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Influence of Poultry Litter Application Methods on the Longevity of Nutrient and *E. coli* in Runoff from Tall Fescue Pasture

K. R. Sistani · C. H. Bolster · T. R. Way · H. A. Tobert · D. H. Pote · D. B. Watts

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Abstract Significant quantities of the broiler chicken (*Gallus gallus domesticus*) litter produced in the USA are being applied to pasture lands. The traditional surface- broadcast application of animal manure onto permanent pasture, however, may lead to high concentration of nutrients and pathogenic microorganisms near the soil surface that could be transported off site by runoff water. Subsurface banding of poultry litter has the potential to reduce nutrient and pathogen losses through runoff. However, this has not been thoroughly investigated. In this study, we used rainfall simulations to examine the effect of broiler litter application methods on the longevity of nutrient and *Escherichia coli* losses in runoff by successive runoff events. Runoff plots were constructed on Hartsells fine sandy loam (Typic Hapludults) soil with permanent Kentucky 31 tall fescue (*Festuca arundinacea*) pasture in Crossville, AL. Treatments included two methods of litter application (surface broadcast and subsurface banding), commercial fertilizer, and control (no litter or fertilizer applied). To evaluate the longevity of nutrient losses, simulated rainfall (110 mm h^{-1}) was applied to each plot on days 1, 7, and 14 following litter and fertilizer applications. Total P (TP), inorganic N, and *E. coli* concentrations were all significantly greater in runoff from broadcast litter application than the subsurface litter banding treatments. The TP losses from broadcast litter applications averaged 6.5 times those from subsurface litter applications. About 81% of the runoff TP concentration was in the form of dissolved reactive phosphorus for both litter application methods. The average losses of NO_3–N and total suspended solids from subsurface litter banding plots were 358 g ha^{-1} and 68 kg ha^{-1} compared to 462 and 60 kg ha^{-1} for the broadcast method, respectively. This study shows that subsurface banding of broiler litter into perennial grassland can substantially reduce nutrient and pathogen losses in runoff compared to the traditional surface-broadcast practice.

Keywords Poultry manure · Phosphorus · Runoff water · Rainfall simulation · Manure application method

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K. R. Sistani (✉) · C. H. Bolster
USDA-ARS, Animal Waste Management Research Unit,
230 Bennett Lane,
Bowling Green, KY 42104, USA
e-mail: karamat.sistani@ars.usda.gov

T. R. Way · H. A. Tobert · D. B. Watts
USDA-ARS, National Soil Dynamics Laboratory,
Auburn, AL 36832, USA

D. H. Pote
USDA-ARS, Dale Bumpers Small Farms Research Center,
Booneville, AR 72927, USA

1 Introduction

Nonpoint-source pollution of water bodies during the past 20 years has received global attention. Runoff from agricultural land, particularly manured land, is a major nonpoint source of nutrients, eroded sediments, and bacteria (Abu-Zreig et al. 2003; Gaston et al. 2003; Sistani et al. 2003; Little et al. 2005). Cabrera and Sims (2000) reported over 11.4 million t of broiler litter (a mixture of manure, bedding materials, feathers, and feed) was generated in 1996, of which more than 90% was land-applied. Over two thirds of total US broiler chicken (*Gallus gallus* L.) production is located in the southeastern United States, which is a major segment of the farm economy in the region (Economics Research Service 2004). Phosphorus (P) issues at the agriculture environment interface are particularly challenging due to potential P contributions to water quality problems (Carpenter et al. 1998). Phosphorus-enriched surface water may become eutrophied leading to increased aquatic vegetation growth and an increase in biological oxygen demand (Sharpley et al. 1994; Parry 1998; Carpenter et al. 1998). In addition, contamination of surface waters by fecal-borne microorganisms can result in serious human health problems, including death (Bicudo and Goyal 2003).

With regard to permanent pasture systems, the inability to incorporate poultry litter into soil leads to increased nutrient concentration, such as P, Cu, and Zn near the soil surface. When soil P sorption capacity is reached, potential P movement increases via, (a) runoff water at the field edge (Sharpley et al. 1994), (b) leaching through the soil (Heckrath et al. 1995), or (c) lateral transport of dissolved P within the soil (Walthall and Nolfe 1998). In a simulated rainfall study, Edwards et al. (2000) showed that P loss magnitude was related to the proximity of the preceding rainfall. Pote et al. (1996, 1999), and McDowell and Sharpley (2002) also reported that rainfall frequency and antecedent soil moisture affect runoff P transport.

Currently, surface broadcasting is a common method of litter application on soil in the USA. However, broadcasting manure concentrates nutrients and pathogenic microorganisms at the soil surface, leaving them susceptible to runoff water (Doran and Linn 1979; Coyne et al. 1995; Eghball and Gilley 1999; Edwards et al. 2000; Dou et al. 2001; Zhao et al. 2001; Pote et al. 2003; Soupir et al. 2006). Kleinman and Sharpley (2003) reported that differential erosion of broadcast manure caused significant differences in runoff total P concentrations between different soil types. Ross et al. (1979) reported that N and P losses in runoff were almost completely eliminated, when dairy manure was injected into the soil. Likewise, using rainfall simulations, Torbert et al. (2005) reported a clear reduction in the losses of NH_4–N and PO_4–P loads in runoff when litter was incorporated in the subsurface compared to surface application, indicating that incorporation would be an effective way to reduce nutrient runoff losses from litter applied to cultivated land in heavy clay soil. Giddens and Rao (1975) found that incorporation of poultry litter into the top 10 cm of soil reduced NH_3–N volatilization by 55% and doubled the NO_3–N concentration in the soil. While incorporation of litter into soil minimizes nutrient losses in tilled systems, it has not been practiced for perennial forage systems (Pote et al. 2003) because the incorporation would destroy the grass, requiring the pasture to be reestablished. However, experimental equipment under study in this project may allow incorporation of litter in a perennial grass with minimal damage to the forage.

In Alabama, there are guidelines aimed at reducing nutrient losses from litter application by avoiding litter applications before large rainfall events (USDA-NRCS, AL code 590). However, little work has been done to investigate the effectiveness of new litter application methods in perennial pastures. The objective of this study was to determine the impact of litter application methods on the longevity of nutrients and *Escherichia coli* losses by consecutive runoff events from tall fescue plots receiving commercial fertilizer and broiler litter.

2 Materials and Methods

2.1 Site Description and Experimental Design

Runoff plots were constructed on a Hartsells fine sandy loam soil (fine-loamy, siliceous, subactive, thermic Typic Hapludults) at the Alabama Agricultural Experiment Station Sand Mountain Research and Extension Center, Crossville, AL. Plots were covered with permanent Kentucky 31 tall fescue (*Festuca arundinacea*) pasture. The tall fescue was clipped to approximately 10 cm and the clipped vegetation was removed. Protocols established by the National Phosphorus Research Project (2001) were followed to construct plots and perform rainfall simulation. Each plot was 1.5 m wide and 2.4 m long with the long axis oriented parallel to the slope. Galvanized sheet metal plot borders extended approximately 13 cm below the soil surface and 7 cm above the soil. A galvanized sheet metal trough was located on the downslope end of each plot to collect and transport runoff to a collection point. Prior to initiating runoff, the metal troughs were sterilized with 70% ethanol followed by rinsing with sterilized distilled water.

Two different broiler litter application methods were compared, with broiler litter applied at a rate of 8.97 Mg ha^{-1} by either broadcast application or by subsurface banding. The subsurface banding treatment consisted of applying the litter in shallow trenches (approximately 5 cm depth and 4 cm width) at 38 cm intervals using a tractor-mounted experimental poultry litter applicator device. As the applicator device ran, the single pass of the trencher component formed the full 4 cm width of the trench, and the trencher held the trench open, while the device deposited litter in the trench. The trenches where laid out perpendicular to the slope, and each plot consisted of seven trenches across the plot. Additional treatments included a broadcast application of commercial fertilizer (19-19-19) applied at a rate of 269 kg N ha^{-1}, which is equivalent to the N applied in the broiler litter treatment and a control treatment that received no nutrient additions. The 8.97 Mg ha^{-1} litter rate provided 296 kg N ha^{-1}, 433 kg K ha^{-1}, and 234 kg P ha^{-1}. The commercial fertilizer (19-19-19), formulated from ammonium nitrate, ammonium sulfate, muriate of potash (potassium chloride), and triple super phosphate (monocalcium phosphate), was applied at a rate of 296 kg N ha^{-1} to equal the N rate applied in the broiler litter treatment, which also provided 246 kg K ha^{-1} and 129 kg P ha^{-1}.

Rainfall simulation began on May 17, 2006 and was repeated on the same plots on a weekly basis for three consecutive weeks after litter and commercial fertilizer applications to measure the longevity of the nutrient and bacterial losses in runoff from different treatments.

Rainfall was applied with a rainfall simulator at approximately 110 mm h^{-1} (corresponds to 10-year storm event for the region) to generate runoff and was maintained to provide a 30-min runoff event after the runoff started. During the 30-min runoff period, 500 mL water samples were collected at 5-min intervals during the runoff event. Runoff water flow rate was estimated by recording the time to fill a 500-mL sample bottle at each sampling time. Runoff was pumped from the collection basin and collected in a tank to determine the total runoff volume. Upon completion of the simulation, runoff volume in the tank was measured, and a cumulative water sample was collected. Samples of source water used in rainfall simulation were also collected for chemical and bacterial analysis.

2.2 Sampling and Data Analysis

Broiler litter used in this study was collected from local broiler production facilities. Total litter nutrient content was determined by a digestion procedure using a Mars 5 microwave digestion system (CEM Corp., Matthews, NC), in which 0.5 g of litter sample was mixed with 9 mL HNO_3 and 3 mL HCl in a Teflon microwave digestion vessel. The samples were placed under a hood and allowed to pre-digest for 45 min. Vessels were then assembled and placed in the microwave for complete digestion. The method consisted of increasing the temperature to 175°C in 6.5 min and then holding the temperature at 175°C for an additional 12 min. Samples were then filtered through a Whatman 42 filter paper (Whatman, Inc., Florham Park, NJ) followed by nutrient determination using a Varian Vista-Pro inductively coupled plasma spectrophotometer (ICP; Walnut Creek, CA). The pH of the litter was measured in a 1:5 litter/water mixture.

The runoff samples for dissolved reactive P (DRP) and nitrate and ammonium nitrogen (NO_3–N and NH_4–N) were filtered through 0.45-μm filters prior to analyses (Self-Davis and Moore 2000). Runoff water was also analyzed for total P (TP) after microwave digestion. The TP was determined using ICP, while a Lachat instrument (Loveland, CO) was used for DRP and inorganic N analysis. Total suspended solids (TSS) were determined by filtering 50 mL of runoff water through a pre-weighed dried filter paper (2V Whatman) and weighing again after drying at 103°C.

Prior to the rainfall simulation experiments, soil samples were collected and extracted with Mehlich 3 extractant (Mehlich 1984) using 2 g soil in a 1:10 soil/extractant ratio, shaken for 30 min, and filtered through Whatman filter paper (2V) for determination of initial concentrations of P and metals using ICP (Table 1).

For *E. coli* enumeration, runoff water samples were collected at three different times for each runoff event in autoclaved 500-mL sample bottles. Immediately following collection the samples were placed on ice and analyzed within 24 h of collection. Appropriate volumes of sample were filtered through 0.45-µm Millipore filters (Fisher Scientific, Pittsburgh, PA), and the filters were placed on Difco (Detroit, MI) modified membrane-thermotolerant *E. coli* (modified mTEC) agar and incubated at 44.5°C for 24 h (EPA Method 1603). Red and magenta colonies were enumerated as *E. coli*. For each plot, the concentrations of the three samples collected over the 30-min runoff event were averaged.

Analysis of variance was used to analyze data using the PROC GLM procedure of SAS (SAS Institute 1999). Least significant difference (LSD) was used to separate means at the 0.05 probability level. For the *E. coli* data, statistical analyses were performed on log-transformed data.

3 Results and Discussion

3.1 Effect of Litter Application Method

Litter application method had little effect on runoff pH, which ranged from 7.3 to 7.8 for all runoff events, but the application method significantly affected nutrient concentrations in runoff (Table 2). For example, mean concentrations of NH_4–N were 93% less in runoff from subsurface banded litter than in runoff from broadcast litter during the first simulated rainfall event. That pattern was maintained at 80% for runoff 2 and 47% for runoff 3, as NH_4–N concentrations were consistently much lower in runoff from the banded treatment compared to the surface-broadcast application. Indeed, NH_4–N concentrations in runoff from the banded treatment were not statistically different than NH_4–N concentrations in runoff from control plots that received no nutrient applications at all. Because NH_4–N was a major N component of the commercial fertilizer used in this study, it is not surprising that NH_4–N concentrations were consistently (all three runoff events) greater in runoff from the inorganic fertilizer treatments than from any poultry litter treatment (Table 2).

Effects of application method on NO_3–N concentrations were different relative to those for NH_4–N concentrations in runoff from poultry litter treatments. Subsurface banding decreased NO_3–N concentrations to control-plot levels (far below NO_3–N concentrations from broadcast litter) only in runoff 1 (Table 2). The elevated NO_3–N concentrations from banded treatments in runoff 2 and 3 may be attributed to the presence of good conditions for nitrification during the 7- and 14-day intervals between litter application and the runoff event. This observed increase in NO_3–N levels is consistent with results reported by Adams et al. (1994) on NO_3–N leaching from poultry manure. In runoff 1, NO_3–N concentrations from the commercial fertilizer were statistically equal to the subsurface banded litter. However, in subsequent runoff events, NO_3–N concentrations in runoff from the commercial fertilizer were significantly greater than those from litter application (Table 2).

Mean concentrations of TSS observed in runoff from this study were generally small (≤0.58 g L^{-1}) because

Table 1 Initial soil chemical analyses (Mehlich 3 extraction, except for pH C and N) and nutrient composition of broiler litter applied in May 2006

	pH	N	C	P	K	Ca	Mg	Al	Cu	Fe	Mn	Na	Zn
		g kg^{-1}						mg/kg^{-1}					
Soil													
Depth (cm)													
0–5	6.12	2.15	24.00	0.18	0.39	1.26	0.19	672	11	48	42	42	12
5–10	5.77	0.89	10.00	0.06	0.12	0.61	0.07	750	3	45	26	29	2
Liter													
May 2006	6.91	32.96	295.78	26.07	48.25	39.21	10.91	3,821	1,284	5,178	1,103	12,474	1,097

Table 2 Mean concentration of selected constituents in runoff from different broiler litter application methods and fertilizer to tall fescue plots for three successive runoff events in 3 weeks after application

Runoff constituent	Control	Fertilizer	Litter (broadcast)	Litter (subsurface band)
Runoff 1				
pH	7.5 ab	7.8 a	7.3 b	7.5 ab
NH_4–N (mg L^{-1})	0.18 c	10.01 a	7.33 b	0.52 c
NO3–N (mg L^{-1})	0.32 b	0.34 b	2.40 a	0.31 b
Total suspended solid (g L^{-1})	0.58 a	0.52 ab	0.43 b	0.23 c
Runoff 2				
pH	7.3 a	7.4 a	7.3 a	7.4 a
NH_4–N (mg L^{-1})	0.30 c	3.06 a	0.94 b	0.19 c
NO3–N (mg L^{-1})	1.14 c	2.57 a	1.31 bc	1.79 b
Total suspended solid (g L^{-1})	0.49 a	0.32 b	0.26 b	0.55 a
Runoff 3				
pH	7.3 a	7.3 a	7.3 a	7.5 a
NH_4–N (mg L^{-1})	0.14 bc	0.50 a	0.19 b	0.10 c
NO3–N (mg L^{-1})	1.20 bc	2.84 a	0.90 c	1.61 bc
Total suspended solid (g L^{-1})	0.24 b	0.05 c	0.29 b	0.47 a

Within each row (constituent), means followed by the same letter are not significantly different according to LSD at the 0.05 level

lush forage growth effectively protected the soil against erosion from this pasture site. However, subsurface banding yielded greater TSS concentrations in runoff 2 and 3 than the surface broadcast method, and this probably was due to the dislodging of soil that was loosened when the trenches were formed during the subsurface banding process (Table 2).

The effects of poultry litter application method on phosphorus (P) concentrations in runoff varied significantly from runoff 1 to runoff 3. In runoff 1, mean concentrations of DRP and TP from the subsurface litter banding method were about 89% less than from the broadcast method (Figs. 1 and 2). These results are consistent with the 80% to 95% decreased nutrient losses in runoff observed by Pote et al. (2003) when they incorporated poultry litter into bermudagrass pasture and compared results to surface-applied litter. Throughout all three runoff events in our study, mean concentrations of (DRP) in runoff from subsurface banded litter were no greater than in runoff from the control plots that received no nutrient applications, while DRP concentrations in runoff from broadcast litter (and commercial fertilizer) were several times greater (Fig. 1). The TP concentrations in runoff from all treatments (Fig. 2) followed the same trend as DRP concentrations, reflective of the fact that about 81% of the TP in runoff was in the form of DRP, regardless of litter application method. Sharpley et al. (1992) also reported that the DRP fraction was the dominant form of P in runoff from pastures and hayfields and attributed this to the low rates of soil erosion from such sites.

Concentrations of *E. coli* in runoff from the broadcast litter treatment were significantly greater than in runoff from the other treatments in runoff 1 and greater than subsurface banded litter in runoff events 2 and 3 (Fig. 3). For all runoff events, *E. coli* concentrations from the subsurface banded treatments were similar or lower than the concentrations measured for the control plot. Our observation that *E. coli* concentrations from the banded treatments were not statistically different from the control or fertilizer treatments suggests that subsurface banding of litter may be an effective strategy for controlling pathogen losses from litter-applied fields. Although direct incorporation of manure may actually lead to extended pathogen survival, in part because the soil protects the pathogens from UV irradiation and may limit their exposure to desiccation (Hutchison et al. 2004), any extended survival would likely be temporary and

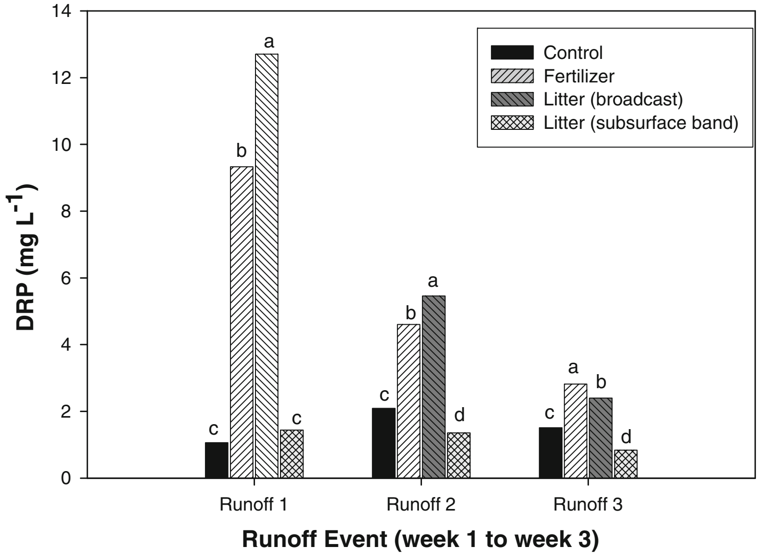

Fig. 1 Dissolved reactive phosphorus (DRP) losses in three successive runoff events in 3 weeks after broiler litter application. Within each runoff event, *bars with the same letter* indicate no significant difference according to LSD at the 0.05 level

negated immediately if the pathogens became exposed at the soil surface and susceptible to being be transported in runoff water. Therefore, subsurface litter banding should help protect water supplies against pathogen contamination from applied poultry litter.

Unlike nutrient and *E. coli* concentrations, total runoff volumes were statistically the same for all treatments in all runoff events (Table 3). This is consistent with results from a study by Sauer et al. (1999), who reported no significant differences in runoff volume among manure-treated tall fescue plots. Because runoff volume was not affected by treatment, the treatment effects on nutrient loads followed approximately the same pattern as their effects on nutrient concentrations in runoff. For example, TP losses from subsurface banded litter application were significantly less (91%, 82%, and 64%) for runoff events 1–3, respectively, than from broadcast litter applications (Table 3). These results imply that subsurface banding effectively eliminated the interaction between P in the litter and the surface water runoff during the study. In fact, in many cases, nutrient loads from subsurface banded plots were not statistically different from the control plots. This indicates that subsurface litter banding could be an effective management practice to reduce nutrient

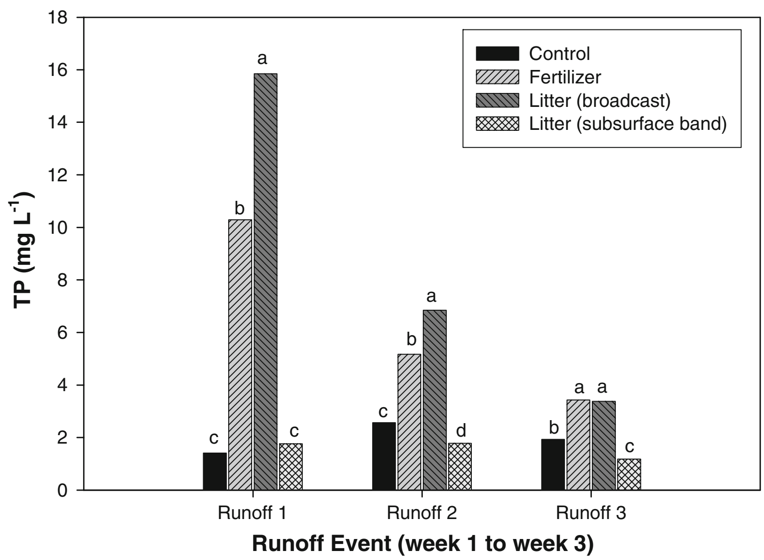

Fig. 2 Total phosphorus (*TP*) losses in three successive runoff events in 3 weeks after broiler litter application. Within each runoff event, *bars with the same letter* indicate no significant difference according to LSD at the 0.05 level

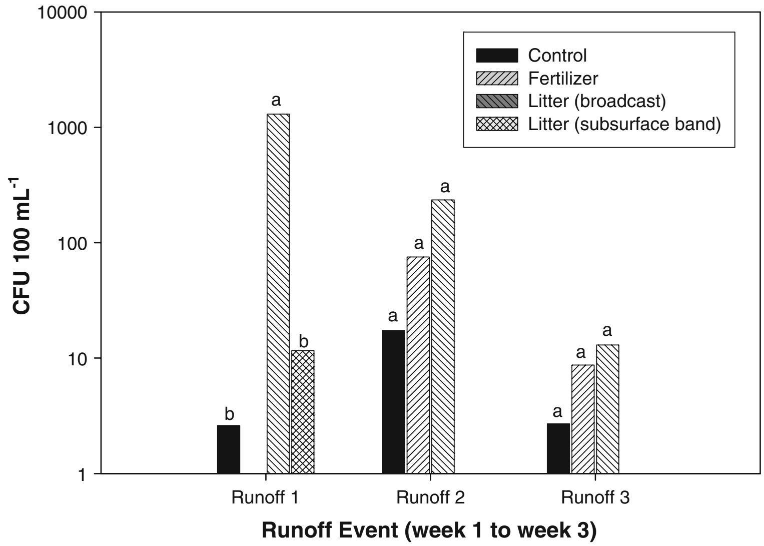

Fig. 3 *E. coli* losses in three successive runoff events in 3 weeks after broiler litter application. Within each treatment, *bars with the same letter* indicate no significant difference according to LSD at the 0.05 level. If bar is not present, then average concentrations were below detection limit (4 CFU 100 mL^{-1}). For the second runoff event, samples were available from only one plot for the control and from one plot for the fertilizer treatments

Table 3 Constituent losses (load) from tall fescue plots treated with fertilizer and two methods (surface broadcast vs. subsurface banding) of broiler litter in three successive weekly runoff events (runoff 1–3) corresponding to 1, 7, and 14 days after treatment applications

Runoff constituents	Control	Fertilizer	Litter (broadcast)	Litter (subsurface band)
Runoff 1				
Total P (g ha^{-1})	100 b	1,977 a	2,780 a	223 b
DRP (g ha^{-1})	77 c	2,063 a	2,397 a	220 b
NH_4–N (g ha^{-1})	15 c	2,139 a	1,271 b	63 c
NO3–N (g ha^{-1})	31 b	75 b	498 a	41 b
Total suspended solids (kg ha^{-1})	50 b	86 a	76 a	30 b
Runoff 2				
Total runoff volume (L)	31 a	41 a	64 a	49 a
Total P (g ha^{-1})	556 b	1,157 a	1,237 a	227 c
DRP (g ha^{-1})	467 b	1,027 a	1,030 a	178 c
NH_4–N (g ha^{-1})	78 c	719 a	194 b	46 c
NO3–N (g ha^{-1})	652 b	954 a	529 bc	448 c
Total suspended solids (kg ha^{-1})	109 a	72 b	48 b	72 b
Total runoff volume (L)	93 a	82 a	68 a	49 a
Runoff 3				
Total P (g ha^{-1})	449 b	622 a	691 a	252 b
DRP (g ha^{-1})	395 b	565 a	582 a	218 b
NH_4–N (g ha^{-1})	33 b	83 a	41 b	34 b
NO3–N (g ha^{-1})	647 b	818 a	438 b	585 b
Total suspended solids (kg ha^{-1})	60 b	11 c	56 b	101 a
Total runoff volume (L)	99 a	67 a	76 a	80 a

Within each row (constituent), means followed by the same letter are not significantly different according to LSD at the 0.05 level

DRP dissolved reactive phosphorus

losses in runoff events that occur within 3 weeks after litter application.

The TSS losses from subsurface banded litter were greater than from broadcast litter in runoff events 2 and 3, and this may be attributed to the gradual erosion of loose soil covering the trenches for subsurface litter banding. The TSS losses observed in this pasture study were relatively small (<101 kg ha^{-1}) compared to TSS losses reported from row crops or bare soil.

3.2 Longevity of Nutrient Losses

In addition to comparing nutrient and *E. coli* losses between different application methods, we compared losses of these constituents from each treatment over successive rainfall events. The runoff NH_4–N concentration from plots receiving broiler litter by the broadcast method decreased from 7.33 mg L^{-1} in runoff 1 to 0.19 mg L^{-1} in runoff 3. The corresponding decreases in NH_4–N for the subsurface banding method were 0.52 to 0.10 mg L^{-1} and for fertilizer from 10.01 to 0.50 mg L^{-1} (Table 2). The NO_3–N concentration increased from runoff 1 to runoff 2 for the fertilizer and subsurface application treatments and then decreased in runoff 3 for only the subsurface application treatment. With broadcast application of litter, the NO_3–N concentration decreased gradually from runoff 1 to runoff 3. The increase in runoff NO_3–N for the fertilizer treatment for three consecutive runoff events, from 0.34 to 2.57 and then 2.84 mg L^{-1}, is puzzling. The increase in runoff NO_3–N was also observed from the control plots. For the broadcast litter treatment, the NH_4–N and NO_3–N concentrations were significantly greater than for the subsurface application method in the first runoff but not in the second and third runoff events.

TSS in runoff decreased over successive rainfall events for all the treatments except for the subsurface litter application (Table 2). The runoff DRP concentration for the broadcast litter and fertilizer treatments decreased drastically from runoff 1 to runoff 3 (Fig. 1). In each runoff event other than event 3, the DRP concentration for the broadcast litter treatment was the greatest followed by fertilizer and then subsurface litter application. In runoff event 3, the DRP concentration was greater for the fertilizer treatment than the other treatments. The runoff DRP concentration for the broadcast litter application decreased about 57% for week 2 and 81% for week 3 compared to the concentration for week 1. The rate of DRP decrease for the fertilizer treatment was 51% for week 2 and 70% for week 3. The runoff DRP concentration for the subsurface litter application method did not change much in runoff 2, but then decreased in runoff 3. Unexpectedly, runoff DRP concentration of the control plots increased in runoff 2 and then decreased in runoff 3. The runoff TP concentration for the broadcast litter method decreased from 16 mg L^{-1} in runoff 1 to about

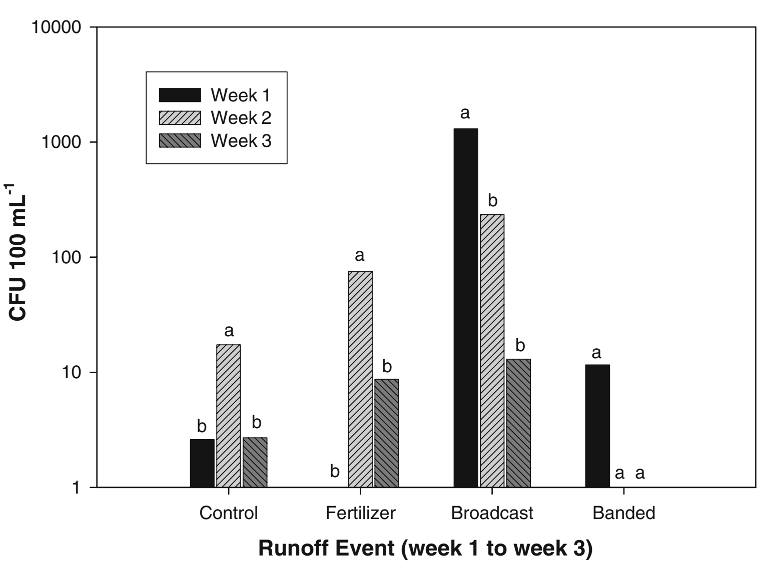

Fig. 4 *E. coli* losses in three successive runoff events from different treatments. Within each treatment, *bars with the same letter* indicate no significant difference according to LSD at the 0.05 level. If bar is not present, then average concentrations were below detection limit (4 CFU 100 mL^{-1})

4 mg L^{-1} in runoff 3. The reduction in runoff TP for the broadcast litter and fertilizer treatments was much greater than for the subsurface litter application method in runoff events 2 and 3 (Fig. 3). The runoff TP concentrations for the broadcast litter application and fertilizer treatments were the same in runoff 3, but were significantly greater than runoff TP for the subsurface application and control treatments. For the broadcast litter application, runoff concentrations of *E. coli* dropped from 1,303 colony-forming units (CFU) 100 mL^{-1} in runoff 1 to 235 CFU 100 mL^{-1} in runoff 2 to 13.3 CFU 100 mL^{-1} in runoff 3 (Fig. 3). For the subsurface banded treatment, concentrations dropped to below the detection limit in weeks 2 and 3. For the control and fertilizer treatments, however, *E. coli* concentrations increased from week 1 to week 2 then returned to week 1 levels in week 3 (Fig. 4). This increase, however, may be due to sampling error as we sampled from only one plot for the control and one plot for the fertilizer treatments for the second runoff event.

4 Conclusions

Broadcast litter application method had greater runoff inorganic N concentrations and loads than subsurface litter banding. The broadcast litter treatment also had significantly greater DRP, TP, and *E. coli* than subsurface litter application in all runoff events. The suspended solid load for all treatments was generally low and its trends were inconsistent. The fertilizer treatment produced runoff with greater NH_4–N concentrations but smaller NO_3–N concentrations than the litter application treatments.

The longevity of nutrient and *E. coli* losses in runoff was tested in three successive runoff events for three consecutive weeks after litter application, on the same tall fescue plots. All runoff P measurements and NH_4–N concentrations decreased in the second runoff and further decreased in the third runoff events for all treatments. However, NO_3–N concentration for fertilizer and subsurface litter application increased in the second runoff then decreased in the third runoff event. Nitrification of NH_4–N to NO_3–N may have been responsible for the greater longevity of NO_3–N concentration in runoff water. Concentrations of *E. coli* were lower in the second and third runoff events as compared to the first runoff event for the broadcast treatment, likely a result of die-off, that becomes bound to surface soil particles or may have infiltrated through the soil and therefore were present in runoff to a lesser degree.

The results strongly suggest that subsurface banding of broiler litter into perennial grassland significantly reduces nutrient and pathogen losses by runoff events compared to the traditional surface-broadcast practice. Depending on the method of litter application, nutrient concentrations in runoff generally decrease with successive runoff events.

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