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Full Length Research Paper

Hindrances to the use of Manure in phosphorus and sediment in run-off

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Surface application of animal manure increases nutrients at the soil surface with increased potential for nutrient loss in runoff. Non-application setbacks are often required with the intent to reduce nutrient loss to surface water. The objective of this research was to determine the effect of setback distance on phosphorus and sediment in runoff. The research was conducted in eastern Nebraska on 24 ha of a terraced field with a 4 to 7% slope and predominantly Yutan silty clay loam Mollic Hapludalf soil. Experimental units were drainage areas served by risers for the tile-outlet terrace system. The seven treatments included no manure applied and setbacks with radii of 0, 5, 10, 20, 30, and 40 m; the setback distances were limited on the terrace side by the top of the terrace bund. Composted feedlot manure was applied at approximately 74 Mg ha^{-1} with 222 kg Pha^{-1} applied. Over a two-year period, the mean precipitation was 770 mm per year and six major runoff events occurred. Setback distance did not affect dissolved P, particulate P, total P, and sediment concentrations or losses except that sediment loss was greater by 51% with increased setback distance, confirming the value of manure in reducing soil erodibility. Sediment and P concentrations were related to time since the on-set of a runoff event and peak intensity of rainfall events. The results show that manure application setbacks around risers on fields protected with tile-outlet terraces are ineffective in reducing P and sediment runoff.

Key words: CAFO, compost, concentrated animal feeding operations, ISCO, terraces, water quality.

INTRODUCTION

Application of organic or inorganic phosphorus (P) to cropland can increase the risk of P loss to surface waters.

Agricultural runoff is considered a major nonpoint P source of pollution for many lakes, rivers, estuaries, and coastal waters, often causing accelerated eutrophication (Carpenter et al., 1998) . Transport of P from agricultural areas to surface waters is primarily by runoff and erosion, and P concentration may be affected by surface soil P content and the method, rate, and timing of fertilizer and manure P application (Sharpley et al., 1993). The loss of P to surface water may be reduced by management

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Abbreviations: CFM, composted feedlot manure; DP, dissolved P; PP, particulate P; TP, total P.

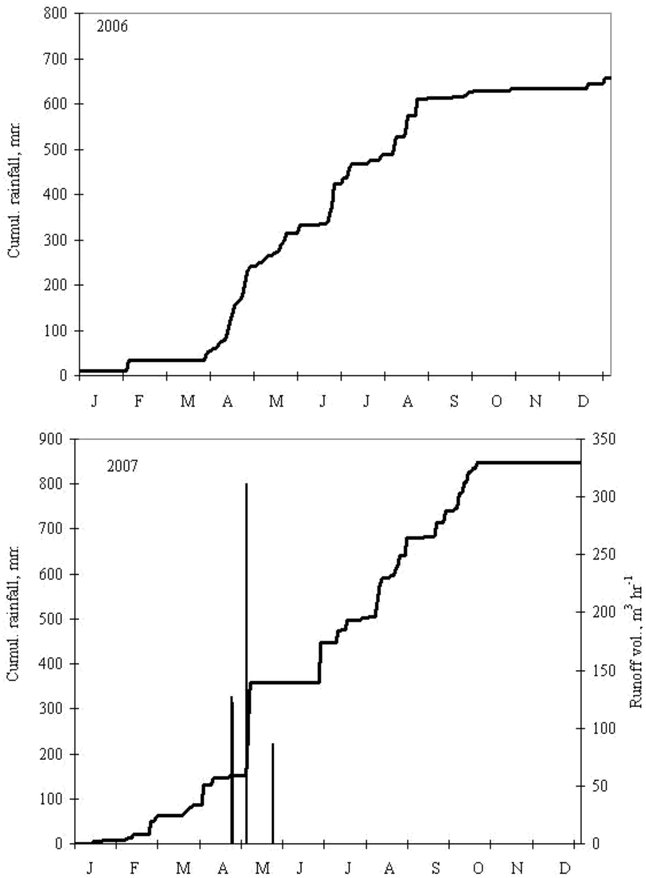

Figure 1. Cumulative rainfall for 2006 and 2007 and mean runoff volume (m^3 ha^{-1}), as indicated by the bars, of four runoff events collected using ISCO samplers in eastern Nebraska in 2007. Runoff volume was not recorded for runoff events in 2006.

practices such as non-application setbacks.

Setbacks, with or without perennial vegetation, are distances between pollutant sources and an aquatic ecosystem (National Research Council, 2000). The distance from the point of P application to concentrated flow can affect the risk of P reaching surface water (McDowell and Sharpley, 2002). A 30- m setback of manure application from surface waters and conduits (channels, open tile line-intake structures, sinkholes, and agricultural wellheads) to surface waters is required for regulated confined animal feeding operations (CAFOs) (USEPA, 2003) to minimize "the potential runoff of pathogens, hormones such as estrogen, and metals and to reduce nutrient and sediment runoff" (Federal Register page 3054). An 11-m setback in perennial vegetation is an alternative. In some situations, a CAFO may be able to demonstrate to the permitting authority that a setback or vegetative buffer can be reduced or is unnecessary.

Setback effectiveness for reducing runoff P has not been well evaluated in field situations. The setback concept may not adequately consider the value of manure application to enhanced formation of water-stable soil macro-aggregates and reduced runoff and erosion (Wortmann and Shapiro, 2008; Gilley and Risse, 2000). This effect can persist for several years after manure application (Wortmann and Walters, 2007). Withholding application of manure from setback areas means loss of this beneficial effect in the setback area. Liu et al. (1997) found that P applications did and did not significantly affect dissolved P (DP) concentrations in runoff for 10 and 5% slopes, respectively. Setbacks may be of little value on fields with well-designed and maintained terrace systems that effectively reduce soil erosion and enhance sedimentation within the field. Mickelson et al. (1998) reported that 20.1 m setbacks around a riser of a tile-outlet terrace did not reduce off-site herbicide transport, at least in part because the setback area is the ponding area where water may be over 1 m deep. Franti et al. (1998) reported that setbacks reduced atrazine and cyanazine losses only in proportion to the area not sprayed.

Setbacks can complicate manure application and soil fertility management. A 30-m setback from a point, such as a well or tile intake, can be 0.28 ha that is not available for manure application but still available for crop production (Koelsch, 2005). It is likely a producer will apply needed nutrients on the setback areas using fertilizer to maintain productivity and this may negate any possible positive effects of the setbacks for reducing P loss. The inconvenience of the setbacks may often causes producers to apply manure to other land that is not protected by tile-outlet terraces and with higher runoff P risk.

Research was conducted to evaluate the USEPA setback requirement for tile-outlet terraces by determining the effect of setback distance on runoff P and sediment loss following surface application of composted feedlot manure (CFM) . The effects of rainfall intensity and time during runoff events on runoff P and sediment loss were evaluated.

MATERIALS AND METHODS

Site characteristics

The study was conducted on 24 ha (59 acre) of a field protected with underground-outlet terraces located northeast of Lincoln, NE, at 41°3'43"N and 96°29'51"E. The mean elevation was 374 m. The mean precipitation was 767 mm per year with 75 to 80% falling from April to September, often at intensities of > 25 mm per day, and occasionally, 125 to 150 mm per day (Figure 1). The slope was 4 to 7%. The soil was deep, moderately well-drained Yutan silty clay loam formed in loess (fine-silty, mixed, superactive, mesic Mollic Hapludalf). The soil was sampled for the 0 to 20 cm depth before 48 h after runoff ceased; the remaining sample was discarded.

Samples were collected from runoff events that had runoff for most manure and fertilizer application using a 1.9 cm (0.75 in) diameter soil probe for basic chemical analyses. The soil chemical analysis was as follows: pH, 6.8; organic matter, 29.2 g kg^{-1}; Bray-P, 52 mg kg^{-1} (ppm); NO_3-N, 7.25 mg kg^{-1}; and K, 509 mg kg^{-1}.

Experimental design, treatments, and crop management

The experimental units were the drainage areas of 21 tile-outlet terrace risers grouped into three blocks of seven treatments. Blocking was according to slope aspect with approximately east, west, and north to northeast aspects for blocks 1, 2, and 3, respectively.

The treatments were CFM applied with non-application setbacks of 0, 5, 10, 20, 30, and 40 m, and no CFM applied. The CFM was applied to bare, frozen soil in February 2006 to minimize compaction. The CFM contained 3.71, 0.04, 0.89, 3.00 kg mg^{-1} of organic N, nitrate N, ammonium N, and P, respectively. This resulted in the application of 222 kg P ha^{-1}. The intended CFM application rate was 56 Mg ha^{-1} but application was by the animal feeding operation and calculation from the total amount applied to the 24 ha research site determined the mean application rate to be 74 Mg ha^{-1}. This is a high but not excessive rate as feedlot manure is commonly applied at heavy rates once in 3 to 6 *year* to minimize compaction, with much of the P removed in harvests between the applications. Winter application of feedlot manure is common in this part of Nebraska where repeated snow melts during the winter are common with little or no runoff. Winter application on bare soil is considered to pose less P runoff risk than spring application but more than late summer and fall application (Wortmann and Walters, 2007). Considering availability factors of 15, 0, and 100% for organic N in CFM, ammonium N with no incorporation, and nitrate N, respectively, 107 kg ha^{-1} of manure N was estimated to be available to the 2006 corn (*Zea mays* L.) crop (Eghball and Power, 1999).

The CFM was first carefully applied around flagged setback areas reducing risk of CFM application in the setback while applying to the rest of the field. No fertilizer P was applied to the setback area or the rest of the field. The mean P application rate for the drainage area of the experimental units ranged from 220 kg ha^{-1} for the 0 m setback compared with 152 kg ha^{-1} for the 40 m setback.

Crop management was at the farmer's discretion but uniform across the trial area with the understanding that no fertilizer P was to be applied and no tillage was conducted. Corn was planted on 3rd May 2006 and soybean (*Glycine max* L.) was planted on 21st May 2007. No tillage was conducted during these years. Urea-ammonium nitrate (32-0-0) was applied at 146 kg N ha^{-1} in 2006. This was more N than was needed where CFM was applied as CFM was expected to supply 107 kg ha^{-1}, but the farmer opted to apply the fertilizer N uniformly to setback and non-setback areas. No fertilizer was applied in 2007. A tipping-bucket rain gauge (Onset Data Logging Rain, Global Water Instrumentation, INC, Gold River, CA) was positioned on the east side of the field to record rainfall time and intensity in increments of 0.25 mm.

Sampling

At each of 21 risers, a 1-L bottle was installed to collect runoff samples with the inlet tube 75 mm above the soil surface. The inner and outer diameters of the inlet tubes were 6 and 9 mm, respectively. A 0.5 L sub-sample was collected for analysis within risers on 30th March, 6th April, and 8th August in 2006, and on 25th April, 7th May, and 25th May in 2007. The 25th May 2007 event actually began on the 24th May and ISCO samples were collected on both 24th and 25th May; therefore, the ISCO data was analyzed as four events in 2007. Two other runoff events with much missing data were excluded from statistical analysis.

Automated samplers (ISCO Inc., Lincoln, NE) were installed in 2007 in experimental units with the 0 and 30 m setback distances to measure the depth of ponded runoff and collect runoff samples. The ISCO samplers held 12 jars and collected samples every 10 min once the ponded runoff reached the sampler's intake.

The runoff samples were kept at 4°C until analyzed. Sediment concentration was gravimetrically determined by drying 100 mL of unfiltered runoff at 104°C. Total P (TP) was determined on unfiltered runoff samples using perchloric/nitric acid extraction ($HClO_4$–HNO_3). Dissolved P in runoff was determined after filtration of a 100 mL sample through a <0.45 µm filter (Pote and Daniel, 2000). Particulate P (PP) was determined as the difference between TP and DP. Phosphorus was measured colorimetrically at 880 nm with a Spectronic 601 (Milton-Roy, Rochester, NY) according to Murphy and Riley (1962).

Calculations

The drainage area of each sampler was calculated using survey equipment to calculate the stage storage curve that defines the relationship between the depth of water and the associated storage volume in the drainage area. This step involves initially establishing contours for the ponding area and determining the elevation-storage relationship for the pond.

Discharge rate through the riser, Q (m^3 s^{1}), was calculated using ISCO data as a function of the riser orifice diameter, orifice depth, and ponding depth (Martin et al., 1997):

$$Q = C_d A_o (2 g H)^{0.5}$$

Where the discharge coefficient (C_d) = 0.65, A_o = orifice area (m^2), g = gravitational constant = 9.8 ms^{-2}, and H = depth from the pond surface to the orifice (m). Runoff volume ($m^3 ha^{-1}$) was calculated from the total volume discharged.

Mean runoff or inflow (I) rate (m^3 ha^{-1} hr^{-1}) was calculated from change in storage volume and estimated discharge to the underground tile for each 10 min interval:

$$I = (S_{j+1} – S_j) / t + (O_{j+1} – O_j) / 2$$

Where I is inflow rate (m^3 ha^{-1} hr^{-1}), S is storage (m^3), O is the discharge from the riser ($m^3 ha^{-1} h^{-1}$) calculated from Q, and t is time step (h).

Statistical analysis

The analysis of variance (= 0.05) was conducted using Proc Mixed (SAS Institute, 2003) to determine the effects of setback treatments on sediment, TP, DP, and PP concentrations for samples collected in the 1-L bottles with setback distance as a fixed effect and block as a random effect. ISCO runoff volume, concen-tration, and load data from the 30 m and no setback treatments were analyzed using the Proc Mixed model for the effects of setback treatments with rainfall event as a repeated measure.

Table 1. The mean effect of 74 Mg ha^{-1} composted feedlot manure applied with 30 m compared with no setback on runoff volume and concentrations and loads of total P (TP), particulate P (PP), dissolved P (DP), and sediment for four runoff events in 2007 based on ISCO sampling.

Setback distance (m)	Runoff volume (m^3 ha^{-1-})	Sediment (g L^{-1})	TP	DP	PP	Sediment	TP	DP	PP
			(mg L^{-1})			(kg ha^{-1})			
0	171	0.84	2.74	1.03	1.72	182	0.47	0.28	0.21
30	175	1.24	2.78	1.16	1.69	279	0.46	0.26	0.23
Setback	NS	NS	NS	NS	NS	*	NS	NS	NS
Setback × event	NS	NS	***	NS	**	NS	NS	NS	NS

*, **, *** Significant at P 0.1, 0.05, and 0.001 respectively. NS, not significant.

Drainage area, amount of P applied, and mean P application rate per experimental unit were significant for some variables as co-variants in the ANOVA but did not increase the results that were statistically significant. All reported results are from ANOVAs without co-variants.

Various relationships were evaluated. Pearson correlation coefficients and means with confidence intervals were determined for the effect of sampling method on sediment and P concentrations. Polynominal regression analysis was used to relate the 10-min peak rainfall intensity with sediment and nutrient concentrations in runoff using the 1-L bottle data. Regression analysis (exponential decay) was used to relate sediment and P concentrations to sampling time (min) during runoff events.

RESULTS AND DISCUSSION

Effect of setback distances on P and sediment concentration

Application of CFM and setbacks did not significantly affect P concentrations when measured from the 1-L sample bottles for the mean of five rainfall events. The means with confidence limits (P = 0.05) were 1.3 ± 0.20, 1.82 ± 0.31, and 3.20 ± 0.42 mg L^{-1}, respectively, for DP, PP, and TP. There was not a significant relationship of P concentrations with setback distance and no difference in P concentrations for CFM applied compared with no CFM applied. Sediment concentration, averaged across the five runoff events, was not affected by setback distance, but was significantly greater (P = 0.003) with no CFM applied (3.69 g kg^{-1}) compared with the mean for all setback distances with CFM applied (1.98 g kg^{-1}). Another very intense and erosive runoff event was excluded from this analysis because of heterogeneity of variance, but also because of much variation independent of the treatments.

Runoff volume and concentrations of sediment and DP were not different for the 0-m compared with the 30-m setback as determined from the ISCO sampling data collected from four runoff events in 2007 (Table 1). The setback distance by runoff event interaction was significant for total and PP concentrations because of relatively high concentrations with the 30-m setback for the 24th April 2007 compared with other runoff events. Sediment load was significantly less with 0-m compared with 30-m setback.

Setbacks did not reduce dissolved and TP concentrations and runoff. Application of CFM did reduce sediment concentration compared with no CFM applied when measured with the 1-L sample bottles. Sediment load was greater with setbacks compared with no setback. The results confirm the value of manure application in reducing erosion, possibly because of an increase in water-stable aggregates (McDowell and Sharpley, 2001; Wortmann and Shapiro, 2008). Wortmann and Shapiro (2008) also reported higher P concentration in water-stable aggregates compared with the whole soil, with the aggregates protecting much soil P from runoff. When repeated manure application results in excessive levels of soil test P, however, the soil amendment effect is inadequate to compensate for the high levels of soil P, and runoff P is increased (Wortmann and Walters, 2006, 2007). In this study, even with surface application of 222 kg ha^{-1} P in the winter, CFM application did not add significantly to P in runoff and setbacks were not beneficial in reducing P and sediment runoff.

Another factor that affected P but not sediment in runoff was that manure P was applied at a lower mean rate to experimental units with greater setbacks. The drainage areas ranged from 0.39 to 2.13 ha and setback area comprised, on average, 0, 0.7, 2.9, 21.4, 23.3, and 35.8% of the drainage area for the 0, 5, 10, 20, 30, and 40 m setbacks, respectively. Therefore, 35.8% less manure P was applied with the 40 m compared with the 0 m setback, which is expected to reduce runoff P concentration and load, and yet setback distance did not affect P concentrations in runoff.

Sediment, PP, and DP react differently in erosion, run-off, and ponding events. The results of this study are in

Table 2. Sample means and confidence limits (P = 0.95) comparing use of 1- L bottles for sampling with ISCO samples. Means of six experimental units and three runoff events.

Pollutant	1-L bottle	ISCO
Sediment, g L^{-1} Total	1.71 ± 0.60	1.14 ± 0.37
P, mg L^{-1} Dissolved	3.02 ± 0.50	2.72 ± 0.43
P, mg L^{-1} Particulate	1.37 ± 0.29	1.47 ± 0.18
P, mg L^{-1}	1.66 ± 0.46	1.30 ± 0.31

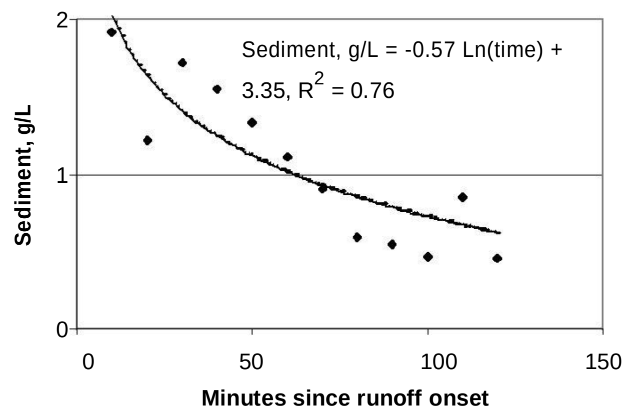

Figure 2. Effect of time since on-set of runoff ponding on sediment concentration based on samples collected at 10-min intervals with ISCO samplers. Each point represents the mean of eight observations from runoff of both 0 and 30 m manure application setbacks and for four runoff events.

in agreement with findings that setbacks were not effective in reducing herbicide runoff (Mickelson et al., 1998), except in proportion to the area not sprayed (Franti et al., 1998).

Sampling method comparison

The 1-L bottle sampling method is an inexpensive means of obtaining samples from drainage areas but gives only one sample per drainage area per event and is useful only for pollutant concentrations. The ISCO sampling has the advantage of collecting multiple samples per event while measuring ponding depth to provide a means to calculate runoff rate, but at much higher cost. Mean concentrations with ISCO were not outside the confidence intervals of the mean concentrations with the 1-L bottle method, but the coefficient of correlation between the two methods was significant for DP concentration only (r = 0.6; P = 0.003) (Table 2). Some of the difference in results from the two methods was probably due to time during the event when the sample was collected, at least for sediment concentration which dropped steadily during the runoff event (Figure 2). Using the 1-L bottles, samples were collected within 30 min after the ponding reached the inlet tube while ISCO samples were collected throughout the event. Concentrations of P were not consistently related to time during runoff events.

Rainfall properties and sediment and phosphorus concentration

Particulate P was 70% of the TP load in agricultural runoff. Sediment and P concentrations were increased with higher peak rainfall for spring runoff events (Figure 3). The peak rainfall intensities, determined as the maximum intensity for an event over a 10 min period, were 72 mmh^{-1} on 30th March, 52 mmh^{-1} on 6th April, and 58 $mmha^{-1}$ on 8th August in 2006 and 29 mmh^{-1} 25th April, 17 mmh^{-1} on 6th May, and 12 mmh^{-1} on 24th May in 2007.

The relationship of sediment and P concentrations with

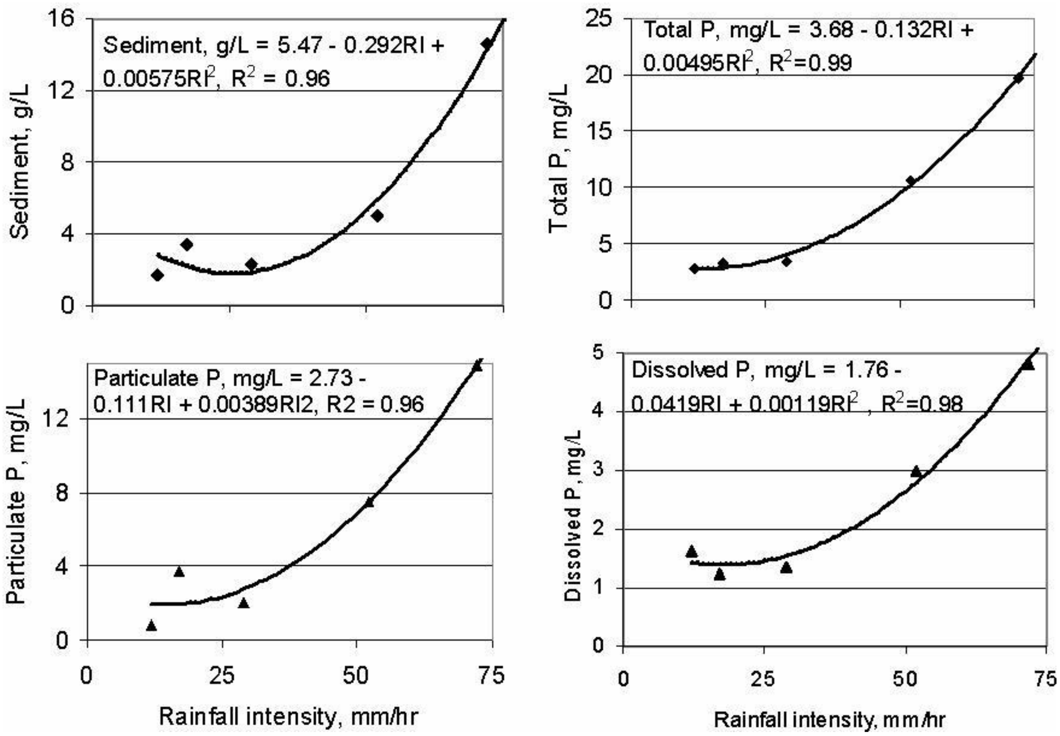

Figure 3. The effect of peak 10-min rainfall intensity on concentration of (A) sediment, (B) total P, (C) dissolved and (D) particulate P based on 1-L samples collected by risers of tile outlet terrace systems during six spring runoff events in eastern Nebraska in 2006 and 2007.

rainfall intensity has been reported by others (Owens and Shipitalo, 2006; Cassell et al., 1998; Quinton et al., 2001). Detachment of soil particles during intense rainfall results in increased sediment and P concentrations in runoff (Fraser et al., 1999). Most runoff events occurred in March to May in the current study as well as in other studies conducted in eastern Nebraska (Wortmann and Walters, 2006, 2007). Soil water content is often high during these months, thus reducing the rate of water infiltration and increasing the potential for runoff. Maintaining ground cover during this period before corn or soybean crop canopies are formed may be important to minimizing sediment and P loss. As the season progresses, the crop canopy and the extraction of water from the soil tend to reduce runoff and erosion potential erosion potential.

Conclusion

Setbacks around risers of tile-outlet terrace systems were not effective in reducing P loss in runoff. Application compared with no application of CFM resulted in reduced sediment concentration by 51%. Sediment loss in runoff was less with 0-m (182 kg ha) compared with 30-m setback (279 kg ha^{-1}) . Rainfall intensity is a major factor influencing sediment and P concentration because it affects soil detachment by raindrop impact and transport of detached particles by runoff. These research findings do not support the use of setbacks around risers of tile-outlet terraced land as a means for reducing P loading of surface waters. This study did not address manure-borne antibiotics or pathogens, but the failure of setbacks to reduce DP in runoff, as well as the works of Mickelson et al. (1998) and Franti et al. (1998) which found that setbacks did not reduce herbicide in runoff, indicates that setbacks around risers are not effective for reducing other manure contaminants. Sediment loss can be reduced with manure application. Setbacks around risers of tile-outlet terrace systems are ineffective in reducing P in runoff.

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