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QUALITY OF RUNOFF FROM PLOTS TREATED WITH MUNICIPAL SLUDGE AND HORSE BEDDING

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ABSTRACT. *Land application of horse stall bedding and municipal sludge can increase runoff concentrations of nutrients, organic matter, and bacteria as well as steroidal hormones such as estrogen. Concentrations of materials in runoff from sites treated with animal manure can be reduced by aluminum sulfate, or alum* [$Al_2(SO_4)_3 \bullet 14H_2O$] *treatment. The objectives of this study were to assess plots treated with horse stall bedding or municipal sludge for: (a) runoff quality [concentrations of nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), orthophosphate-phosphorus (PO_4-P), fecal coliform (FC), chemical oxygen demand (COD) and 17-β estradiol (17β-E, a form of estrogen)]; (b) changes in runoff quality caused by alum treatment; and (c) time variations in concentrations of the analysis parameters. Horse bedding and municipal sludge were applied to twelve 2.4 × 6.1 m fescue plots (six each for the bedding and sludge). Three of the bedding-treated and three of the sludge-treated plots were also treated with alum. Simulated rainfall (64 mm/h) was applied to the 12 treated plots and to three control (no treatment) plots. The data were analyzed as originating from separate completely randomized, one-way designs with three replications of each treatment. The first design had treatment levels of bedding, bedding and sludge, and control, while the second design had treatment levels of sludge, sludge and alum, and control. The control data were common to both designs. The first 0.5 h runoff was sampled and analyzed for the parameters described above. Analysis parameter concentrations for the waste treated plots were generally lower than those previously reported for runoff after organic treatments. In some cases, concentrations were no different from the controls. Mass losses of all parameters were low and agronomically insignificant. Alum addition decreased runoff PO_4-P concentrations and increased NO_3-N concentrations but had no effect on concentrations of other parameters. A significant effect of alum addition on 17β-E and COD concentrations was anticipated on the basis of previous studies; its absence might have been due to inadequate mixing or interval between addition and simulated rainfall. Relationships between concentration and collection time followed two patterns: (a) highest concentrations occurring during the first sample (two minutes following runoff initiation; NO_3-N, COD, FC and 17β-E) and (b) delay in peak concentration until four minutes following runoff initiation (NH_3-N and PO_4-P). The detection of different general relationships between concentration and time suggests that different mechanisms are dominant in transport of the parameters analyzed.*
Keywords. *Manure, Sludge, Estrogen, Aluminum sulfate, Runoff.*

The most common use of organic soil amendments such as animal manures and municipal sludge is land application, usually at agronomic rates to make beneficial use of the plant nutrients and organic matter in these materials. Yields of row crops such as corn (*Zea mays* L.; Wengel and Kolega, 1972) and forage crops such as fescue (*Festuca arundinacea* Schreb.; Huneycutt et al., 1988) are known to respond favorably to organic amendments.

The presence of relatively mobile nitrogen (N), phosphorus (P), organic matter, microbes, and other materials near the soil surface following organic amendment application can decrease the quality of runoff, particularly for the first post-application runoff event. Studies such as those reported by Westerman et al. (1983), McLeod and Hegg (1984), and Edwards et al. (1992, 1993a,b) indicate that runoff from grassed areas treated with animal manures can contain elevated concentrations of nutrients, solids, and organic matter relative to untreated areas. The majority of runoff quality studies have focused on runoff transport of nutrients, organic matter, solids, and (to a lesser degree) microorganisms. A growing number of studies, however, have investigated runoff transport of hormones such as estrogen and testosterone. Nichols et al. (1997) applied poultry litter to fescue (*Festuca arundinacea* Schreb.) plots and measured concentrations of 17β-estradiol (17β-E, the most potent of estrogens) ranging from 0.3 to 1.3 μg/L in runoff from simulated rainfall. Shore et al. (1993) linked poultry litter application on nearby fields to increased (500 to 5400 μg/L) stream flow estrogen concentrations.

The primary environmental concern with regard to nutrients in runoff is related to eutrophication of downstream water bodies. The eutrophication rate of inland water bodies is usually P-limited (Schindler, 1974, 1977), but N can also be a concern in N-limited waters particularly in coastal zones. Irrespective of whether the rate of eutrophication is limited by P or N, the plant-available forms of these nutrients appear to be of most

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importance because of their potential for direct uptake by aquatic vegetation and algae (Pote, 1997). Microorganisms are of concern due to their potential for causing sickness in humans who contact or ingest the water. Water is not usually analyzed for pathogenic microorganisms, but is instead analyzed for fecal coliforms (FC), which are considered a surrogate for other microorganisms. The effects of steroidal hormones (e.g., estrogen) in runoff are not as widely recognized but nevertheless have the potential for causing undesirable human health impacts. Estrogen is relatively resistant to biodegradation and accumulates when ingested. Sharpe and Shakkebaek (1993) have questioned whether increased incidence of male reproductive tract disfunctionality is related to exposure to estrogen.

The potential for adverse environmental impacts of land-applying organic materials is the impetus of ongoing studies to reduce off-site losses of N, P, and other potential pollutants. Physical management options such as buffer strips (Young et al., 1980) and incorporation (Ross et al., 1979) as well as management options such as application timing (Edwards et al., 1992) have been advocated for reducing pollution from sites treated with organic materials. More recently, chemical amendments have been investigated and found effective in reducing runoff transport of selected pollutants. Shreve et al. (1994) found that mixing alum with poultry litter dramatically reduced runoff concentrations of P. Nichols et al. (1997) found that the alum addition also reduced runoff concentrations of 17β-E by more than 40%.

The organic materials used in this study were selected because they have not received much attention in the context of runoff studies, even though they are of interest in regions having significant urban area and horse production (e.g., the inner Bluegrass region of Kentucky). The reason for examining time variations in analysis parameter concentrations was to investigate the presence of patterns in concentrations and to determine whether there were pattern differences among analysis parameters. Pattern differences might indicate differences in mobility and dominant transport mechanism(s), information that could be useful in developing/refining relatively physically based models that describe time variations in concentrations. The objectives of this study were to: (1) characterize concentrations of nitrate N (NO_3-N), ammonia N (NH_3-N), orthophosphate-P (PO_4-P), fecal coliforms (FC), chemical oxygen demand (COD) and 17β-E in runoff from plots treated with horse stall bedding and municipal sludge; (2) assess runoff quality effects of alum addition to those treatments; and (3) determine time variations in concentrations of the analysis parameters.

Procedure

General

The study was performed in September 1996, using plots constructed on a Maury silt loam (fine, mixed, mesic *Typic Paleudalf*) soil at the University of Kentucky Maine Chance Agricultural Experiment Station. Plots dimensions were 2.4 × 6.1 m with the long axes oriented up- and down-slope. The plots were graded to a uniform 3% slope along the major axis and cross-leveled across the minor axis. The vegetation for all plots was Kentucky-31 "tall" fescue (*Festuca arundinacea* Schreb.), maintained at a height of between 8 to 13 cm by mowing with a commercial mower and string trimmer. Each plot was bordered with galvanized iron (10 cm above and below ground surface) to isolate runoff. Soil samples were collected from each plot in early summer of 1996 and analyzed by the University of Kentucky Regulatory Services Laboratory for nutrient content and other characteristics according to standard methods (table 1). The mean pH of the soil is not atypical for the site and would result in negligible affects on the P solubility, because (a) the interval between application and simulated rainfall was short, and (b) lime was added to with the bedding and sludge to increase the pH, as described later. No amendments were added to the plots between the time of soil sampling and the date of the experiment.

A gutter was constructed and installed across the lower end of each plot to concentrate runoff for measurement and sampling. These gutters were constructed of sheet metal and had a 5% slope to ensure "self-cleaning". Runoff from the gutter enters a 5-cm inside diameter (ID) length of polyvinyl chloride (PVC) pipe and empties approximately 45 cm above the bottom of a sump. Each sump is lined with 30-cm ID Advanced Drainage Systems (ADS) pipe; the sump bottoms consist of 30-cm ID ADS end caps. Runoff is sampled as it exits the PVC pipe and before contacting the interior of the sump. Unsampled runoff leaves the sump through 10-cm holes in the sump bottoms and exits the research site through the plot surface drainage system. A plot schematic is given as figure 1.

Horse Bedding, Municipal Sludge, and Alum Treatment

The experiment was conducted and analyzed as two completely randomized designs with three replications of each treatment. For the first design, the treatment variable was plot amendment, with levels of horse bedding (HB), horse bedding and alum (HB+A), and control (C). The

Table 1. Soil properties

Parameter	Mean*	SD†
pH	5.5	0.3
	------------mg/kg------------	
Total N	1,865	164
P‡	92	10
Organic matter	31,000	3,200

* Mean of 30 samples.
† Standard deviation.
‡ Mehlich 3 extraction.

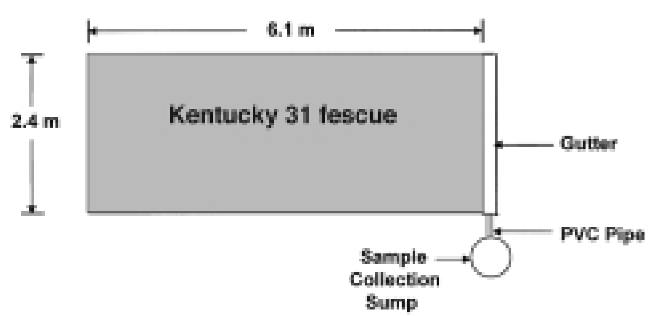

Figure 1–Plot schematic (not to scale).

treatment variable for the second design was again plot amendment, but with values of municipal sludge (MS), municipal sludge and alum (MS+A) and control (C). The plots used as controls were common to both designs. There were three replications of each treatment, requiring a total of 15 plots.

The horse bedding was obtained from stalls that held mares between 12 to 16 weeks gestation. The stall bedding consisted of Kentucky bluegrass (*Poa pratensis*). After the mares had been stalled for 12 h on the fresh bedding, the bedding was removed from the stalls and uniformly mixed prior to application to the plots. The municipal sludge was obtained from the Lexington, Kentucky, sewage treatment plant. The horse bedding and municipal sludge were sampled and analyzed for selected constituents as given in table 2. Analyses of N, P, and K followed standard soil analysis techniques. Phosphorus and K were analyzed according to the Mehlich 3 extraction technique, while N was measured according to the combustion technique. Contents of 17β-E in the horse bedding and sludge were measured based on the procedure described by Nichols et al. (1997). A sample of each material was mixed in a flask with 300 mL of deionized water (approximately 1:5 material:water ratio, by volume). The flasks were shaken for 2.5 h. From each flask, 100 mL of liquid was pipetted off and placed into a centrifuge tube. The samples were then centrifuged for 1 h at 2200 rpm. Finally, 10 mL of each sample was extracted from each tube and analyzed for 17β-E according to methods described later in the article.

The horse bedding was applied at 9.1 Mg/ha to six of the plots. Alum was then applied to three of the plots by manual surface sprinkling at 0.6 Mg/ha (based on alum addition at a target of 10% of dry bedding mass as, reported by Shreve et al., 1994). Municipal sludge was applied to six plots at 7.7 Mg/ha. For three of the six plots treated with municipal sludge, the sludge was mixed with alum (0.15 Mg alum/ha; target of 10% of dry sludge mass) prior to application. As discussed by Shreve et al. (1994), (slake) lime was added (5% of dry mass of bedding/ sludge) to the alum-treated plots to prevent further soil surface acidification (and accompanying runoff of soluble metals). In the case of the plots that received horse bedding, the lime was sprinkled over the surface of the plots (323 kg lime/ha) following application of the bedding and alum. The lime was mixed together (74 kg lime/ha) with the sludge and alum for the plots receiving municipal sludge.

The gross horse bedding and municipal sludge application rates specified earlier were selected to provide half the typical annual N uptake of the grass, adjusted for estimated losses (approximately 70 kg/ha). Based on the composition data given in table 2, the actual application rates of N, P, and K were 99.7, 27.9, and 184.6 kg/ha, respectively, for the plots treated with horse bedding and 56.8, 35.5, and 3.8 kg/ha, respectively, for the plots treated with municipal sludge.

Table 2. Horse bedding and municipal sludge composition*

Parameter	Horse Bedding	Municipal Sludge
	--------------------mg/kg--------------------	
N	11,800	37,700
P	3,320	23,600
K	21,700	2,410
	--------------------μg/kg--------------------	
17β-E	35.1	5.2
	----------------------%----------------------	
H_2O	7.4	80.4

* Mean of three replications.

Runoff Sampling and Analysis

Five rainfall simulators, each capable of applying from 0 to 120 mm/h simulated rainfall to one 2.4 × 6.1 m plot, were used to supply the water used to generate runoff from the plots. The simulator design is based on the simulator described by Miller (1987), but each simulator provides greater areal coverage. Simulated rainfall intensity is governed by the frequency with which the solenoid-actuated valves are opened to allow water to pass through the nozzles. A programmable logic controller interfaced with a computer controls the frequency of actuation. The current simulators are very portable and capable of rapid set-up and take-down. Each simulator can be operated independently (simultaneously providing water to separate 6.1 m-long plots at separate simulated rainfall intensities), or they can be used in series to provide rainfall to longer plots. The simulated rainfall intensity was 64 mm/h, applied within 1 h of bedding/sludge application and maintained until 0.5 h runoff had occurred from each plot. Total rainfall duration therefore generally differed between plots, but runoff duration was constant.

Runoff was sampled (approximately 1 L sample size) at 2, 4, 8, 14, 22, and 30 min after the beginning of runoff. Runoff samples were collected by inserting an unused polyethylene container (1 L volume) underneath the runoff exiting the gutter through the PVC pipe. Runoff entered the container for a period of 60 s or until the container was filled, whichever came first. The times required to collect the samples were measured with a digital stopwatch with a precision of 0.01 s to enable computation of runoff rates. The minimum time required to collect a sample was generally no less than 10 s.

Each runoff sample was analyzed for NO_3-N, NH_3-N, PO_4-P, COD, FC, and 17β-E. Samples were filtered (0.45 μm pore dia.) within 1 h of collection for NO_3-N, NH_3-N, and PO_4-P analyses. Technicians of the Biosystems and Agricultural Engineering Department Chemistry Laboratory performed all runoff sample analyses. Analyses of NO_3-N, NH_3-N, PO_4-P, COD, and FC followed standard methods (Greenberg et al., 1992). Analyses for 17β-E were performed within 48 h of sample collection using an enzyme-linked immunosorbent assay kit having a detection limit of 0.02 μg/mL.

Data Analysis

The basic data for a particular plot consisted of a set of six values of runoff rate and, for each value of runoff rate, corresponding concentrations of NO_3-N, NH_3-N, PO_4-P, COD, FC, and 17β-E. Runoff volume was calculated by numerically integrating runoff rate with respect to time. Mass transport of each parameter was calculated by summing the products of concentration and associated partial runoff volume. Flow-weighted mean parameter concentration was calculated by dividing mass transport by runoff volume.

Effects of bedding/sludge treatment and alum addition on runoff concentrations of analysis parameters were assessed through one-way analysis of variance (ANOVA). The effect of the HB and HB+A treatments on runoff concentrations of NO_3-N, for example, were assessed by performing a one-way ANOVA on flow-weighted mean runoff concentrations of NO_3-N from the HB, HB+A, and C treatments. A significant ($p < 0.05$) F-statistic was taken as indicating concentration differences relative to the control. In the cases where treatment effects were significant, means separation (Tukey's procedure) was performed to assess differences relative to the control treatment and to determine the impact of alum addition. This procedure was also used to determine the effects of the MS and MS+A treatments on runoff concentrations of analysis parameters. Analogous methods were used to determine the effects of bedding/sludge treatment and alum addition on mass transport of the analysis parameters.

Relationships between analysis parameter concentration and time of sample collection were assessed by first calculating for each concentration value a corresponding relative concentration defined as parameter concentration divided by the flow-weighted mean concentration. All relative concentrations were grouped within analysis parameter according to time of collection (i.e., lumped across the HB, HB+A, MS, MS+A, and C treatments). One-way ANOVA was performed on the relative concentrations taking time of collection as the treatment variable. When ANOVA indicated a significant ($p < 0.05$) treatment effect, means were separated according to Tukey's method.

Results and Discussion

Flow-weighted mean concentrations of analysis parameters are given in table 3. Coefficients of variation of the concentration data are not shown but are relatively low (averaging 30%), indicating good repeatability of the results. Addition of horse bedding increased runoff concentrations of PO_4-P, COD, FC, and 17β-E relative to the control plots, usually by an order of magnitude or more. Municipal sludge addition had generally similar effects as horse bedding (although to a lesser degree) with the exception that it did not increase runoff PO_4-P concentration. The concentrations of NO_3-N, NH_3-N, PO_4-P, and COD were in no cases alarmingly high. Relative to values reported for other organic amendments applied under similar plot conditions (e.g., poultry litter, Edwards and Daniel, 1993a; poultry manure, Edwards and Daniel, 1992; swine manure, Edwards and Daniel, 1993b), concentrations of these parameters were, in fact, quite low in proportion to amounts of N applied. Flow-weighted mean concentration of 17β-E in runoff from the HB treatment plots was comparable to that reported by Nichols et al. (1997) for poultry litter applied at agronomic rates. Concentrations found in the runoff of this study were on the low end of the range of concentrations found to impact the sex distribution of salmon (Nakamura, 1984).

The only consistent effects of alum addition were related to runoff NO_3-N and PO_4-P concentrations. Alum addition caused significant ($p < 0.05$) increases in NO_3-N concentration, relative to the C, HB, and MS treatments. The reason for the increased NO_3-N concentration is not clear, but might be related to SO_4 displacement of NO_3 anions, causing greater availability of NO_3-N for transport by runoff. Alum had the expected effect of lowering PO_4-P concentrations in runoff, presumably due to the alum and P combining to form insoluble precipitates as discussed by Moore and Miller (1994). When added to the horse bedding, alum decreased runoff PO_4-P concentrations by 97%, which was even less than the mean PO_4-P concentration for the control plots. Even though addition of the municipal sludge did not influence PO_4-P concentrations relative to the control plots, mixing alum with the sludge decreased concentrations by 78%, to less than one fourth of mean background concentration. In contrast to the results of Nichols et al. (1997), alum did not decrease concentrations of 17β-E from either the bedding- or sludge-amended plots. The lack of a detectable alum effect might have resulted from inadequate mixing because of the subject material (in the case of the horse bedding) and/or insufficient reaction time (in the case of the sludge). The subject of mixing alum with animal manures to reduce runoff losses has not been thoroughly investigated, so it is likely that additional work will be necessary to define optimal mixing procedures. In any event, the results of this study can serve as an indication of the effects of alum addition under conditions of no mixing and light mixing of short duration.

Mass transport response to horse bedding/sludge application and alum addition tended to mimic that of runoff, but fewer effects were significant (table 4). Runoff

Table 3. Flow-weighted mean* runoff concentrations of analysis parameters

Parameter	Amendment: Horse Bedding, No Alum	Horse Bedding, Alum	Horse Bedding, Control	Municipal Sludge, No Alum	Municipal Sludge, Alum	Municipal Sludge, Control
	mg/L					
NO_3-N	0.17b†	0.47a	0.15b	0.37b	1.26a	0.15b
NH_3-N	2.00a	2.57a	2.08a	2.43a	1.63a	2.08a
PO_4-P	5.21a	0.14c	0.56b	0.54a	0.12b	0.56a
COD	56.6a	75.5a	23.0b	36.2a	43.3a	23.0b
FC	5.8×10^3a	6.2×10^3a	4.2×10^2b	6.5×10^2b	1.2×10^3a	4.23×10^2c
	μg/L					
17β-E	0.60a	0.51a	0.01b	0.08a	0.08a	0.01b

* Mean of three replications.
† Within-row means for a given amendment are not significantly different ($p < 0.05$).

Table 4. Runoff transport of analysis parameters*

Parameter	Amendment: Horse Bedding, HB	Horse Bedding, HB+A	Horse Bedding, C	Municipal Sludge, MS	Municipal Sludge, MS+A	Municipal Sludge, C
	g/ha					
NO_3-N	9.4b†	82.1a	13.6ab	38.6b	171.7a	13.6b
NH_3-N	166.5a	418.7a	193.9a	258.2a	376.1a	193.9a
PO_4-P	652.5a	18.7a	70.0a	124.7a	22.1a	70.0a
	kg/ha					
COD	6.1a	12.7a	2.5a	5.5a	10.0a	2.5a
	mg/ha					
17β-E	60.9a	76.4a	0.7b	12.1a	14.7a	0.7b

* Mean of three replications.
† Within-row means for a given amendment are not significantly different ($p < 0.05$).

PO_4-P concentrations, for example, were higher for the HB and MS than for the C treatment plots and decreased with alum addition; mass transport, however, was not significantly affected by bedding/sludge application or alum addition. The relative lack of treatment variable effects on mass transport can be attributed to variability in runoff, as has been noted in similar studies (e.g., Edwards and Daniel, 1994). If runoff amounts had been constant across all plots, then the mass transport effects would have mirrored the concentration effects. Variability in mass transport, however, is generally greater than that in concentration or runoff alone, having the net effect of making significant treatment effects more difficult to detect. Mean runoff in this study was 13.8 mm (averaged across all treatments) with a standard deviation of 11 mm, resulting in a coefficient of variation of 0.8. Thus, significant effects of the treatment variables on concentrations were sometimes masked for with regard to mass transport.

Losses due to mass transport were small in agronomic terms. In all cases for NO_3-N, NH_3-N and PO_4-P, they were less than 1 kg/ha and were greater than 0.5 kg/ha in only one case. It appears that losses of mineral N and

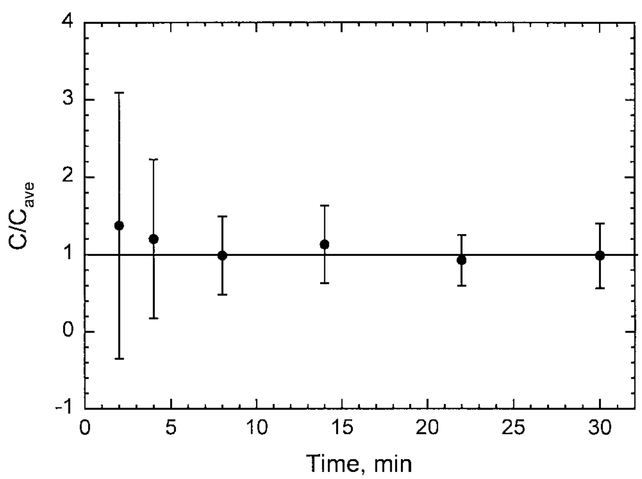

Figure 2–Response of relative NO_3-N concentration (C/C_{ave}) to time following runoff initiation.

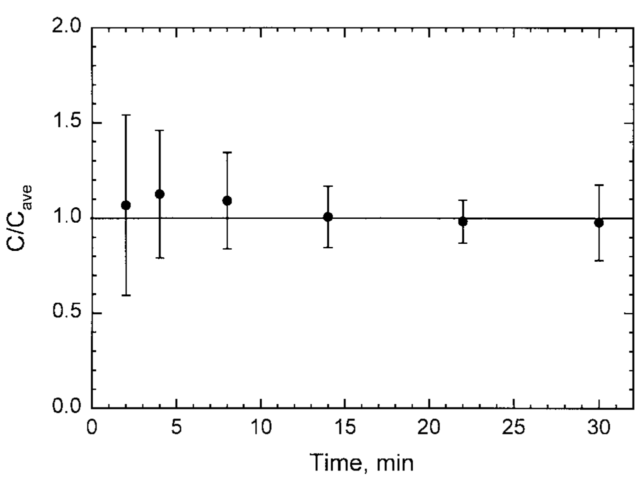

Figure 3–Response of relative NH_3-N concentration (C/C_{ave}) to time following runoff initiation.

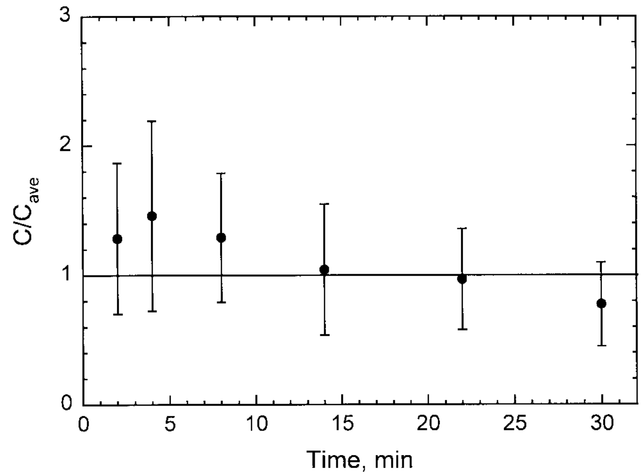

Figure 4–Response of relative PO_4-P concentration (C/C_{ave}) to time following runoff initiation.

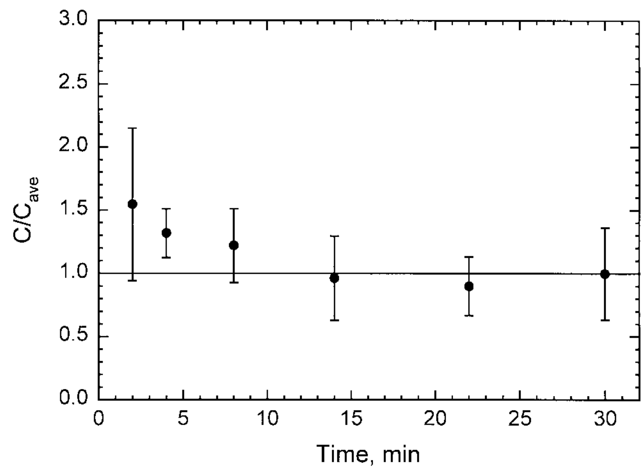

Figure 5–Response of relative COD concentration (C/C_{ave}) to time following runoff initiation.

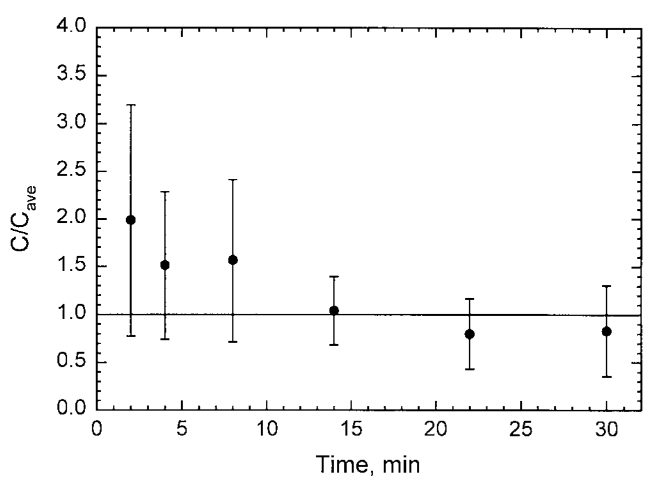

Figure 6–Response of relative FC concentration (C/C_{ave}) to time following runoff initiation.

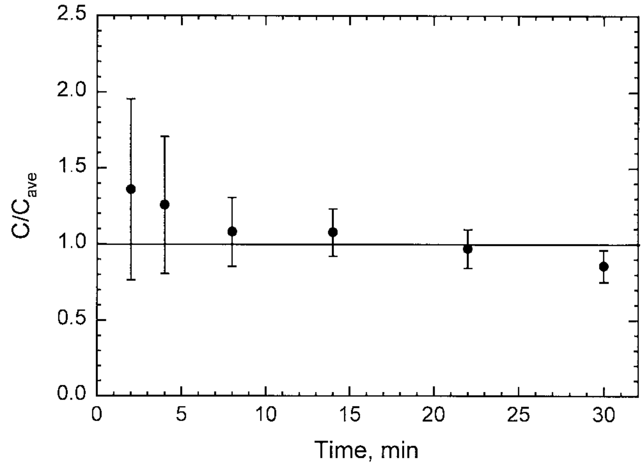

Figure 7–Response of relative 17β-E concentration (C/C_{ave}) to time following runoff initiation.

PO_4-P are insignificant from a plant growth perspective, even when storms occur shortly after application.

Responses in relative runoff concentrations of NO_3-N, NH_3-N, PO_4-P, COD, FC, and 17β-E to collection time are given in figures 2-7, respectively. Mean relative concentrations are grouped across all treatments in these figures, because treatment had no apparent impact on the behavior of relative concentrations with respect to collection time. The majority of analysis parameters (NO_3-N, COD, FC, and 17β-E) followed a pattern of high relative concentrations early in runoff with concentrations gradually declining thereafter to approximately the mean value. Analysis of variance indicated no significant effect of collection time on NO_3-N relative concentration. However, the 2-min concentrations of COD, FC, and 17β-E as well as the 4-min concentrations of FC and 17β-E were significantly different from the final concentrations. Figures 3 and 4 suggest that relative runoff concentrations of NH_3-N and PO_4-P follow a different pattern, with relative concentrations peaking at approximately four minutes following initiation of runoff. Collection time had no significant effect on relative runoff concentration of NH_3-N, but ANOVA indicated a significant ($p < 0.01$) effect of collection time on relative runoff PO_4-P concentrations. Means separation indicated that only the 4-min and 30-min relative concentrations of PO_4-P differed significantly.

The effects, if any, of varying rainfall intensity on the behavior of relative concentrations are not indicated by these results. Edwards and Daniel (1993a) found that flow-weighted mean concentrations of poultry litter constituents, for example, decreased in response to increasing rainfall intensity. Additional work with rainfall intensity as a variable will be required to assess whether that variable influences relative concentrations.

The results of assessing temporal variation in relative concentrations might reflect differences in initial mobility among analysis parameters. For example, the analysis parameters that followed the pattern of high initial relative concentrations might be readily available for runoff transport (i.e., washoff). The parameters following the second pattern, however, might be more strongly bound to soil particles and other material, requiring more time to be released into the runoff. The findings of this study are obviously not strong enough to support definitive statements regarding release and transport mechanisms. The existence of different relative concentration trends with time, however, suggests that the dominant transport mechanisms differ among parameters.

Summary and Conclusions

This experiment was conducted to (1) characterize runoff transport of NO_3-N, NH_3-N, PO_4-P, FC, COD and 17β-E in runoff from plots treated with horse stall bedding and municipal sludge; (2) evaluate the effects adding alum to the bedding/sludge on runoff transport; and (3) assess time variations in concentrations of the analysis parameters. Fescue plots were treated with bedding alone, sludge alone, bedding with alum, and sludge with alum. Runoff from those plots (as well as three additional control plots) was produced from simulated rainfall applied at 63 mm/h and sampled throughout 0.5 h of runoff.

Addition of horse bedding and municipal sludge increased runoff concentrations of PO_4-P (horse bedding only), COD, FC and 17β-E relative to the control plots. Concentrations of these parameters were generally not high, however, in comparison to those reported in studies involving organic amendments applied at comparable rates. Addition of alum to the horse bedding and municipal sludge increased runoff NO_3-N concentrations, due possibly to SO_4 displacement of NO_3 anions. Alum addition decreased runoff PO_4-P concentrations but had no effect on other parameters, due possibly to inadequate mixing and/or reaction time. Mass losses of nutrients were agronomically small, even though the simulated storm parameters were relatively severe.

Two patterns of relative concentration response to time since runoff initiation were apparent: one in which the peak relative concentration was associated with the first sample collected and one in which the peak was associated with the second sample. The first pattern was applicable to COD, FC and 17β-E, while PO_4-P followed the second. Relative concentrations of NO_3-N appeared to be related to the first response pattern and those of NH_3-N to the second, but ANOVA indicated no significant effect of sample collection time on relative concentration. These findings suggest differences in initial mobility and/or transport mechanisms among analysis parameters.

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