Control of pollutants using stand-off pads containing different natural materials

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Abstract

Farmers are increasingly using management systems such as moving cows out of paddocks onto stand-off pads to protect wet soils from damage during winter. Studies were carried out to investigate nutrient and faecal bacterial retention or loss from stand-off pad materials. A preliminary laboratory study found that a range of natural materials, including crushed pine bark, wood chips, zeolite and soil can retain between 66% and 76% of applied cows' excreta nitrogen (N). Zeolite was found to be particularly good at reducing ammonia (NH_3) volatilisation losses from the columns. A field-scale stand-off pad study at a Waikato dairy farm, in the winter season of 2005, indicated that carbon (C)-rich materials including both bark and sawdust can be used as stand-off pad materials with effective retention of N and faecal bacteria. Both bark and sawdust pads retained about 60% of deposited excreta N. Substantially more *Escherichia coli* were recovered in the drainage from the bark pad (total yield 3.1 x 10^{11} *E. coli*) than from the sawdust pad (total yield 7.5 x 10^{9} *E. coli*) demonstrating that sawdust was more effective than bark in retaining these faecal bacteria.

Keywords: stand-off pads, winter management, dairy, nitrogen, faecal bacteria, natural materials

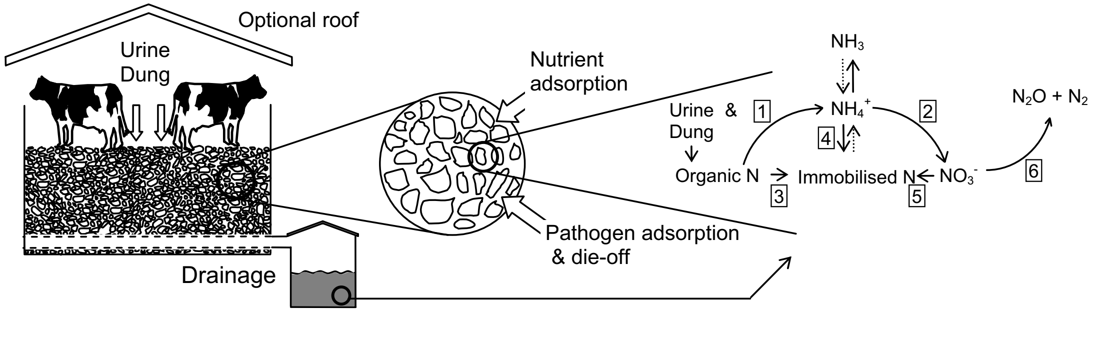
Introduction

When conditions are wet, grazing animals can cause soil physical damage and affect pasture production. To protect wet soils from damage some dairy farmers are moving cows out of paddocks including temporarily holding them on farm races, using "sacrifice" paddocks, or using specially constructed stand-off pads. These practices will be most successful if they also avoid gaseous losses and prevent the transfer of nutrients and faecal bacteria to the wider environment. Guidelines have been produced for the design and management of stand-off and feed pads (Dexcel 2005). These guidelines state that cows prefer soft surfaces such as woodchips so that they can lie down in comfort. Experimental studies are being carried out to develop effective stand-off pads constructed from natural materials on which cows can stand for extended periods of time when paddocks are not suitable for grazing (Fig.1). Important criteria for our studies were to achieve maximum environmental protection by the use of pad materials that are optimal for retaining nutrients and faecal bacteria from cows' excreta.

There are literature reports of the effectiveness of some materials for nutrient retention that could be potentially used in stand-off pads (e.g. Luo *et al.* 2004). When cow manure was mixed with pine bark, the bark was found to retain N, reduce gaseous losses including ammonia (NH_3) and hydrogen sulphide (H_2S) (Luo *et al.* 2004). This retention of N may be due to adsorption and/or immobilisation of N and sulphur (S) (e.g. points 3, 4 and 5 in Fig.1) by the C-rich bark material. Zeolite, an alumino-silicate mineral, has been used to retain cations and anions from wastewater (Nguyen & Tanner 1998) and may be a useful material to incorporate in pads.

Livestock manures contain a range of enteric microorganisms, some of which are infectious for humans as well as animals (Hutchison *et al.* 2004a), including *Campylobacter* (Ross & Donnison 2003), the most prevalent infectious microorganism in New Zealand. Studies have shown that enteric pathogens decline in stored manure slurry (e.g. Hutchison *et al.* 2004b) but that they are seldom completely eliminated (Avery *et al.* 2005) and moisture content is an important factor

Figure 1 Simplified diagram of a stand-off pad system.



controlling survival (Berry & Miller 2005). There are few reports of the effects of adding natural materials such as sawdust or wood chips to manure but Miller *et al.* (2003) tested faecal bacterial survival in pens to which either straw bedding or woodchip bedding was added. These workers found no bactericidal effect which they attributed to a low ratio of bedding to manure. Under wet conditions that generate overland flow, large numbers of microorganisms are transferred from faeces to waterways (Muirhead *et al.* 2005). A pad design that includes materials that maximise retention of bacteria, together with an efficient drainage collection system could allow time for bacterial die-off outside the soil/plant/water system and prevent transfer to waterways.

The success of stand-off pads depends on the effectiveness of pad materials in continuously retaining nutrients and pathogens. The retention of nutrients means that after the stand-off period, pad materials could be then used as fertiliser or be composted for gardening purposes. To be effective for this purpose, pad materials should be chosen for maximum nutrient retention, to enhance fertiliser value, but guidelines will be needed to ensure that faecal bacterial concentrations have been reduced to minimal levels at the time of use.

The objective of this study was to identify naturally available materials of sufficient supply and with high adsorption potential that would be suitable for use as pad materials. In this paper we present the results of two studies. Firstly a laboratory-scale study that was undertaken to evaluate the capacity of several potential stand-off materials to retain nutrients, particularly N. Secondly we present the results of a field-scale study carried out on a working dairy farm in which we compared two stand-off pads that differed only in their fill material, one being filled with bark and the other with sawdust.

Materials and methods

Laboratory-scale column study

The study of nutrient retention by natural materials consisted of 12 columns that were held in a constant temperature (10^{o}C) laboratory. Each column consisted of tested pad materials contained within an upright 300 mm tall ´ 300 mm internal diam. high density polyethylene (HDPE) pipe, sealed to a HDPE base plate. The columns were placed on a metal frame, which gave access to the drainage collection system. The rim of the columns extended about 70 mm above the material surface level to contain applied excreta.

The natural materials used in the column study were untreated pine bark and wood chips, natural zeolite and topsoil. The bark, wood chips, and zeolite had a size range of 4-10 mm. The soil used was Horotiu silt loam (allophanic soil) that had been passed through a 10 mm screen. There were three replicate columns for each of the four materials. A range of chemical characteristics for these materials are summarised in Table 1.

Table 1 Characteristics of natural materials used in the column study.

	Soil	Pine bark	Wood chips	Zeolite
Total N (%)	0.483	0.094	0.026	0
Organic C (%)	4.55	31.2	26.7	0
C/N ratio	9.4	323	1027	0
pH	5.4	5.1	5.3	5.4

Cow excreta (1:1 ratio of urine and dung) were applied to the columns every day for 5 weeks. Fresh excreta were collected early in the morning for each application. Samples (approx 100 g wet weight) were taken, stored and bulked on a weekly basis for chemical analysis. The excreta were applied daily onto the columns at a loading rate of 3.5 L/m^2 in accordance with a typical loading rate over 20 hours produced by the recommended number of cows on a stand-off pad (Dexcel 2003). The total amount of N applied during the 5 weeks was 403 g N/m^2. The columns were retained in the constant temperature laboratory for another 5 weeks to stimulate a likely holding period prior to field use (e.g. land application). After this 5 week period, representative samples were taken from each column for chemical analysis. In order to simulate rainfall, deionized water was added to each column twice a week. Over the 10 weeks of the trial, each column received a total of 330 mm of deionized water (about 16.5 mm per application). This amount of water was equivalent to the 75th percentile from local records for winter rainfall over the past 10 years.

Field-scale stand-off pad study

Two stand-off pads were constructed in May 2005 at Dexcel's Scott Farm, in the Waikato region. This farm is associated with the Resource Efficient Dairying (RED) farmlet systems trial (Clark 2003). The pads, each 20 m long, 7.5 m wide and 0.9 m deep, and with their own separate drainage system, contained either crushed pine bark (particle size 3-12 mm) or sawdust. Each pad was overlaid with about 0.1 m depth of coarse bark (particle size 12-25 mm). Pads were used for holding 21 cows for about 18 h a day during the winter period (31 May to early August) in 2005. Monitoring of pad performance was carried out regularly to determine N retention in pad materials and N and faecal bacteria losses into drainage water.

Methods of analysis

Volatilised ammonia from the laboratory columns over 24 hour periods were collected every week for the first 5 weeks of the trial. The samples were collected immediately following the application of excreta. Ammonia volatilisation was measured by placing clear acetate lids on the top of the columns and passing air through the lids. A fixed proportion of the air was then passed through dreshel bottles containing 0.0375M H_2SO_4 to trap any ammonia produced. The acid was analysed for ammonium using colorimetry.

To measure N in drainage water and natural materials, all drainage water was collected and the volumes recorded in both the column and field studies. Samples of the drainage were stored frozen until analysis. Drainage water was analysed for TKN, NH_4^+-N and NO_3^--N according to standard methods (APHA 1995). At the end of the column study, columns were dismantled and the materials were analysed for the same forms of N. The bark and sawdust materials were also sampled from the field stand-off pads when cows finished using the pads in August 2005, and analysed.

For faecal bacterial analysis, samples of natural materials were homogenised with buffer (0.1% peptone plus 0.85% NaCl). Drainage water samples were analysed without processing. Where required, samples were serially diluted in the same buffer. Bacterial analysis was by the five-tube most probable number (MPN) technique. The analytical procedures were those given in *MIRINZ Meat Industry Microbiological Methods 4th Edition* (AgResearch 2006). Specifically: *E. coli* was analysed by Method 12.3.3 and *Campylobacter* by applying a five-tube MPN format to Method 13.1.

Data analysis

The ammonia emission rates were integrated over time for each column in the laboratory column study to estimate the total emission over the measurement period. Drainage volumes and concentrations of TKN, NH_4^+-N, and NO_3^--N were used to calculate cumulative N in drainage water. Concentrations of N in materials were used to calculate amounts of cumulative N in materials. The data collected from the column study were analysed using ANOVA procedure to compare means for different materials. Paired Student's *t* test was used to compare amounts of faecal bacteria in bark and sawdust pad drainage water.

Results and Discussion

Laboratory-scale study

Cumulative volatilisation losses of NH_3 are presented in Table 2. Among the materials examined, zeolite was the most efficient in reducing NH_3 loss, and wood chips were the least efficient. The cumulative NH_3 volatilisation losses from the columns were in the following order: zeolite < bark ≤ soil ≤ wood chips. These NH_3 losses amounted to about 13%, 25%, 30% and 39% of the applied excreta N from columns containing zeolite, bark, soil and wood chips, respectively.

The effects of the different natural materials in reducing drainage N losses are also presented in Table 2. For columns containing soil, bark and zeolite, most of the losses were occurring when excreta was being applied during the initial 5 weeks. Most of N in drainage from zeolite, pine bark and wood chips was in the ammonium form (Table 2). Lower ($P<0.05$) amounts of N were found in the drainage from soil columns. After 10 weeks, the cumulative total N drainage losses from the columns were in the following order: soil < zeolite ≤ bark < wood chips. These losses were about 1%, 8%, 9% and 14% of total excreta N applied to the columns containing soil, zeolite, bark and wood chips, respectively.

Chemical analyses of materials suggested that significant amounts of N, ranging between 66% and 76% of applied excreta, had accumulated in zeolite, bark and soil (Table 2). About 35% of applied excreta N accumulated in the wood chips. Most of the N was retained in the top layers (0-75 mm) of all the materials (data not shown). The analyses also indicated that most of applied excreta P, K and S had accumulated in the bedding materials (data not shown). Some applied excreta N was not accounted for (Table 2), which was probably largely due to sampling and measurement errors.

The effects of natural materials in retaining N (Table

Table 2 Cumulative N in NH_3 gas loss, drainage and pad materials (g N/m^2) after total application of 403 g excreta N/m^2 in the column study (numbers in brackets are percent of N in applied excreta N).

	Zeolite	Bark	Soil	Wood chips	$LSD_{0.05}$
Ammonia N loss	53 (13)	101 (25)	121 (30)	157 (39)	43
Organic N in drainage	6.2 (1.5)	7.9 (2.0)	2.6 (0.6)	11 (2.7)	3.5
Ammonium N in drainage	24 (6.0)	26 (6.5)	1.1 (0.3)	43 (11)	4.6
Nitrate N in drainage	ud[1]	ud	0.3	ud	
Cumulative N in materials	267 (66)	270 (67)	305 (76)	139 (34)	41
Unaccounted for N[2]	53 (13)	-1.9 (0)	-27 (-7)	53 (13)	

[1] Under detection limits.
[2] Unaccounted for N was due to errors of sample collection and analysis.

2) can be attributed to enhanced microbial N immobilisation and/or direct absorption of ammonium ions (Bolan *et al.* 2004; Luo & Lindsey 2006). Bolan *et al.* (2004) have also demonstrated that treatment of farm effluent with pine bark achieves a considerable reduction in the N concentration, which they attributed to immobilisation of N by the C- rich bark material (C:N ratio = 265:1). Crushed pine bark and zeolite both have large total surface areas and cation exchange capacities (CEC). Ammonium ions, mineralised from cows' excreta, can adsorb onto these surfaces, thereby decreasing the quantity of dissolved ammonium ions and the quantity of equilibrated NH_3 gas available for ammonia volatilisation. This was demonstrated by lower NH_3 volatilisation losses from bark and zeolite columns, particularly from the zeolite column (Table 2). Sorption of odorous compounds, including NH_3 gas, by pine bark and zeolite has also been found to be an important mechanism in removal of odours by biofilters containing mixtures of bark and zeolite (Luo & Lindsey 2006). As wood chips generally have a smaller surface area than crushed bark they can retain fewer ammonium ions and organic N compounds, leading to more N losses through volatilisation and leaching (Table 2). Sawdust has similar properties to wood chips, but has a higher surface area. Therefore, sawdust could be another useful material for stand-off pads to reduce N losses. Soils can retain large proportions of N but generally have relatively low porosities and are prone to consolidation over time. These properties of soil can easily result in poor water drainage through the soil columns, and surface ponding could occur during wet winters. Ponding of the soil was observed during this column study. Due to their availability and the ability to retain N, the C-rich materials (including both pine bark and sawdust) were chosen for the field stand-off pad study.

Field-scale study

The results from the field stand-off pad study showed that both bark and sawdust retained a considerable amount of N from cows' excreta (Table 3). During the 2005 winter we estimated that about 170 kg of excreta N was deposited by the cows on each stand-off pad. However, only about 4% (6-6.6 kg N) of the deposited excreta N was collected in the drainage from the pads. Most of the N in the drainage was in the ammonium form (data not shown). Analyses of both fresh and used materials showed that both sawdust and bark retained about 60% of the deposited excreta N, most of which was recovered from the top layers. Mass balance calculation indicated that about 35% of the deposited excreta N was not accounted for in the pad materials and drainage. Other chemical analyses of materials also indicated that both sawdust and bark retained significant amounts of deposited excreta P, K and S (data not shown). In February 2006, 8 months after commencing use of the pads, there was no indication of any breakdown of the sawdust and bark materials within the pads. The results from the field study (Table 3) confirmed the findings from the column study (Table 2), further suggesting that the C-rich materials (bark and sawdust) can be used as stand-off pad materials for effective retention of N and other nutrients.

Retention and leaching of faecal bacteria

Escherichia coli are natural inhabitants of the large intestine of warm blooded animals including dairy cows and are consistently present in dung but not in urine. In this study, 21 cows used both the sawdust and the bark stand-off pads for 18 hours per day from the 31 May to early August 2005. This equated to a total of 664-cow days on each stand-off pad and a daily deposition of about 20 kg of dung (AgResearch unpublished data) by each cow. The average concentration of *E. coli* in the faeces deposited on the pads was 2.4×10^8/kg wet weight giving a calculated total of 3.2×10^{12} *E. coli* deposited on each pad. Drainage was collected and analysed on a weekly basis. More *E. coli* were consistently recovered in bark pad drainage than in sawdust pad drainage as shown in Figure 2 and this difference was statistically significant ($P<0.05$). The total yield of *E. coli* during this period was 7.5×10^9 *E. coli* in the sawdust pad drainage and 3.1×10^{11} *E. coli* in the bark pad drainage. Using these data, we estimate the retention of *E. coli* to be 99.7% in the sawdust pad and 90.2% in the bark pad.

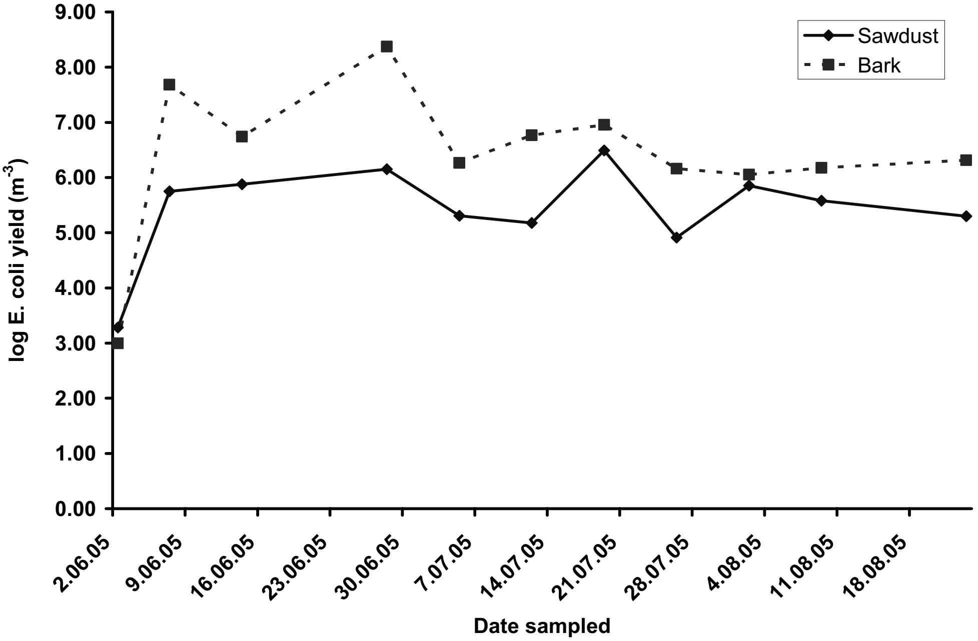
We also measured thermotolerant *Campylobacter*, a pathogenic faecal bacterial species commonly present in

Table 3 N balance after 21 cows had been held on stand-off pads in the winter (31 May to early August 2005) of 2005.

	Amount (kg N)		Recovery (%)	
	Sawdust	Bark	Sawdust	Bark
Deposited excreta N	170	170		
Drainage N	6.0	6.6	4	4
Accumulative N in materials	102	103	60	61
Unaccounted for N[1]	62	60	36	35

[1] Unaccounted for N was due to gaseous losses and/or errors of sample collection and analysis.

Figure 2 Recovery of *E. coli* in the cumulative drainage from the sawdust and the bark stand-off pads over the period (31 May to early August 2005) when 21 cows spent 18 h per day on the pads.



dairy cows, in the drainage from each pad. The total yield was 1.1 x10^7 *Campylobacter* in the bark drainage and 5.5 x 10^6 *Campylobacter* in the sawdust drainage. Although these differences are not statistically significant they follow the same pattern as *E. coli*, i.e. more *Campylobacter* were leached from the bark than from the sawdust pad.

After the cows were removed from the stand-off pads in August, we continued to collect drainage approximately monthly until 11 November 2005. Over the entire 5-month collection period, a total of 103 m^3 of drainage was collected from the sawdust pad and 107 m^3 from the bark pad. The total yield of *E. coli* in drainage collected after the cows had moved out was 2.1 x10^9 *E. coli* from the sawdust pad and 2.9 x 10^9 *E. coli* from the bark pad. In contrast to *E. coli,* no *Campylobacter* were recovered in the drainage from either pad during this period.

Stand-off pads efficiently capture a large proportion of faecal bacteria shed by cows. However, while the pads are in use, substantial numbers of both *E. coli* and *Campylobacter* are transported to the drainage. The pad materials retained large numbers of faecal bacteria and the continued recovery of *E. coli* in drainage liquid demonstrated that these bacteria remained viable for the two and a half month monitoring period after the cows had been removed.

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