequentially, beginning with the bottom-most gutter and then proceeding up-slope. Rates and depths of runoff at the down-slope plot ends were calculated from runoff sample volumes and the times required to collect the respective samples. Runoff rates and depths at other sampling locations were taken as directly proportional to those measured at the corresponding bottom-most sampling locations, with the area ratio used as the proportionality constant.

Runoff concentrations of Cu, Fe, K, Na, Ni, and Zn were determined using a Spectro Model D ICP (Spectro Analytical Instruments, Fitchburg, Mass.). The runoff amounts and metal concentration data were used to compute mass losses of the investigated metals past the various VFS lengths.

Two-way analyses of variance were performed to determine the effects of poultry litter-treated source area length (6 and 12 m), VFS length (0, 3, 6, 9, and 12 m), and interaction on mean concentration and average transport for the metals investigated. Means were separated using the Student-Newman-Keuls test whenever analysis of variance indicated a significant treatment effect.

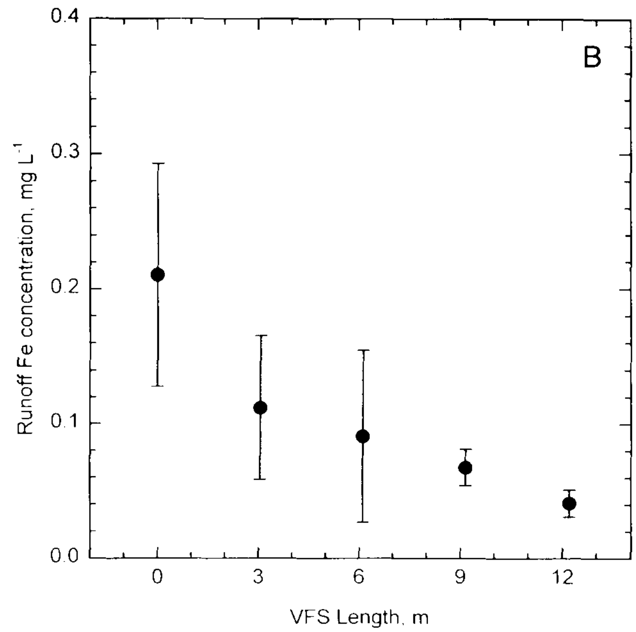
Results and Discussion

Runoff Concentrations of Metals

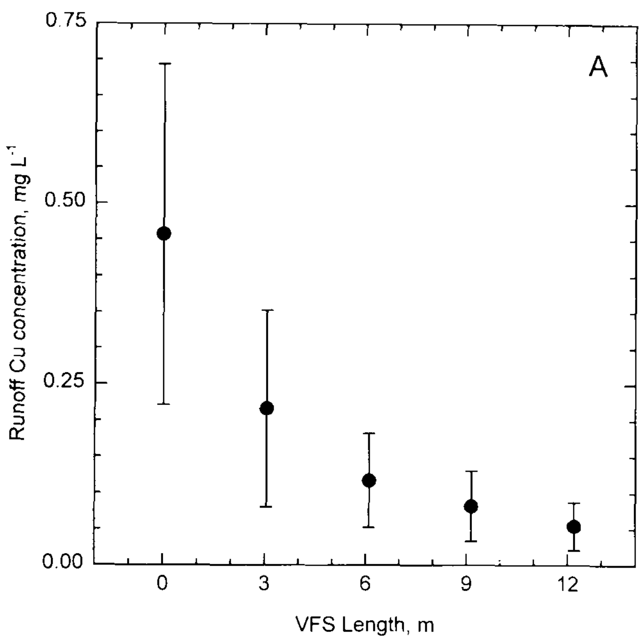
Runoff concentrations of Ni were in all cases less than the detection limit for the method used and are therefore excluded from all following discussion. The length of poultry litter treatment area did not affect runoff concentrations of any of the metals investigated, and there was no significant interaction between litter-treated length and VFS length. Runoff concentrations of all investigated metals, however, were significantly ($p < 0.001$) affected by VFS length as demonstrated in figure 2a-c.

The response of runoff concentration to VFS length was in all cases well-described as a first-order relationship. Fitted values of initial concentrations $C_{X,O}$ and rate coefficients k_X for the equation:

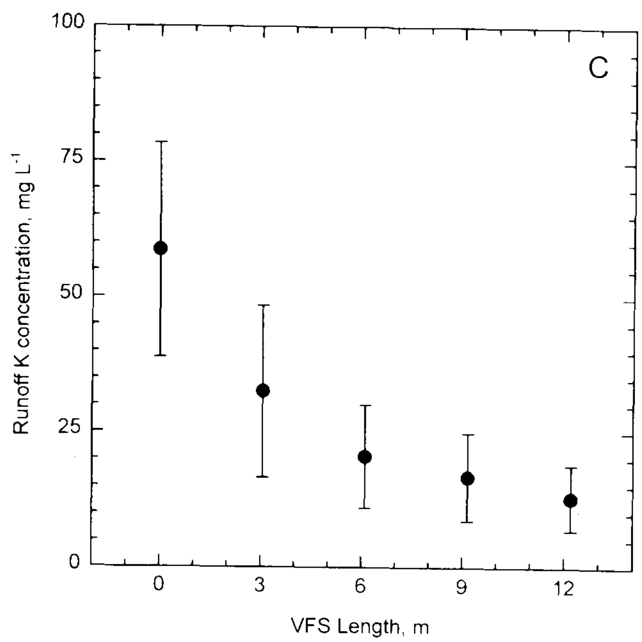
$$C_X(L) = C_{X,O}e^{k_X L} \quad (1)$$



(b)

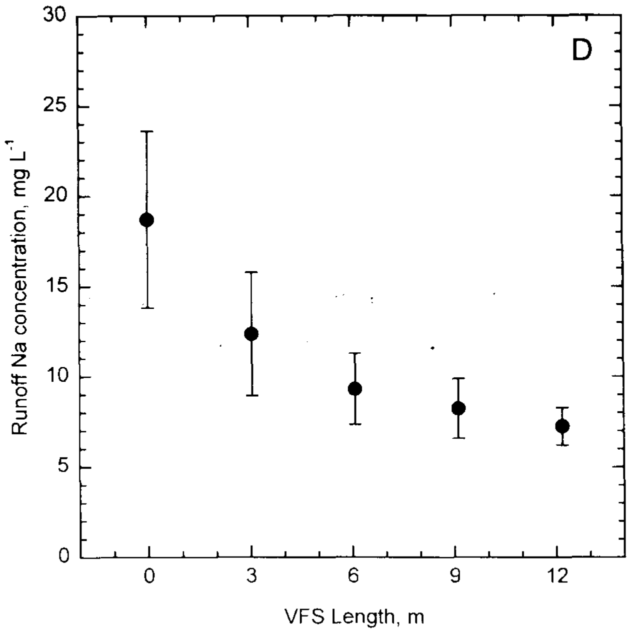


(a)



(c)

Figure 2–Response of runoff (A) Cu, (B) Fe, (C) K, (D) Na, and (E) Zn concentration to vegetative filter strip (VFS) length.



(d)

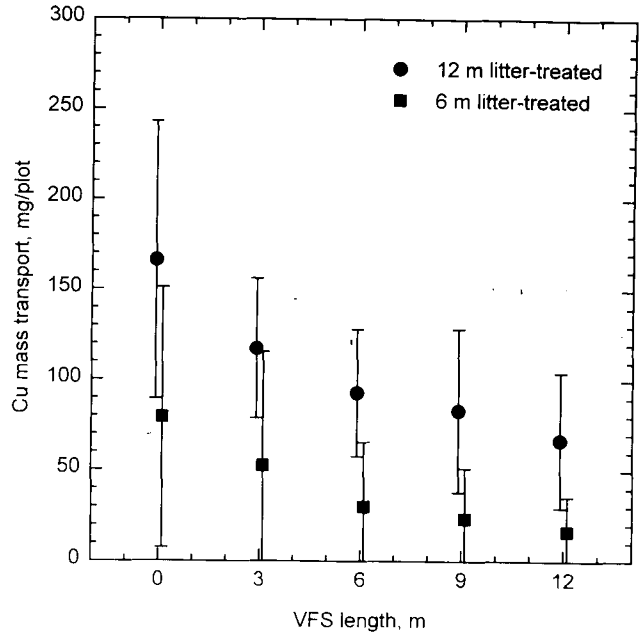
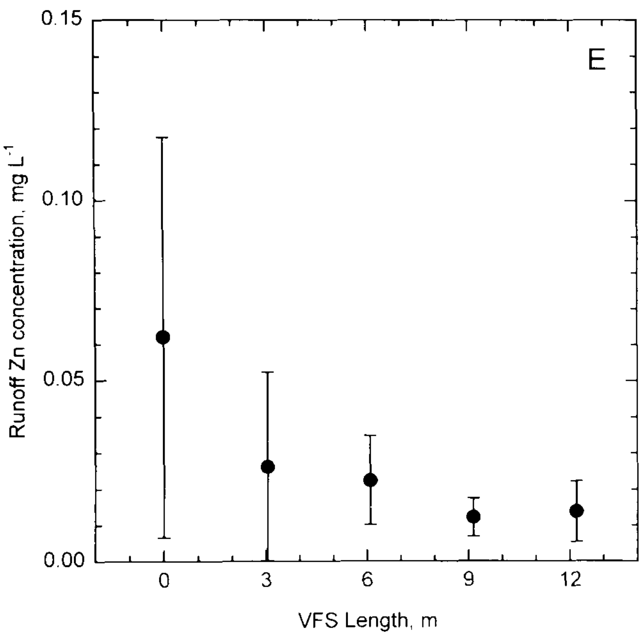


Figure 3–Response of Cu mass transport to vegetative filter strip (VFS) length.



(e)

Figure 2 (continued)–Response of runoff (A) Cu, (B) Fe, (C) K, (D) Na, and (E) Zn concentration to vegetative filter strip (VFS) length.

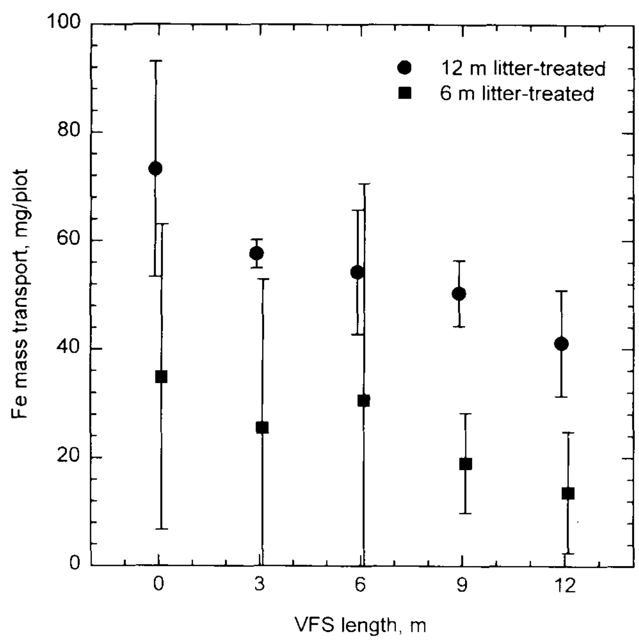


Figure 4–Fe mass transport measured at experimental vegetative filter strip (VFS) lengths. There are no significant differences in mass transport values for a given litter-treated length.

as determined from the data are given in table 3. In the above equation, C_X is runoff concentration (mg L^{-1}) of parameter X at VFS length L (m), $C_{X,O}$ is concentration entering the VFS, and k_X is the rate coefficient. All values of the coefficient of determination (r^2) in table 5 are significant ($p < 0.05$). The apparent functional relationship between runoff concentration and VFS length indicates that the length effect on concentration diminishes as VFS length increases. Means separation indicated that for Cu, Fe, K, and Zn, no significant reductions in runoff concentration occurred for VFS lengths greater than 3 m. In other words, a 3 m-long VFS performed as well, with regard to concentration reduction, in these cases as a 12 m-long VFS. Runoff concentrations of Na decreased up to a VFS length of 6 m and did not differ significantly for greater VFS lengths.

The average Cu concentrations entering the VFS (0.45 mg L^{-1}) were considerably above the recommendation of 0.02 mg L^{-1} for freshwater fish. Runoff Cu concerns might thus be of concern if runoff directly entered a small stream without being sufficiently

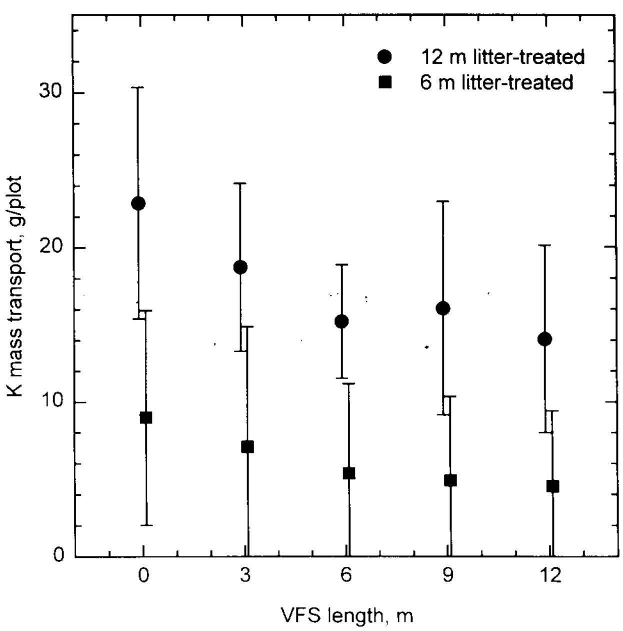


Figure 5–K mass transport measured at experimental vegetative filter strip (VFS) lengths. There are no significant differences in mass transport values for a given litter-treated length.

Table 3. First-order equation parameters for relating concentration to vegetative filter strip length

Parameter	C_0* (mg L^{-1})	k	r^2†
Cu	0.34	−0.19	0.45
Fe	0.17	−0.12	0.61
K	46.5	−0.13	0.48
Na	16.1	−0.07	0.65
Zn	0.03	−0.10	0.30

* C_0 and k are the parameters of the equation $C(L) = C_0e^{-kL}$ where C(L) is the runoff concentration of a particular parameter and L is vegetative filter strip length.

† Coefficient of determination (from regression using natural logarithms of concentrations and vegetative filter strip lengths).

diluted by runoff that is relatively deficient in Cu. Average concentrations of Fe (0.2 mg L^{-1}) and Zn (0.06 mg L^{-1}) entering the VFS were considerably below the values cited earlier as recommended for protection of freshwater fish, suggesting that these metals have a relatively low potential for direct adverse impacts under conditions similar to those of this study. The combined K and Na concentrations (76 mg L^{-1}) entering the VFS could be sufficient to promote foaming, as per previous discussion, but this can be viewed as more of a potential nuisance than a direct threat to aquatic life.

Decreases in runoff metals concentrations with increasing VFS length should generally be expected and do not necessarily indicate that the VFS is actually removing any of the runoff metal content. Pollutants entrained in runoff from the treated area can be diluted by rainfall as the runoff travels down-slope; pollutant concentrations could thus decrease with increasing VFS length even though no pollutant mass is removed from the runoff. Simple dilution might not be expected when the concentration of a particular pollutant near the VFS soil surface is similar to that of the treated area or when runoff from the VFS is less than for the contributing treated area. In the first case, pollutant mass would be transferred from the VFS to the runoff just as it is transferred from the contributing area; the increasing runoff depth would thus be balanced in terms of concentration by the additional mass gained.

Runoff Mass Transport of Metals

Mass transport of all metals except Zn significantly ($p<0.002$) increased with litter-treated length. Since concentrations were not affected by litter-treated length, this finding reflects greater volumes of runoff from the plots with longer litter-treated lengths. The lack of a significant response of Zn mass transport to litter-treated length is not clear, but might be related to the relative mobility of Zn. Table 2 indicates that slightly more Zn than Cu was applied in the poultry litter, yet figures 2a and 2e show that runoff Zn concentrations were nearly an order of magnitude less than runoff Cu concentrations. The Zn in poultry litter therefore appears to be less mobile than the Cu.

Vegetative filter strip length significantly ($p<0.07$) affected mass transport of only Cu, as indicated in figure 3. In the cases of Fe (fig. 4) and K (fig. 5), the data suggested a trend of decreasing mass transport with increasing VFS length, but no significant trend was detected. No trend in mass transport with regard to VFS length was apparent for Na and Zn. No significant interaction effect on mass transport between litter-treated length and VFS length was detected for any metal.

The findings with respect to metals mass transport would probably be easier to explain if no metal's mass transport had been significantly affected by VFS length. As shown in table 4, variability in runoff depths was appreciable, and this variability would have made differences in mass transport (the product of concentration and runoff volume) more difficult to detect. Runoff variability, however, does not explain why only Cu mass transport responded to VFS length. The relatively small runoff concentrations (and the associated relative imprecision) of some metals similarly does not explain the results, because runoff Cu concentrations were much less than those of, for example, K and Na. Relatively high concentrations of Fe, K, Na, and Zn within the VFS can also be eliminated as causing the observed findings, since, in comparison to Cu, the soil metals content in the VFS was small relative to what was added through the litter. It is possible that even though simple infiltration could have acted to promote mass removal of all metals in the VFS, other mechanisms (e.g., adsorption to soil clay particles) could have played a larger role with regard to Cu than to other metals.

Table 4. Plot runoff depths

Litter Treated Length (m)	Replication	Runoff Depth (mm)
6	1	25.2
	2	13.2
	3	6.0
12	1	29.9
	2	21.4
	3	20.0
Mean		19.3
Standard Deviation		8.6

Table 5. Runoff mass transport of metals

Parameter	Mass Transport Mean (mg/plot)	C_v*
Fe		
6 m treatment	24.7	0.94
12 m treatment	55.3	0.26
K		
6 m treatment	6,150	0.90
12 m treatment	17,400	0.35
Na		
6 m treatment	2,490	0.64
2 m treatment	6,900	0.23
Zn	9.0	0.70

* Coefficient of variation.

Table 5 lists metals mass transport averaged across all VFS lengths (except for Cu, given in fig. 7) and separated by litter-treated lengths (except for Zn, which was not affected by litter-treated length). Mass transport was usually a small fraction of the amount applied, particularly for Cu and Zn. The proportions of metals lost in runoff are generally comparable to those reported earlier (Edwards and Daniel, 1993) for total N and total P under very similar conditions. Loss proportions varied significantly (p <0.0001) as a function of the particular metal. Expressed as proportions of amounts applied, 1.8, 3.7, 6.3, 9.5, and 0.2% of applied Cu, Fe, K, Na, and Zn, respectively, were lost in runoff. The very low proportion of applied Zn lost in runoff is further evidence for a relatively low mobility of Zn, as discussed earlier.

Conclusions

Observed concentrations of Fe, K, Na, Ni, and Zn in runoff from 6 and 12 m-long fescuegrass plots treated with poultry litter were not high enough to be a direct threat to aquatic life in receiving waters. Runoff Cu concentrations were relatively high (mean of 0.45 mg L^{-1}), however, suggesting that Cu impacts might be of concern unless sufficiently diluted. Runoff concentrations of all metals except Ni (which was present in concentrations below the detection limit) decreased significantly after the runoff had flowed across the VFS. In the cases of Cu, Fe, K, and Zn, runoff concentrations did not significantly decrease for VFS lengths greater than 3 m; runoff Na concentrations decreased up to a VFS length of 6 m and did not decrease significantly thereafter. Mass transport of all metals except Cu was not significantly affected by VFS length, suggesting that VFS removal mechanisms such as adsorption to soil clay particles might play a relatively greater role with regard to Cu than to Fe, K, Na, and Zn.

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