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ScienceDirect
Bioresource Technology 99 (2008) 3224–3232
BIORESOURCE TECHNOLOGY

Runoff and drainage water quality from geotextile and gravel pads used in livestock feeding and loafing areas ☆

Anshu Singh *, José R. Bicudo [1], Stephen R. Workman

Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, KY 40546, United States

Received 24 February 2005; received in revised form 21 May 2007; accepted 22 May 2007
Available online 1 August 2007

Abstract

Geotextile and gravel pads offer a low-cost alternative to concrete for providing all-weather surfaces for cattle and vehicle traffic, and are used in many livestock facilities to minimize mud, runoff and erosion of heavy traffic areas. The objective of this study was to compare different combinations of geotextile and gravel used in heavy livestock traffic areas that minimize the potential for water pollution. Three different pad combinations were constructed in 2.4×6-m plots as follows: (i) woven geotextile + 100 mm of gravel + 50 mm Dense Grade Aggregate (DGA); (ii) woven geotextile + geoweb® + 100 mm DGA; and (iii) non-woven geotextile + 152 mm of gravel + 50 mm DGA; (iv) mud lots as control. The third combination was equivalent to one of the base treatments specified by the Kentucky Natural Resource and Conservation Service (NRCS). All treatment combinations were duplicated. Lysimeter pans were installed in four out of eight plots for the collection of leachate or drainage water. Runoff was collected at the lower end of the plots. About 14 kg of beef cattle manure were added evenly to the plots. Rainfall at 50 mm/h was applied using rainfall simulators. In the first five of ten experiments, manure was removed from the surface of the pads after each experiment. In the remaining five experiments manure accumulated on the surface of the pads. The effect of pad treatment was significant on the electrical conductivity (EC), total solids (TS), chemical oxygen demand (COD), nitrite (NO_2–N), total nitrogen (TN) and total phosphorus (TP) values in surface runoff at the 5% level. Manure removal did not have any significant effect on the nutrient content of runoff or leachate samples except for ammonia (NH_4–N) values. Although a mass balance indicated relatively small amounts of organic matter and nutrients were lost by runoff and leaching, the actual contamination level of both runoff and leachate samples were high; TP levels as high as 12 mg/l (5.4 mg/m^2) in runoff and nitrate (NO_3–N) values as high as 10.8 mg/l (1.6 mg/m^2) in leachate were observed.

Keywords: Cattle; Manure; Organic material; Nutrients; All-weather surfaces

1. Introduction

Many beef and dairy cattle operations make use of holding pastures for winter-feeding or calving, and loafing lots. These areas usually have high animal densities and can be a source of surface and groundwater contamination. The runoff and the leachate that percolates through the soil column are a rich source of phosphorus and nitrogen. Nitrogen is lost to surface water as ammonium-nitrogen or as nitrate through leaching. Increasing nitrate content in surface (Heathwaite, 1993; Mueller et al., 1995; Howarth et al., 1996) and ground water (Burkart and Stoner, 2002; Kranz et al., 1998; Nolan and Stoner, 2000) has been a national trend in recent years. Excessive levels of nitrate in drinking water can lead to adverse human health impacts such as infant methemoglobinemia ('blue baby' syndrome-Royal Commission on Environmental Pollution, 1979; WHO, 1985). Phosphorus, on the other hand, is recognized as the primary factor for the eutrophication of surface water bodies which results in adverse impacts such as

☆ The information reported in this paper (No. 05-05-019) is part of a project of the Kentucky Agricultural Experiment Station and is published with the approval of the Director.

* Corresponding author. Tel.: +1 859 257 3000; fax: +1 859 257 5671.
E-mail address: asingh@bae.uky.edu (A. Singh).
[1] Present address: CH2M Hill Canada Limited, 180 King St S, Suite 600, Waterloo, ON, Canada N2J 1P8.

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doi:10.1016/j.biortech.2007.05.065

fish kills, reduced biodiversity, objectionable tastes and odors, increased drinking water treatment costs and the growth of toxic organisms. Although it has been estimated that most phosphorus is lost via overland flow (McDowell et al., 2002), the movement of phosphorus through the soil profile can be significant for soils that have very low sorption capacity (i.e. soils low in clay, iron and aluminum oxides, and carbonates) (McGechan, 2002). In addition, heavily used areas can become muddy during wet weather, which limits equipment mobility, affects animal performance (Riskowski and DeShazer, 1976; Degen and Young, 1993; Fox and Tylutki, 1998), and contributes to erosion and reduced environmental quality (Younos et al., 1998).

Geotextile and gravel pads offer a low-cost alternative to concrete for providing all-weather surfaces for cattle and vehicle traffic, and for feeding/loafing areas (Turner, 1996, 1997; Janni et al., 1999). These pads have been used with success in many dairy and beef facilities in several states. Producers have enthusiastically adopted pads for heavy use areas, and cost share programs have enhanced the rapidness of adoption. Geotextile fabric applications in agriculture are designed to keep soil and gravel (or other earthen materials) separate. The fabric improves stability, load bearing capacity, filtration, and drainage of the site.

Special considerations may need to be made in areas where livestock manure is stored or deposited and the soil material underlying or adjacent to the geotextile fabric is permeable. Since the fabric improves drainage, there may be some potential for rapid movement of manure, nutrients, and bacteria into the surrounding soil and possibly into an adjacent water supply.

Studies with cattle manure (total solids between 1 and 7.5%) showed some clogging of geotextile specimens while in direct contact with manure (Barrington et al., 1998), indicating potential transformation of geotextiles into a seal or barrier to groundwater pollution. Barrington et al. (1995) also investigated the sealing efficiency of several organic liners and found that a liner made of 15% straw and 85% beef cattle manure gave the lowest seepage rate.

Bicudo et al. (2003) have recently conducted a pilot-scale study to determine the effect of different geotextile and gravel layer combinations on the vertical movement of water and contaminants (total solids – TS, and chemical oxygen demand – COD) from beef cattle manure. Different combinations of geotextile, geoweb®, gravel, and dense grade aggregate (DGA) resulted in significant attenuation of both TS and COD material contained in beef cattle manure. The amount of organic matter and solids found in the leachate ranged between 1200 and 1300 g/l of COD, and between 1700 g/l and 2270 g/l of TS for all treatments. Significant increase in TS and COD in the drainage water was observed when high levels of manure and rainfall were combined. Goode (2003) reported additional results from the same pilot-scale study including leachate characteristics in terms of nutrients and fecal coliforms. Treatment combinations of geotextile and gravel pads did not significantly affect most nutrients (nitrogen and phosphorus) and fecal coliforms contained in the leachate from the pads. However, column treatment was statistically significant in predicting NO_3–N ($p < 0.10$) found in the leachate. A treatment consisting of non-woven geotextile, geoweb®, and 10 cm DGA resulted in the highest amount of NO_3–N in the leachate (0.34 mg/m^2), whereas a treatment consisting of woven geotextile, 100 mm gravel, and 50 mm DGA resulted in the least amount among all treatments (0.29 mg/m^2). Ranking of overall results (including eight different parameters) made by Goode (2003) indicated the most effective pad combinations that would minimize groundwater pollution to be: (i) either woven or non-woven geotextile fabric; (ii) a layer of 152 mm of DGA; or (iii) geoweb® filled with 100 mm of DGA.

Although deeper layers of DGA can minimize the potential for groundwater pollution as contaminants are more efficiently retained in the pad profile, the material can be rapidly compacted by animal or farm vehicle traffic when the geoweb® is not used. The geoweb® generates lateral confinement forces and soil-to-geogrid friction. Together these mechanisms create a conduit structure, which improves long-term load deformation performance of common granular fill materials. Compaction of the unconfined DGA layer may lead to increased potential for runoff pollution. Addition of a gravel layer between the fabric and DGA would help improve pad strength and drainage properties.

Currently there are no available data in the literature related to runoff and drainage characteristics of geotextile-gravel pads. The objective of our study was to determine the combinations of geotextile, geoweb® and gravel/DGA that result in the least polluted runoff and leachate when pads are subjected to moderate to heavy rainfall and different manure loads.

2. Methods

2.1. Experimental design

A set of field experiments were conducted to test four different geotextile and gravel pad combinations in a randomized block design. Treatments were as follows: (1) Geotextile (woven 2002) + Geoweb® + 100 mm of DGA (GGD); (2) Geotextile (woven 2002) + 100 mm Gravel + 50 mm of DGA (GgD); (3) Geotextile (non-woven 4506) + 152 mm Gravel + 50 mm of DGA (NRCS); (4) Control – Mud Plot (C). Treatments were chosen on the basis of earlier pilot-scale experiments reported by Bicudo et al. (2003) and Goode (2003). Treatment (3) consists of one of the base treatments recommended by the Kentucky Natural Resources Conservation Service (KY NRCS, 1998). A mud plot was used as control. All treatments were replicated twice.

Beef cattle manure was added to the pads before each experiment. Two different types of manure application were used. In the first five experiments, manure was removed from the pads between each experimental run (manure removal test). In the remaining five experiments, new manure was added between each experimental run and allowed to accumulate on the surface of the pads (manure accumulation test).

2.2. Pad construction

Experiments were performed using eight plots measuring 2.4 by 6.1 m, constructed on a Maury silt loam soil at the University of Kentucky Maine Chance Farm. The plots had a uniform 3% slope along the major axis and were cross-leveled along the minor axis.

Each plot was bordered with galvanized iron (100 mm above and below the ground surface) to isolate runoff, and with wood boards to hold gravel and DGA in place. A gutter was installed across the lower end of each plot to concentrate runoff for measurement and sampling. Discharge from the gutter entered a 50 mm i.d. length of polyvinyl chloride (PVC) pipe and emptied approximately 450 mm above the bottom of a sump. Each sump was lined with 300 mm i.d. Advanced Drainage Systems (ADS) corrugated plastic tubing; each sump bottom consisted of a 300 mm i.d. ADS end cap.

A lysimeter pan, measuring 0.88 m by 1.37 m, was installed in the center of the plot at a depth of 38 mm from the surface before adding geotextile fabric, geoweb®, gravel and DGA. The lysimeter pans were only installed in four plots, so there was no replication. Leachate was collected through a 6.2 mm i.d. length of tygon tube and emptied into the sump.

Runoff and leachate were sampled from the PVC pipe and tygon tube, respectively, and before reaching the bottom of the sump. Unsampled runoff and leachate discharged through a 100 mm diameter hole in the sump bottom and exited the research site through an adjacent drainage system (Fig. 1).

2.3. Beef cattle manure characteristics

Manure was applied on each plot to simulate a stocking density of approximately 6 beef cattle being on the pad for 4 hours per day. A manure application rate of 13.62 kg/plot was used, based on a solid manure production rate of 14.7 kg/head-day (MWPS, 2000). Manure was obtained from open lots located at the University of Kentucky Animal Research Center in Woodford County, KY, a day prior to the run. The manure was stored in a cold room (about 4 °C) prior to the experiments in the field and was thoroughly mixed before application on pads.

Table 1 shows the characteristic of the beef cattle manure used on each experiment. A wide variation in manure characteristics, especially COD and nutrient contents was observed even though manure was collected from the same location each time. Compared to ASAE Standards (1999, 2005), pH and TP values were higher whereas, COD and total solids were lower.

2.4. Runoff and leachate collection and analysis

Three rainfall simulators were used to generate runoff, each capable of applying from 0–120 mm/h to one 2.4 by 6.1 m plot. The simulator design operates on the same principle as that described by Miller (1987), but provides greater area coverage as described by Edwards et al. (1999). The plots were pre-wetted before applying manure, by applying a simulated rainfall rate of 50 mm/h for 30 min or until runoff occurred. Simulators were shut off and manure was then applied manually on the plots. Rainfall simulators were started again at 50 mm/h rate after runoff which had occurred during the pre-wetting process had completely stopped.

Runoff and leachate were sampled (approximately 1 L sample size) at 2, 4, 6, 8, 16, 24 and 32 min and 1.5, 3.5, 5.5, 7.5, 15.5, 23.5 and 31.5 min, respectively. Samples were collected by inserting clean polyethylene bottles (1 L volume) underneath the stream of runoff exiting the gutter or the stream of leachate exiting the lysimeter. Sample collection was for a period of 60 s or until the container was filled, whichever occurred first. The times required to collect individual samples were measured with a digital stopwatch (0.01 s precision) to enable computation of runoff rates.

All samples were cooled immediately after sampling and kept at around 4 °C, and were analyzed within 24 h. Water samples were analyzed for pH, electrical conductivity (EC), fecal coliform (FC), total solids (TS), chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen (NH_4–N), nitrate nitrogen (NO_3–N), nitrite nitrogen (NO_2–N), total phosphorus (TP) and orthophosphate (Ortho-P). Fecal coliform were analyzed within 4 h of sample collection. The analyses of pH, EC, FC, COD and TS were conducted in the Biosystems and Agricultural

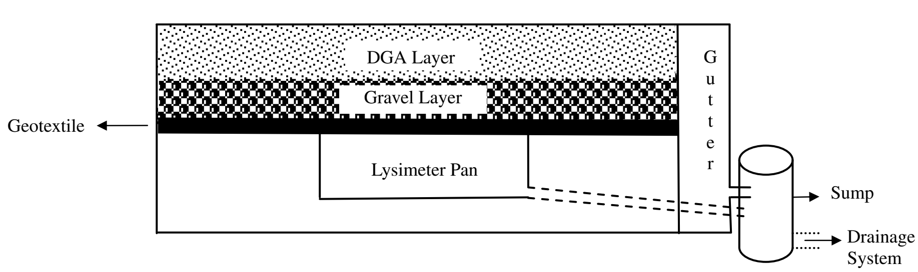

Fig. 1. Cross-sectional view of the plot.

Table 1
Composition of beef cattle manure

Type of experiment	Experiment number	pH[a]	EC[a] (mS/cm)	MC[b] (%)	TS[a] (mg/l)	COD[a] (mg/l)	TAN[b] (mg/kg)	TN[b] (g/kg)	TP[b] (g/kg)
Manure removal at the end of experiment	1	8.92	0.88	63.9	1249	1007	430	20.1	6.67
	2	8.96	0.66	76.4	2234	4064	347	23.5	8.01
	3	8.64	0.85	78.3	2658	4285	513	22.7	9.10
	4	8.59	0.47	72.8	1533	2357	546	12.8	5.45
	5	8.60	0.51	74.8	2697	3572	927	10.4	4.68
Manure accumulation	1	8.64	0.85	78.3	2658	4285	513	22.7	9.10
	2	9.14	0.63	74.2	1646	2595	285	23.1	9.39
	3	9.06	0.61	77.6	1792	4159	133	22.0	9.27
	4	8.16	1.01	78.4	4585	4448	969	24.7	11.7
	5	8.41	0.71	72.4	1370	2881	271	25.9	12.2

EC – electrical conductivity; MC – moisture content; TS – total solids; COD – chemical oxygen demand; TAN – total ammoniacal nitrogen; TN – total nitrogen; TP – total phosphorus.
All results are based on wet weight except TN and TP which are on dry basis.
[a] Parameters analyzed using manure blends prepared with 100 g manure and 1900 ml of distilled water.
[b] Parameters analyzed using raw manure.

Engineering Department Water Quality Laboratory according to Standard Methods (APHA et al., 1999). All nutrients were analyzed at the Department of Agronomy using a microplate reader technique developed at University of Kentucky (Crutchfield and Burton, 1989; D'Angelo et al., 2001). Ammonia, nitrites, nitrates, and orthophosphates were determined after filtration of samples using a filter of 0.45 mm pore diameter.

One flow-weighted composite runoff sample was made from six individual samples for a particular plot. A flow-weighted composite leachate sample was similarly made. Runoff and leachate volumes were calculated by numerically integrating runoff and leachate rates with respect to time. Mass values were obtained by multiplying the concentration of each constituent by the respective runoff or leachate volume.

2.5. Infiltration rate determination

Infiltration rate was calculated using Horton's equation (Haan et al., 1994)

$$\mathrm{f_h}(t) = \mathrm{f_c} + (\mathrm{f_o} - \mathrm{f_c})\mathrm{e}^{(-kt)}, \quad (1)$$

where $\mathrm{f_h}$ is the infiltration rate, ml/m^2-h; $\mathrm{f_c}$ is the steady-state infiltration rate, ml/m^2-h; $\mathrm{f_o}$ is the initial infiltration rate, ml/m^2-h; k is an empirical constant; t is time, h.

Initial infiltration rate and the empirical constant were calculated from regression analysis. Infiltration rate was calculated using t as 31.5 min as steady-state infiltration rate was obtained only after about 31.5 min of simulated rainfall.

2.6. Statistical analysis

All statistical analyses were conducted using MINITAB® Statistical Software (2000). The experimental design was completely randomized, consisting of four treatments, with weekly manure removal or accumulation. Least square mean was used to determine the differences between the treatments. Analysis-of-variance (ANOVA) was performed using the general linear model procedure to determine the effect of manure removal and accumulation, and treatments on the pH, EC, FC, COD, TS and nutrient contents of water samples. All interaction combinations of the main effects were also included in the ANOVA to help account for data variability. A significance level of 5% was used throughout the analysis. The following statistical model was used

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_i j + E_{k(ij)}, \quad (2)$$

where μ is the treatment mean, α is the geotextile pad treatment, β is the manure removal/accumulation, E is the error term, i is the geotextile pad treatment level (1, 2, 3, 4), j is the manure level (1, 2), k is the number of replicates.

3. Results and discussion

3.1. Infiltration rates

Infiltration rates varied between 300 and 1651 ml/m^2-h throughout the experiments, for both manure removal and manure accumulation tests. Neither different pad treatments nor weekly removal or accumulation of manure influenced the pads' infiltration rates significantly. Mud plots had the least infiltration rate with or without manure accumulation. The GGD treatment had the highest infiltration rate during weekly manure removal experiments (Fig. 2).

NRCS treatments had the highest infiltration rate during manure accumulation experiments, up to 1651.44 ml/m^2-h after 31.5 min (data not shown). We expected the infiltration rate to decrease with time due to potential clogging of the geotextile fabric, as observed by Barrington et al. (1998) when evaluating the use of geotextile fabrics as manure storage liners, but no trend in infiltration rate with time was detected in our study.

3.2. Runoff

The effect of manure application on runoff NH_4–N, TN, and TS was statistically significant. Runoff EC, COD, NO_2–N, TP, and TS were also significantly affected by geotextile pad treatment (Table 2). Some of the highest runoff TP and TS mass values were obtained from control muddy plots with either manure removal or accumulation (Figs. 3 and 4). The GGD and NRCS treatments resulted in almost 50% reduction in runoff TP as compared to the mud plots when manure was removed weekly (Fig. 3). Both these treatments were similar in reducing runoff TS (Fig. 4). The wide variation in runoff TS between pad treatments and the mud plots is most likely due to transport of appreciable amounts of soil particles in runoff.

Mean runoff TN mass values from different treatment pads varied between 4.35 and 16.9 mg/m^2 (10.4 and 36.5 mg/l), with comparatively lower values obtained during manure accumulation experiments. The two pad treatments that resulted in the lowest TN runoff values were GGD and NRCS for either manure removal or accumulation tests. Runoff NH_4–N followed the same trend as TN, i.e. values ranged from 0 to 4 mg/m^2 (0–4.6 mg/l) with lower values obtained during the manure accumulation period. The observation that TN and NH_4–N runoff values were lower during manure accumulation might be

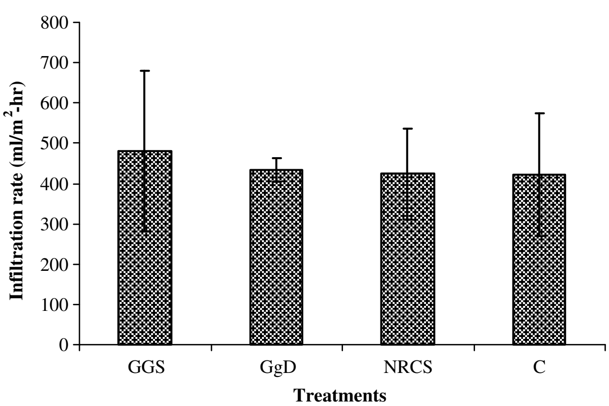

Fig. 2. Infiltration rate of pads with treatments for weekly manure removal. Bars represent standard error.

Table 2
Significance levels (*p*-value) of the main effects of treatments and manure application (with and without accumulation) on pH, EC, FC, COD, TS, NO_2–N, NO_3–N, NH_4–N, TN, Ortho-P, and TP content of runoff and leachate samples

Sample ID	Parameter	Effect*		
		Treatment	Manure	Treatment × manure
Runoff	pH	0.311	0.380	0.643
	EC	**0.006**	0.454	0.832
	FC	0.967	0.079	0.988
	COD	**0.021**	0.861	0.770
	TS	**0.001**	**0.008**	0.918
	NO_2–N	**0.004**	0.953	0.940
	NO_3–N	0.178	0.312	0.519
	NH_4–N	0.100	**0.001**	0.281
	TN	**0.011**	**0.041**	0.306
	Ortho-P	0.165	0.288	0.946
	TP	**0.001**	0.498	0.555
Leachate	pH	0.670	0.692	0.802
	EC	0.380	0.688	0.920
	FC	0.380	0.688	0.920
	COD	0.401	0.343	0.429
	TS	0.215	0.781	0.275
	NO_2–N	0.829	0.157	0.815
	NO_3–N	0.928	0.279	**0.046**
	NH_4–N	0.491	**0.001**	0.408
	TN	0.122	0.404	0.912
	Ortho-P	0.356	0.931	0.993
	TP	0.073	0.947	0.890

* Values in bold are significant at the 5% level.

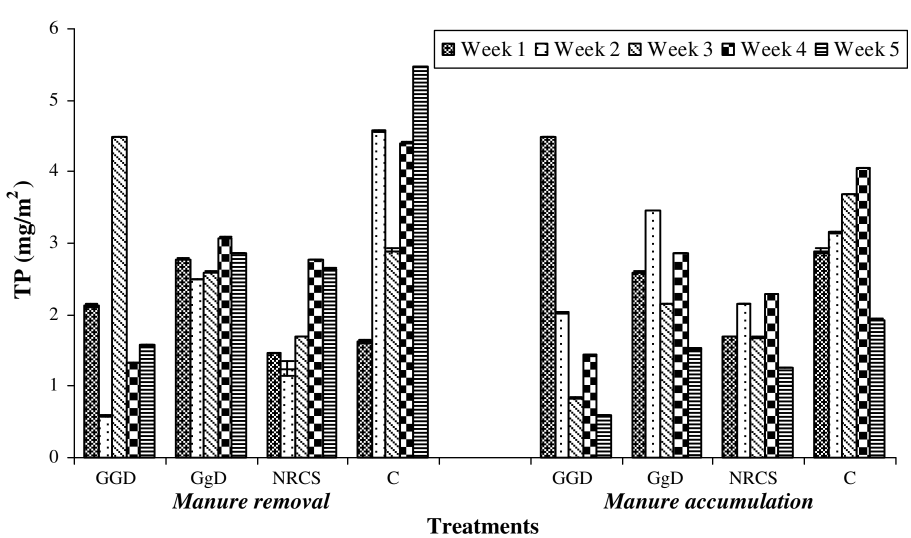

Fig. 3. Runoff total phosphorus (TP) with treatments and time, with or without manure removal. Bars represent standard error.

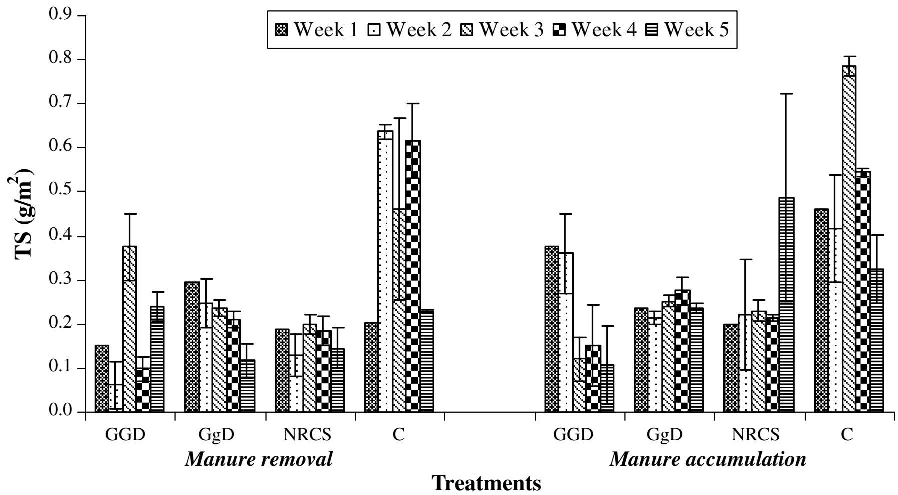

Fig. 4. Runoff total solids (TS) with treatments and time, with or without manure removal. Bars represent standard error.

explained by the higher potential for ammonia volatilization when manure was accumulated on a weekly basis.

The GgD and NRCS treatments resulted in the highest NO_2–N runoff values (between 0.01 and 0.2 mg/m^2 or 0.014 and 0.48 mg/l). NO_3–N values were as high as 34 mg and 3.9 mg/m^2 (0.05 mg/l and 8.3 mg/l) for the mud and NRCS treatments, respectively, although no significant effects of pad treatments or manure removal on NO_3–N were observed.

The COD content of runoff was significantly affected by the geotextile-gravel pad treatments. COD values ranged between 14 and 31.2 mg/m^2 (30 and 69.5 mg/l) and were 34% higher in average for the GGD treatment in relation to the mud plot COD runoff values. The organic matter may get entrapped in the surface layers of the soil profile, thus resulting in lower COD values in runoff from the mud plots as compared to all-weather surface pad types.

Manure accumulation or weekly removal did not have any significant effect on FC in runoff (Table 2). In the case of weekly manure removal, the average FC numbers varied from 11×10^4 to 168×10^4 per 100 ml in all treatments, while in control plots (with mud) FC numbers averaged 11×10^4 per 100 ml. As expected, accumulation of manure resulted in considerable increase of FC values, but no particular trend was observed. In both types of manure application experiments, the GgD treatment produced the highest number of FC in runoff, whereas the GGD treatment produced lower FC numbers as compared to the control muddy plots.

Our results indicate that the GGD treatment seems to be the best option to reduce the potential for runoff pollution from heavy livestock traffic areas.

3.3. Leachate

As mentioned before, leachate samples were collected from only one plot for each type of pad treatment. Since there was no replication, results presented are of limited statistical value. Leachate TN values from treatment pads varied from 0.3 to 7 mg/m^2 (1.8–53 mg/l). Leachate from mud plots had TN contents varying between 1.7 and 3.8 mg/m^2 (13 and 19 mg/l). No significant effect of pad

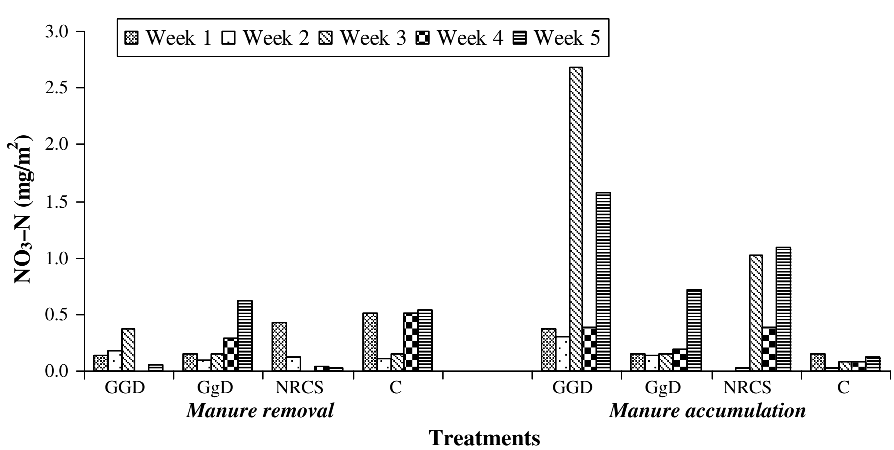

Fig. 5. Leachate NO_3–N with treatments and time, with weekly manure removal and accumulation (no replicates).

treatment or manure removal on leachate TN was observed. NO_3–N levels varied from 0.004 to 0.62 mg/m^2 (0.03–4.4 mg/l) for manure removal experiments, and from 0.03 to 2.7 mg/m^2 (0.3–21 mg/l) for manure accumulation experiments. The effect of pad treatment and manure interaction was significant on leachate NO_3–N values (Table 2). Mud plots generated leachate with the highest NO_3–N levels during manure removal experiments (between 0.1 and 0.5 mg/m^2 or 0.8 and 5.6 mg/l), while the GGD treatment generate leachate with the highest NO_3–N levels during manure accumulation experiments (between 0.3 and 27 mg/m^2 or 2 and 21 mg/l) (Fig. 5).

As shown in Fig. 5, the potential for nitrate leaching decreased when manure was removed from the pads on a weekly basis. Higher nitrification rates in the mud plot might have resulted from existence of more developed nitrifying bacteria colonies within the soil profile and difficulty in removing manure from the soil surface as compared to the DGA surfaces. As manure loading increased on a weekly basis, there was more potential for organic nitrogen to be converted to NH_3–N by bacteria, resulting in higher loss of nitrogen by volatilization as mentioned before. But at the same time, two other processes might be occurring: (i) as NH_4–N leached through the profile, part of it became chemically immobilized due to reactions with the minerals contained in the gravel, DGA, and soil profiles; and (ii) NH_4–N was converted to NO_2–N and NO_3–N. Because manure was left on the surface of the pads for a longer time, it was likely nitrifying bacteria population had time to develop (i.e. get over lag phase), especially within gravel and DGA profiles due to larger pore sizes and better air entrapment than within the soil profile of the mud plot.

Geotextile-gravel pad treatments and manure accumulation did not have significant effect on leachate Ortho-P and TP values (Table 2). TP varied between 0.08 and 1.2 mg/m^2 (0.56 and 2.6 mg/l). Mean TP values were almost 60% lower for the NRCS treatment as compared to the mud plots during weekly removal of manure experiments. Manure accumulation over time increased the leachate TP concentration in control muddy plots up to 67% over other pad combinations (data not shown). Similar trends were observed for leachate Ortho-P values.

The GGD treatment was highly ineffective in trapping TS within the pad profile with or without manure removal (Fig. 6). Leachate TS values ranged between 0 and 0.21 g/m^2 (0 and 475 g/l) in different treatments. Most of the leached TS were likely composed of dissolved salts and minerals, which might have increased with manure accumulation. However leachate EC values did not vary much with either time or manure accumulation (data not shown), thus indicating that the level of dissolved salts in leachate were kept reasonably constant. Higher porosity of DGA and gravel material might have contributed for the transport of suspended matter through the pad profile. Leachate TS generated through the NRCS treatment pad were 72% and 22% lower than leachate TS values generated through the GGD and mud plot treatments respectively, during manure removal experiments. When manure was left to accumulate on pads, the GgD pad seemed to be the most effective treatment combination as far as TS content was concerned.

Leachate COD increased slightly with manure accumulation, but no significant effects of pad treatments was observed (Table 2). COD values were as high as 27 mg/m^2 (61.3 mg/l) during manure accumulation experiments. Leachate from geotextile-gravel pads tended to contain more COD than the mud plot. This was probably due to the higher porosity of DGA and gravel material as compared to the soil characteristics and profile of the mud plot.

FC numbers were greatly reduced in the leachate as compared to runoff samples. Leachate FC numbers varied from 7 to 115 CFU per 100 ml in different treatments (data not shown). Manure accumulation or weekly manure removal did not have any significant effect on number of fecal coliforms in the leachate samples (Table 2). The GGD treatment resulted in the highest FC values in leachate during manure removal experiments (60 to 115 CFU per 100 ml), while the NRCS treatment resulted

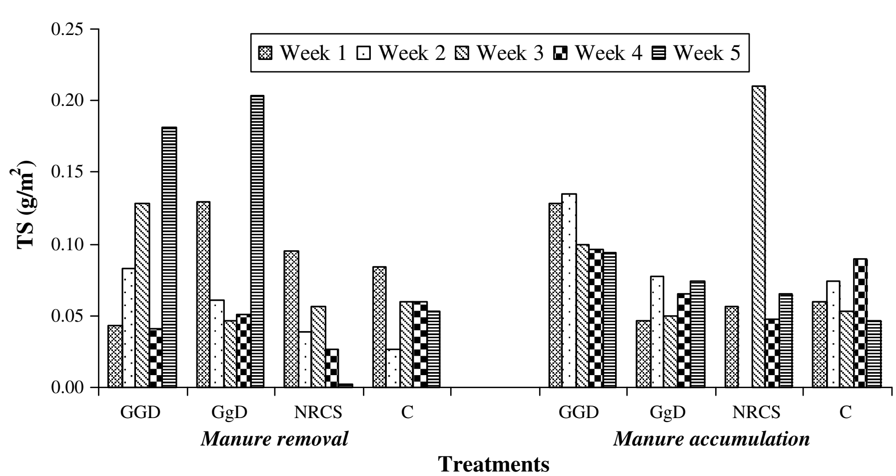

Fig. 6. Leachate TS with treatments and time, with weekly manure removal and accumulation (no replicates).

in the lowest FC values in leachate (7 to 59 CFU per 100 ml). Leachate from the mud plot had the highest FC levels (43 to 100 CFU per 100 ml) during manure accumulation experiments. The efficiency of the NRCS treatment in trapping FC was lower during manure accumulation as compared to manure removal experiments.

3.4. Mass balance

A mass balance was performed to estimate actual losses in COD and nutrients from treatment pads and mud plots. Average values were calculated from manure removal experiments and cumulative values from manure accumulation experiments. Losses in terms of nutrient mass, COD and total solids were similar in all treatments and did not differ with weekly manure removal or accumulation. Over 99.8% of nutrients were retained on the surface of the pads with part being volatilized to the atmosphere, about 0.2% were lost by runoff and about 0.04% leached through the pads. About 92.7% of COD was retained on the surface of the pads, 5.5% were lost by runoff, and 1.8% leached through the pads. Although relatively small amounts of organic matter and nutrients were lost by runoff and leaching, the actual contamination level of both runoff and leachate samples can be high as shown in the previous sections of this paper.

3.5. Economics

The cost of high traffic area pad with geotextile is approximately $\$0.80/ft^2$. This includes the cost of geotextile filter fabric ($\$0.06/ft^2$). Rock base (No. 4 crushed limestone; $\$0.25/ft^2$), densely graded aggregate ($\$0.14/ft^2$) and labor ($\$0.35/ft^2$). On the other hand, a concrete pad costs about $\$4.00/ft^2$. Costs can be kept down in several ways. The key factor to successful construction is the use of a geotextile layer. By using the geotextile, the depth of the rocks needed for stability is roughly cut in half thus reducing the cost.

4. Conclusions

The following conclusions were drawn from results obtained in this study. Manure removal did not have any significant effect on nutrient content of runoff or leachate samples except for NH_4–N mass values. The effect of pad treatment was significant on the runoff EC, TS, COD, NO_2–N, TN and TP values ($p < 0.05$). Runoff FC values (over 10^5 CFU per 100 ml) were significantly higher than leachate FC values (less than 10^2 CFU per 100 ml) for all pad treatments. The GGD treatment appeared to be the best option to reduce the potential for runoff pollution from heavy livestock traffic areas. The GgD treatment was likely the best option to reduce the potential for groundwater pollution from heavy livestock traffic areas. Although relatively small amounts of organic matter and nutrients were lost by runoff and leaching, the actual contamination level of both runoff and leachate samples can be high; TP levels as high as 80 mg in runoff and NO_3–N values as high as 40 mg in leachate were observed.

Acknowledgements

This project was funded through a Kentucky SB-271 Water Quality and Education grant. We would like to thank Lloyd Dunn, Douglas G. Oliveira, Charlie Dunn, John Barnett, Burl Fannin, and Frank Jones from the Department of Biosystems and Agricultural Engineering for helping with rainfall simulation and sample collection. We are also thankful to Jim Crutchfield who let us use his laboratory and methods to analyze nutrients in water samples.

References

APHA, AWWA, WEF, 1999. Standard Methods for Examination of Water and Waste Water, 20th ed. (on CD-ROM), Alexandria, VA.

ASAE, 1999. ASAE Standards, Manure Production and Characteristics, 46th ed. St. Joseph, MI.

ASAE, 2005. ASAE Standards, Manure Production and Characteristics, ASAE D384.2, St. Joseph, MI.

Barrington, S.F., Stillborn, R., Garcia Moreno, R., 1995. Organic liners for the sealing of earthen reservoirs. Bioresource Technol. 52, 101–107.

Barrington, S.F., El Moueddeb, K., Jazestani, J., Dussault, M., 1998. The clogging of nonwoven geotextiles with cattle manure slurries. Geosynth. Int. 5 (3), 309–325.

Bicudo, J.R., Goode, G.L., Workman, S.R., Turner, L.W., 2003. Vertical water movement through geotextile and gravel pads used in heavy livestock traffic areas. In: Proceedings of Ninth International Animal, Agricultural and Food Processing Wastes Symposium, Research Triangle Park, North Carolina, 12–15 October, pp. 364–371.

Burkart, M.R., Stoner, L.D., 2002. Nitrate in aquifers beneath agricultural systems. Water Sci. Technol. 45 (9), 19–29.

Crutchfield, J.D., Burton, H.R., 1989. Improved method for the quantification of nitrite in plant materials. Anal. Lett. 22 (3), 555–571.

D'Angelo, E., Crutchfield, J., Vandivere, M., 2001. Rapid, sensitive, micro scale determination of phosphate in water and soil. J. Environ. Qual. 30, 2206–2209.

Degen, A.A., Young, B.A., 1993. Rate of metabolic heat production and rectal temperature of steers exposed to simulated mud and rain conditions. Can. J. Anim. Sci. 73, 207–210.

Edwards, D.R., Moore Jr., P.A., Workman, S.R., Busheé, E.L., 1999. Runoff of metals from alum-treated horse manure and municipal sludge. J. Am. Water Res. Assoc. 35 (1), 155–165.

Fox, D.G., Tylutki, T.P., 1998. Accounting for the effects of environment on the nutrient requirements of dairy cattle. J. Dairy Sci. 81, 3085–3095.

Goode, G.L., 2003. Seepage quality from geotextile and gravel pads used in heavy livestock traffic areas. MS Thesis, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, KY, p. 95.

Haan, C.T., Barfield, B.J., Hayes, J.C., 1994. Rainfall-runoff estimation in stormwater computations. In: Design Hydrology and Sedimentation for Small Catchments. Academic Press, New York, pp. 38–103.

Heathwaite, A.L., 1993. Nitrogen cycling in surface waters and lakes. In: Burt, T.P., Heathwaite, A.L., Trudgill, S.T. (Eds.), Nitrate: Processes, Patterns and Management. Wiley, Chichester, pp. 99–140.

Howarth, R.W., Billen, G., Swaney, D., Townsend, A., Jaworski, N., Lajtha, K., Downing, J.A., Elmgren, R., Caraco, N., Jordan, T., Berendse, F., Freney, J., Kudeyarov, V., Murdoch, P., Zhao-Liang, Z.,

1996. Regional nitrogen budgets and riverine N and P fluxes for drainages to the North Atlantic ocean: natural and human influences. Boichemistry 35, 75–139.

Janni, K., Funk, T., Holmes, B., 1999. Using All Weather Geotextile Lanes and Pads. MidWest Plan Service AED-45, Iowa State University, Ames, IA.

Kranz, W.L., Kanwar, R.S., Pederson, C.E., 1998. Collection and monitoring of one-meter cubic soil monoliths for leaching studies. Trans. ASAE 41 (2), 333–344.

KY NRCS, 1998. Heavy use area protection. Conservation Practice Standard, Code 561. Kentucky Natural Resources Conservation Service, Lexington, KY.

McDowell, R., Sharpley, A., Withers, P., 2002. Indicator to predict the movement of phosphorus from soil to subsurface flow. Environ. Sci. Technol. 36 (7), 1505–1509.

McGechan, M.B., 2002. Sorption of phosphorus by soil, Part 1: principles, equations and models. Biosys. Eng. 82 (2), 1–24.

Miller, W.P., 1987. A solenoid-operated, variable intensity rainfall simulator. Soil Sci. Soc. Am. J. 51, 832–834.

Minitab, 2000. Minitab Release 13 for Windows®, Minitab Inc., State College, PA.

Mueller, D.K., Hamilton, P.A., Helsel, D.R., Hitt, K.J., Ruddy, B.C., 1995. Nutrients in groundwater and surface water of the United States – an analysis of data through 1992. USGS Water Res. Invest. Rep., 95–4031.

MWPS-18, 2000. Manure characteristics. Manure Management System Series, Section 1, MidWest Plan Service, Iowa State University, Ames, IA, p. 23.

Nolan, B.T., Stoner, J.D., 2000. Nutrients in groundwater of the conterminous United States, 1992–1995. Environ. Sci. Technol. 34, 1156–1165.

Riskowski, G.L., DeShazer, J.A., 1976. Work requirement for beef cattle to walk through mud. Trans. ASABE 19, 141–144.

Turner, L.W., 1996. Reducing Mud Using Highway-Type Filter Materials. Biosystems and Agricultural Engineering AEU-68, University of Kentucky, Lexington, KY.

Turner, L.W., 1997. Using Geotextile for Feeding and Traffic Surfaces. University of Kentucky Cooperative Extension Service AEN-79, Lexington, KY.

Younos, T.M., Mendez, A., Collins, E.R., Ross, B.B., 1998. Effects of a dairy loafing lotbuffer strip on stream water quality. J. AWRA 34, 1061–1069.