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Poultry Litter-Treated Length Effects on Quality of Runoff from Fescue Plots

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ABSTRACT. *Using experimental data and/or mathematical simulation models to identify practices that reduce pollution from manure-treated areas is sometimes perceived as limited by the unknown validity of extrapolating plot-scale data to larger areas and by uncertainties in modeling transport of various pollutants. The objectives of this study were to assess the effect of length of manure treatment on runoff concentrations of poultry litter constituents and to define the modes of transport (particulate versus soluble) for nitrogen (N), phosphorus (P), carbon (C), and solids. Poultry litter was applied to three 1.5- × 18.3-m fescue (*Festuca arundinacea *Schreb.) plots with runoff collection gutters installed at 3.0-m intervals along the lengths of the plots. Runoff was generated from simulated rainfall (50 mm/h for 1 h of runoff), and samples were analyzed for total Kjeldahl N (TKN), organic N (Org-N), ammonia N (NH_3-N), nitrate N (NO_3-N), total P (TP), total organic C (TOC), and total suspended solids (TSS). Soluble fractions of TKN, Org-N, NH_3-N, TP, and TOC were also determined. Manure-treated length had no effect on runoff concentration of any parameter, indicating that a manure-treated length of only 3.0 m would have been sufficient to simulate runoff quality associated with longer manure length treatments. Proportions of TKN, Org-N, NH_3-N, and TP transported in soluble form were high (≥ 74%), and over half of the TOC in the runoff was in soluble form. These results indicate that for conditions similar to those of this study, extrapolation with respect to runoff concentrations might be possible with little adaptation of the data and might simplify the design of management practices that key on edge-of-field runoff concentrations. The results with regard to modes of transport can help to better model losses of N, P, and COD and suggest that losses of these parameters will be most effectively controlled through practices that focus on reducing soluble losses rather than simply reducing erosion.*
Keywords. *Water quality, Nonpoint source pollution, Poultry manure, Nutrient transport.*

Poultry litter, a combination of manure and bedding material that is primarily associated with broiler production, is often applied as a soil amendment to agricultural fields near poultry production sites. In southern states such as Arkansas, poultry litter is most often applied to fescue (*Festuca arundinacea* Schreb.), bermudagrass [*Cynodon dactylon* L. (Pers.)], and other pasture grasses. Poultry litter serves as an excellent fertilizer, and the yield benefits of its application to pasture grasses have been well-documented over the past decades (e.g., Hileman, 1965, 1973; Huneycutt et al., 1988).

Constituents of surface-applied poultry litter can be lost in runoff from intense storms that occur shortly after application. Several researchers have demonstrated that runoff from areas receiving poultry litter can contain relatively high concentrations of nitrogen (N), phosphorus (P), solids, and other materials (Westerman et al., 1983; McLeod and Hegg, 1984; Edwards and Daniel, 1993a). The potential for losses of poultry litter constituents is known to be greatest for the first post-application runoff events, with runoff concentrations of poultry litter constituents approaching background levels after two or three runoff events (McLeod and Hegg, 1984; Edwards and Daniel, 1994a). Losses of poultry litter constituents as proportions of amounts applied have been shown to be relatively low; Edwards and Daniel (1994a) reported that less than 3% of applied N and P was lost in runoff from fescue plots treated with poultry litter for a simulated rainfall event four days following poultry litter application, and other scientists have demonstrated similarly low loss proportions. The water quality implications of poultry litter constituent losses thus appear to dominate the agronomic implications for the situations reported.

Management options to improve quality of runoff from areas treated with animal manures such as poultry litter are typically identified and adapted using experimental data, mathematical simulation models, or a combination of the two methods. The usefulness of experimental data in identifying appropriate management options is sometimes questioned because those data are usually collected on the plot scale when the anticipated application of the results is on the field or larger scale. Models can be similarly limited when used to help identify management options that minimize pollutant losses in runoff. An example of such a limitation is a pollutant transport algorithm that was developed to describe a situation involving row-cropped land, when the desired application of the algorithm is to pasture.

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One of the basic questions to be answered before defining the relationships between plot and field data involves changes in runoff concentrations of various pollutants with manure-treated length. The manure-treated distance across which runoff travels is one of the largest differences between manure-treated plots and fields. Evaluating the effect of manure-treated length on runoff concentrations of manure constituents could thus facilitate the extension of data from plots with short manure-treated lengths to larger land areas with relatively long manure-treated lengths.

The description of how various pollutants are transported in runoff is central to the issue of the degree to which models can be used to help identify practices that limit pollutant losses. Some pollutants, such as organic matter, are assumed to be present in runoff as particulates (e.g., Novotny and Olem, 1994), and their losses in runoff are described in models such as the Erosion/Productivity Impact Calculator (EPIC) (Sharpley and Williams, 1990) by loading functions. Other pollutants, such as P, are taken as transported in both particulate and soluble forms, in which case the soluble pollutant losses are often estimated based on algorithms involving the concentration of the pollutant in the soil, runoff, depth of interacting soil, and an extraction coefficient. The Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980) model's P transport algorithm is an example of partitioning pollutant losses between particulate and soluble forms. Inaccurate specification of the relative modes of pollutant transport or values of transport parameters can have a direct bearing on the subsequent selection of practices to minimize transport. If a pollutant is considered as being transported primarily in particulate form, for example, then practices that minimize erosion should be considered. On the other hand, if a pollutant is transported in mainly soluble form, then perhaps other practices should be examined. The mode of pollutant transport can thus impact the effectiveness of a particular practice in achieving the desired water quality impact. The treatment of transport modes might become increasingly important as the capabilities of simulation models are expanded to accommodate more pollutants and pollutant forms.

The broad goal of this study was to gain information that would facilitate the identification of management practices that minimize runoff losses of poultry litter constituents applied to fescue pasture. The following specific supporting objectives were addressed:

- Define the responses of runoff concentrations of poultry litter constituents to manure-treated length.
- Determine the amounts of poultry litter constituents that are transported in soluble and particulate forms.

The study was limited to one post-application runoff event since, as discussed earlier, this is probably the key event in terms of limiting total losses of poultry litter constituents.

PROCEDURES

The experiment was conducted on the Agricultural Experiment Station at the University of Arkansas, Fayetteville, on a Captina silt loam (fine-silty, mixed mesic, Typic Fragiudult) soil. Three plots were used for the study. Each plot was 1.5 m wide × 18.3 m long and cross-leveled with a 3% slope along the main axis. A good stand (essentially 100% cover with a mean height of approximately 10 cm) of fescue was present on each plot. Gutters with removable covers were installed at distances of 3, 6, 9, 12, and 18 m downslope of the tops of the plots (fig. 1). The construction of the gutter covers enabled the covers to be quickly removed whenever a runoff sample was to be collected, whereupon runoff would enter the gutter and flow to one side where it could be collected. The gutters remained covered when no runoff samples were collected, so that the runoff simply crossed the gutters and continued down slope.

Poultry litter was obtained from poultry houses associated with the University of Arkansas Cooperative Extension Service Broiler Energy Verification Unit. Samples of the litter were collected and analyzed by the University of Arkansas Agricultural Services Laboratory for total N (TN), ammonium N (NH_4-N), nitrate N (NO_3-N), total P (TP), water (H_2O), pH, electrical conductivity (EC), and other constituents, while the remainder of the litter was refrigerated (4° C) for approximately seven days until applied to the plots. Total N composition was determined from the combustion method (Campbell, 1991). Inorganic N species were determined by extraction with 2 M potassium chloride followed by distillation. Amounts of P, potassium (K), iron (Fe), zinc

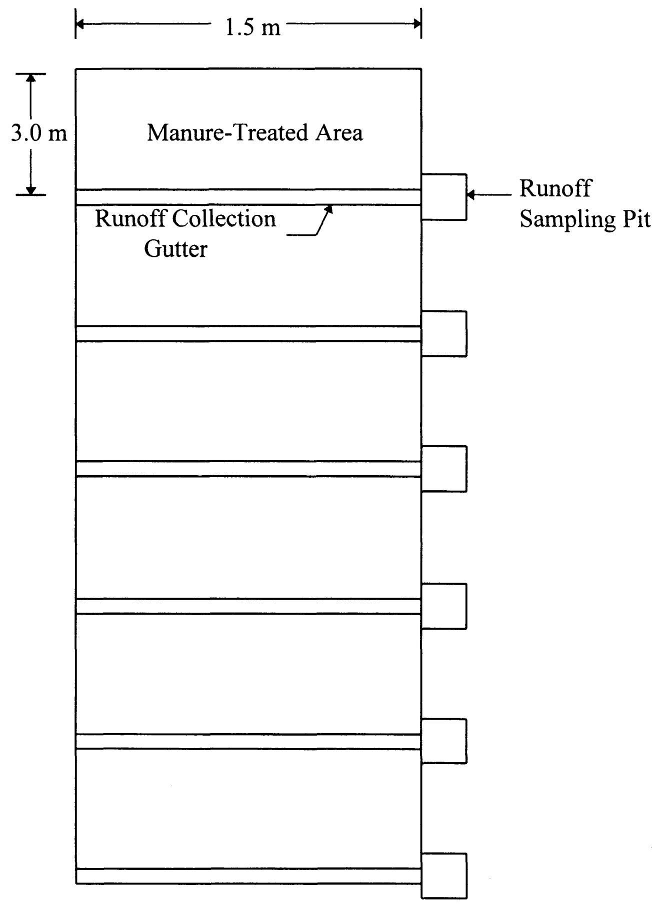

Figure 1–Schematic of experimental plot (not to scale).

(Z), and copper (Cu) in the litter were determined by preparing samples according to Campbell and Plank (1991), digesting with nitric acid, and analyzing by the inductively coupled plasma method (Donohue and Aho, 1991). The gravimetric method was used in determining litter sample H_2O content. Analyses of pH and EC were performed on mixtures of one part water to two parts litter and one part water to one part litter, respectively. The results of the litter analyses are given as table 1.

Poultry litter was manually applied on 19 July 1994 to the entire 18.3 m of each plot, taking care to apply the litter as uniformly as possible. The gross amount of litter applied to each plot was 15.6 kg, resulting in an application rate of 146.4 kg N/ha. The N application rate was chosen to be compatible with rates currently recommended under similar conditions in Arkansas (Chapman et al., 1992). Gross application rates of other litter constituents are given in table 2.

Thirty soil samples (0 to 2.5 cm depth) were collected from each plot one day prior to litter application, mixed together to form a composite sample, and analyzed according to standard methods (Page et al., 1982) for various parameters (table 3).

Simulated rainfall was applied at 50 mm/h (constant intensity) within 0.5 h of litter application using rainfall simulators described by Edwards et al. (1992). The simulated rainfall was maintained on each plot until 1 h of runoff had occurred. The total rainfall duration required to produce 1 h of runoff ranged from 1.2 to 2 h. The relatively high rainfall intensity and long duration, coupled with essentially no interval between litter application and simulated rainfall represented a "near-worst case scenario" but was considered justified to avoid introducing unwanted sources of variability in the data. All runoff occurred as diffuse overland flow with no formation of rills.

Runoff from each collection gutter was sampled at 0.04 h after the beginning of runoff and at 0.08-h intervals thereafter. Runoff samples were collected by first sampling the bottom-most gutters and then successively sampling gutters up the lengths of the plots. This "bottom-up" sampling scheme was used to avoid the temporary reductions in incoming runoff rates that "top-down" or simultaneous sampling schemes might have caused. Sample volumes varied, but were typically greater than 1 L. The times required to collect each sample were measured and recorded to allow calculation of runoff rates.

Immediately following collection of all runoff samples for a given plot, the samples were composited to form one flow-weighted composite sample per plot and per sampling location. The composite samples were then split, with one portion filtered through 0.45-μm-pore-diameter filter paper. The unfiltered runoff samples were analyzed according to standard methods (Greenberg et al., 1992; Technicon Industrial Systems, 1976; U.S. Environmental Protection Agency, 1983) for pH, electrical conductivity (EC), total Kjeldahl N (TKN), ammonia N (NH_3-N), organic N (Org-N), NO_3-N, TP, total organic C (TOC), and total suspended solids (TSS). Total Kjeldahl N and TP were analyzed using digestion in sulfuric acid with potassium sulfate and mercuric sulfate catalysts (U.S. EPA, 1983). The salicylate-nitroprusside method was used for NH_3-N determinations (Technicon Industrial Systems, 1976). Sample Org-N concentrations were calculated as the difference between TKN and NH_3-N concentrations. Sample concentrations of NO_3-N were analyzed using the automated cadmium reduction method (Greenberg et al., 1992). The combustion-infrared method was used for TOC analyses. The filtered samples were analyzed as described above for TKN, NH_3-N, Org-N, TP, and TOC.

One-way analysis of variance was used to assess the significance of the effect of manure-treated length on runoff concentrations of analysis parameters. Proportions of poultry litter constituents transported in particulate and soluble forms were determined directly from the concentration data for filtered and unfiltered runoff samples.

Table 1. Poultry litter analysis results

Parameter	Mean*	CV†
pH	7.16	0.01
EC (mS/m)	728.4	0.09
H_2O (%)	24.85	0.04
TN (mg/kg)	34,700	0.08
NH_4-N (mg/kg)	1,448	0.16
NO_3-N (mg/kg)	102	0.24
TP (mg/kg)	14,400	0.08
K (mg/kg)	25,700	0.05
Fe (mg/kg)	154	0.64
Zn (mg/kg)	647	0.06
Cu (mg/kg)	560	0.12

* Mean of 20 samples, "as is" basis.
† Coefficient of variation.

Table 2. Poultry litter constituent application rates

Constituent	Application Rate (kg/ha)
TN	146.4
NH_4-N	6.1
NO_3-N	0.4
TP	60.6

Results

Effects of Manure-treated Length on Runoff Quality

One-way analysis of variance indicated that manure-treated distance had no significant influence on concentration of any poultry litter constituent examined, as demonstrated in figure 2 for TKN and in figure 3 for TP. Statistics of the runoff quality data, calculated from lumping all treatments and replications, are given in table 4. The insignificance of manure-treated length as a source of variability indicates that concentrations of the investigated parameters quickly (within 3 m) approached equilibrium. The equilibrium parameter concentrations

Table 3. Soil analysis results

Parameter	Mean*	CV†
pH	5.5	0.05
Organic matter (%)	1.33	0.30
EC (mS/m)	1.967	0.06
TKN (mg/kg)	601	0.40
NH_4-N (mg/kg)	1.63	0.07
NO_3-N (mg/kg)	2.17	0.81
P (mg/kg)	60.0	0.71

* Mean of three samples, "as is" basis.
† Coefficient of variation.

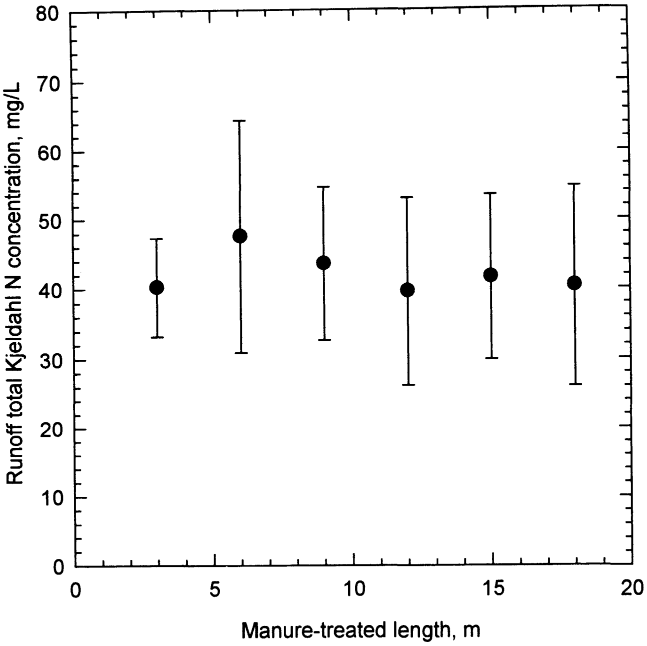

Figure 2–Runoff total Kjeldahl N concentration as a function of manure-treated length.

were most likely governed largely by rainfall intensity, rainfall duration, and amounts of litter constituents initially present near the soil surface, since previous studies have demonstrated the significance of those factors (Westerman et al., 1983; McLeod and Hegg, 1984; Edwards and Daniel, 1993a, 1994a; Edwards et al., 1994). This study does not, unfortunately, shed much light on the operative mechanisms that were responsible for maintaining constant concentrations with increasing manure-treated length. It is possible that infiltration of soluble forms of poultry litter constituents played a significant role in the overall process,

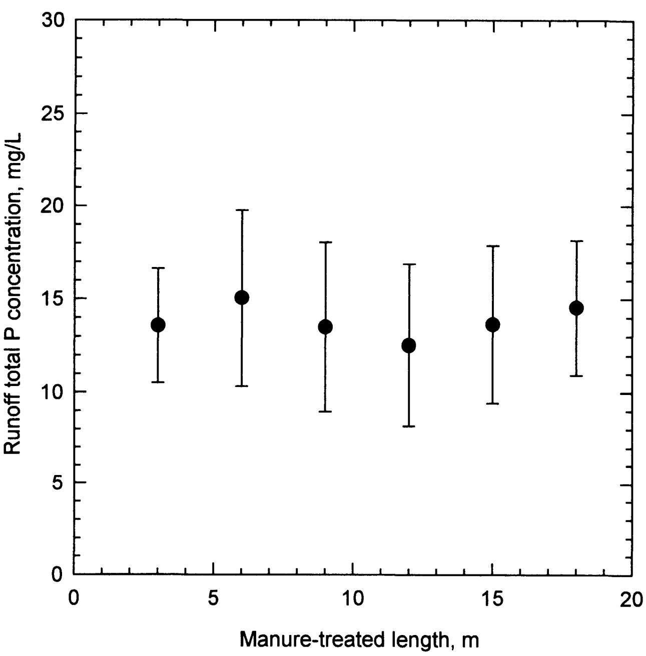

Figure 3–Runoff total P concentration as a function of manure-treated length.

Table 4. Runoff quality analysis results for unfiltered samples

Parameter	Mean*	CV†
pH	7.52	0.01
EC (mS/m)	474	0.19
TKN (mg/L)	42.17	0.26
Org-N (mg/L)	18.43	0.23
NH_3-N (mg/L)	23.75	0.34
NO_3-N (mg/L)	0.57	0.58
TP (mg/L)	13.81	0.25
TOC (mg/L)	65.28	0.39
TSS (mg/L)	106.74	0.35

* Mean of 18 samples (6 manure-treated lengths and 3 replications).
† Coefficient of variation.

but additional work involving runoff sample collection at smaller manure-treated length intervals will probably be necessary to define the relative influence of that mechanism.

The findings with respect to the role of manure-treated length have rather direct implications in a more applied context. If the objective had been to simply estimate concentrations of various parameters in runoff exiting an 18-m plot, then a direct extrapolation of the data from a plot of only 3 m length would have produced the desired result, as indicated by the data. The independence of runoff concentrations and manure-treated length could thus greatly simplify the design of management practices (e.g., vegetative filter strips) where the practice might be applied to fields having varying manure-treated lengths and where the effectiveness of the practice depends partly on edge-of-field pollutant concentrations in runoff.

A comparison of some of the concentrations given in table 4 to those observed during similar experiments (Edwards and Daniel, 1993a) indicates that runoff concentrations of TKN, NH_3-N, and TP were approximately two to three times higher in the 1992 experiment than in this study. This result is attributed to the longer simulated rainfall duration (1 h of runoff) than used in the 1992 study (0.5 h of runoff). Results reported by Edwards et al. (1994) showed decreasing concentrations of these parameters with increasing time during the runoff event. The composite samples collected in this experiment therefore reflected a relatively low weighting of the initially high runoff concentrations of these parameters.

Proportions of Soluble and Particulate Parameter Forms

Composite runoff sample concentrations of soluble Kjeldahl N, Org-N, NH_3-N, reactive P, and organic C obtained after filtration are given in table 5. Statistics of these concentrations were computed across all manure-

Table 5. Runoff quality results for filtered samples

Parameter	Concentration (mg/L) Mean†	Concentration (mg/L) CV‡	F/U* Mean†	F/U* CV‡
Soluble Kjeldahl N	37.60	0.29	0.89	0.15
Soluble organic N	20.63	0.36	1.14	0.32
Soluble NH_3-N	16.97	0.27	0.74	0.19
Soluble reactive P	11.87	0.31	0.85	0.15
Soluble organic C	31.87	0.27	0.53	0.30

* Ratio of filtered to unfiltered runoff sample concentration.
† Mean of 18 samples (6 manure-treated lengths and 3 replications).
‡ Coefficient of variation.

treated lengths and replications because one-way analysis of variance indicated that manure-treated distance had no significant effect on the concentrations. Ratios between concentrations in unfiltered samples and in filtered samples are also given in table 5.

The dominant mode of transport for TKN, NH_3-N, and P is demonstrated in table 5 to be in the soluble form, since the ratios of filtered to unfiltered runoff sample concentrations ranged from 0.74 to 0.85 for these parameters. Only about half the TOC present in runoff was in soluble form (table 5), indicating a relatively high presence of particulate organic C. The ratio of Org-N concentrations for filtered and unfiltered samples obviously exceeds the maximum expected ratio, but the fact that it averaged greater than the physical limit of unity might indicate that the filtration process removed some interferences to the TKN analyses that were present during analyses of the unfiltered samples.

The finding that most P in runoff was in soluble form is consistent with earlier studies involving the same soil and comparable cover conditions when poultry manure (Edwards and Daniel, 1992), swine manure (Edwards and Daniel, 1993b), inorganic fertilizer (Edwards and Daniel, 1994b), and no fertilizer (Daniel et al., 1993; Edwards and Daniel, 1994b) were applied. Nearly two years' monitoring of runoff from four pasture fields treated with organic and inorganic (in which cases the runoff P originated primarily from soil P) N sources confirmed transport of P in primarily the soluble form (Edwards et al., 1993). In comparison to the soluble transport mode, therefore, the particulate mode of transport appears to be of relatively limited significance in the context of TP transport.

Although the TN in the applied poultry litter consisted of 96% Org-N (table 1), only about half the TN in runoff was Org-N with the remainder consisting almost exclusively of NH_3-N. The low proportion of Org-N in runoff and the finding that it appears to have been transported in primarily the soluble form suggests that the largest contribution to runoff Org-N was from soluble organic acids such as uric acid and that other potential Org-N sources, such as spilled feed and the bedding material, had little influence on runoff Org-N concentrations.

The observed distributions of particulate and soluble runoff quality parameters suggest that under comparable conditions, simulation models should account for the relatively high transport in soluble form. From a more practical standpoint, the distribution of soluble and particulate forms of analysis parameters suggests that for the experimental conditions used in the study, efforts to minimize manure constituent losses through minimizing erosion, *per se*, will have little impact on those losses. Manure constituent losses will instead be best controlled by addressing the losses of soluble constituent forms. Conditions that tend to promote erosion (e.g., steeper slope and reduced grass cover) might increase the particulate fraction of transported litter constituents, but additional work would be necessary to define the interactions between these conditions and modes of transport.

Summary and Conclusions

This study assessed the influence of manure-treated length on the quality of runoff from fescue plots treated with poultry litter. Analyses of runoff samples filtered through 0.45-µm-pore-size filter paper were also performed to determine the amounts of poultry litter constituents present in the runoff in soluble and particulate forms. Manure-treated length had no significant impact on the concentration of any constituent investigated. While this result merits further investigation, it suggests that for similar investigations and conditions, plot lengths may be relatively short ($\leq$ 3 m) and yet result in similar runoff concentrations as would be observed for longer plots. The insignificance of manure-treated length as a factor in runoff concentrations of parameters also suggests that the extrapolation from plot-to-field conditions might be valid under some conditions. Most of the TKN, Org-N, NH_3-N, and P detected in the runoff samples was in soluble form, while about half the TOC was in soluble form. Management practices designed to minimize losses of N and P for these conditions clearly should focus on minimizing soluble forms of these nutrients rather than simply minimizing erosion.

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