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The effect of incorporating slurries on the transport of faecal coliforms in overland flow

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Abstract

The contamination of surface waters with pathogenic microorganisms transported from fields to which livestock slurries and manures have been applied is a serious environmental concern. Rainfall simulation experiments were conducted to test the hypothesis that the incorporation of slurry into the soil would reduce bacterial transport in overland flow. A sandy loam soil was packed into soil flumes (2.5 m long x 1 m wide) at a bulk density of 1400 kg m^{-3}. Cattle slurry was either spread onto the soil surface or uniformly incorporated into the soil at a rate of 30 Mg ha^{-1} (7.5 kg/plot). Simulated rainfall was applied to the plots at an intensity of 70 mm h^{-1}, using a pressure irrigation sprinkler. Presumptive faecal coliform (PFCs) concentrations were higher in the runoff from the surface applied treatment (concentration range 1.9×10^4 - 1.1×10^6 PFC 100 ml^{-1}) than from the incorporated treatments (concentration range 6.0×10^3 - 8.7×10^5 PFC 100 ml^{-1}). Rates of transport of organic sediment and PFCs were highest in the initial phase of each experiment and declined as the simulation proceeded. The transport of PFCs and organic sediment were strongly correlated (values of r ranged from 0.72-0.91), although there was considerable variation in this relationship from one experimental run to another. The implications of these findings for the protection of surface waters from pollution by bacterial contaminants are considered.

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Abbreviations*: PFCs:* presumptive faecal coliforms

Key words

Slurry, Faecal Coliforms, Pathogen transport, Overland Flow, Slurry Management, Diffuse pollution

Introduction

About 90 million tonnes of livestock slurry and manure are produced annually in the UK and this represents a significant resource for nutrient recycling via land application (Smith *et al.* 2001). However, the benefits of waste recycling may be partially offset by the risk of water pollution associated with runoff from fields to which slurry or manure has been applied (MAFF, 1998). In addition to the pollution threat posed by chemical components of animal faecal wastes such as readily biodegradable organic compounds, ammoniacal nitrogen and other nutrients, a proportion of livestock slurries and manures also contain pathogens such as *Listeria*, *Campylobacter*, *Salmonella*, *E. coli* 0157, *Cryptosporidium*, and *Giardia* (Nicholson et al., 2000). Thus, the contamination of surface waters with runoff from fields to which livestock wastes have been applied may lead to humans being exposed to such microorganisms via several routes. Examples include exposure to livestock waste derived pathogens via: drinking water (Ongerth and Stibbs, 1987; Hansen and Ongerth, 1991; Poulton *et al.*, 1991; Skerrett and Holland, 2000); bathing waters (Geldreich, 1996; Wyer et al., 1996; Baudart et al., 2000); and water used for the irrigation of ready to eat foods (Tyrrel, 1999). Given the potential impacts of surface water contamination by faecal organisms, managing the application of slurries and manures to soils to prevent the bacterial contamination of surface waters is of obvious importance.

Overland flow is an important pathway for the transport of pathogens to water and there is no shortage of work describing this, see for example Caskey *et al.*, (1971); Reddy *et al.*, (1981); Crane *et al.*, (1983); Sherer *et al.*, (1992); Coyne and Blevins, (1995); Daniel *et al.*, (1995);

Mawdsley *et al.*, (1996); Yeghiazarian and Montemagno, (2000), although there are contradictions. One debate centres on whether or not incorporation or injection will reduce pathogen losses. Daniel *et al*. (1995) found no significant differences in pathogen losses between surface applied and incorporated manure. Similar findings are reported by McCaskey *et al*. (1971) and Heinonen-Tanski and Uusi-Kämppä (2001) for injected and surface applied manures. We believe that these contradictory findings are due to the die off an growth of bacteria within the soil or on its surface prior to a runoff event, and that the incorporation of slurrues and manures will reduce the availability of bacteria for transport in overland flow if all other factors are constant. Our work therefore tests the hypotheses that the incorporation of slurries will lead to a reduced number of bacteria being detached and transported over the soil surface.

Material and methods

The study was performed in the laboratory using soil flumes set at a 5 % slope. The flume (Fig. 1) were 2.5 m long, 1m wide (across slope) and 30 cm deep, with a mesh screen located at the bottom of the slope to retain the soil, to allow drainage and thus to avoid the creation of saturated conditions.

Simulated rainfall was applied to the plots at an intensity of 70 mm h^{-1}, using a pressure irrigation sprinkler. We chose a high intensity storm to represent extreme conditions: a storm of this intensity for 15 minutes is estimated, using the method of Faulkner (1999) as having a return period of 14 years for Bedfordshire, in Southern England. The sprinkler had a nozzle (LECHLER GMbh 56072830-CE) positioned 2 m above the soil surface. Raindrop size ranged between 0.7 mm and 2.8 mm, with a D_{50} value of 1.2 mm.

A sandy loam textured soil (Table 1) of the Cottenham series defined by Clayden and Hollis (1984) and classified as Lamellic Ustipsamment (Soil Survey Staff, 1999) was used throughout the experiments. The soil was passed through a 9.5 mm sieve and packed into the flume at a bulk density of about 1400 kg m^{-3}. One day prior to each runoff experiment, the erosion plot was exposed to simulated rainfall, whilst protected with fabric to avoid soil detachment, and allowed to drain for 24 hours to give an initial soil moisture content close to field capacity.

Cattle slurry from a local dairy farm was applied to the soil at a rate of 30 Mg ha^{-1} (7.5 kg/plot), which is below the maximum value recommend (MAFF, 1998) and represents a normal application rate for many arable farmers in the UK. The dry solids content of the slurry ranged from 8-24%. Prior to application the number of presumptive faecal coliforms (PFCs) present in the slurry was enumerated. Ten g of moist slurry was added to 200 mL of sterile water and placed on a mechanical shaker for 20 min. This solution was serially diluted prior to enumeration of PFCs by membrane filtration (APHA, 1992). The result was expressed on a weight basis of slurry.

The soil slope was exposed to simulated rainfall within 24 h of the slurry application. For each simulation the time to runoff was recorded and then samples were taken every five minutes until runoff had reached a constant value. The sediment concentration was determined gravimetrically for each sample. The organic matter content of the sediment was determined by loss after ignition in a furnace at 550 °C for 4h. One aliquot of each runoff sample was separated for the microbiological analysis. This was analysed in triplicate following serial dilution by membrane filtration (APHA, 1992).

Results

Statistical analysis using the Kolmogorov-Smirnov test revealed that there was no significant difference ($p<0.1$) between the mean total runoff volume from the incorporated and surface applied plots during the 45 minute sampling period (Table 2). The total mass of mineral sediment transported was highest in the incorporated treatment whereas the total mass of organic sediment transported was highest in the surface applied treatment (Table 2). These differences between the concentrations of mineral and organic sediment in runoff from the two treatments were significant at the $p<0.1$ level. Mineral sediment concentrations were generally stable for both treatments throughout the duration of the experiment (Figure 2). All replicates are presented in this, and subsequent figures as samples were not taken at identical times and the results could not therefore be averaged. Although the three replicates for the surface applied treatment behaved similarly, one of the replicates for the incorporated treatment was inexplicably different from the other two. Differences were also observed in the concentrations of organic sediment in the runoff from the two treatments (Figure 3). Organic sediment concentrations were generally higher in the first 20 minutes of the experiment after which the concentrations were broadly similar for the two treatments. Organic sediment concentrations declined more gradually in the runoff from the incorporated plots and were generally less variable than in the runoff from the surface applied plots. The higher rate of organic sediment transport from the surface applied plots was also reflected in the mean total mass of organic sediment transported during the experiment (Table 2). The effect of simulated rainfall on the transport of faecal coliforms from the runoff plots can be seen in Figure 4. To account for variations in the initial faecal bacterial load of the batches of slurry used for the incorporated and surface applied experiments, the data have been normalised by calculating the ratio of the number of faecal coliforms 100 mL^{-1} runoff to the number of faecal coliforms g^{-1} slurry. This analysis suggests that faecal coliforms were very mobile in the first fifteen minutes of the surface applied experiments but that this rate of transport declined rapidly as the simulation progressed. Faecal coliforms were much less readily transported in runoff from the incorporated treatment, and a gradual decline in the rate of faecal coliform transport was observed throughout the duration of the experiment.

Discussion

The results indicate that the method of slurry application affected the dynamics of sediment and faecal bacterial transport. Surface application of slurry led to higher concentrations in runoff of both organic sediment and PFCs when compared to the incorporated treatment. As the surface applied slurry was exposed to the erosive forces of rainsplash and overland flow one would expect the organic matter particles and faecal organisms to be readily detached and transported. Conversely, mineral sediment erosion was suppressed when slurry was surface applied. This is probably explained by the protective effect that the layer of slurry had on the soil surface. The results corroborate our initial hypothesis that the incorporation of slurry will reduce the numbers of PFCs transported by reducing the number of organisms exposed to detachment processes.

There were similarities in the pattern of transport of PFCs and organic matter in both the surface applied and incorporated experiments *i.e.* losses were greatest in the initial part of the storm followed by a decline in concentration as the experiment proceeded. This pattern was most pronounced when the slurry was surface applied. The relationship between faecal coliform and organic sediment concentrations in runoff for the incorporated and surface experiments is shown in Figures 5 and 6 respectively. Although there is apparently a strong correlation between these variables, there is substantial variation between experimental runs in the values of the slope and intercept of the regression lines and the factors responsible for this variation have not yet been elucidated. The PFC concentrations in the batches of slurry used for each experiment did vary but this alone does not appear to account for the differences in PFC concentration in the runoff. The percentage of dry matter was also very variable. It is possible that the batches of slurry used in each experiment varied in terms of the partitioning of PFCs between organic matter particle surfaces and cells/cell aggregates disassociated from these particles.

The decline in organic sediment transport as each experiment proceeded is in contrast to the relatively stable rates of mineral sediment transport throughout the six experimental runs. This suggests that in the initial stages of each storm organic slurry particles were preferentially removed from this soil surface. As the storm proceeded more resistant material was left behind and rates of transport fell. Such a process has been modelled by Rose and his co workers (Hairsine and Rose, 1991; Rose *et al.*, 1994; Sander *et al.*, 1996) and demonstrated experimentally for soil erosion (Heilig *et al*., 2001), whereby finer material is removed leaving a more resistant layer of coarse particles, causing detachment rates to decline through time. Our results suggest that if the transport of organic particles derived from manure and slurry is to be modelled a similar approach will be required.

Conclusions

We conclude that a greater proportion of applied PFCs is transported from surface applied than from incorporated slurries, and that this declines with time due the initial removal of easily detached material leaving behind material that is more resistant to detachment. This gives us an important insight into how microorganisms are detached and transported from soil surfaces and indicates that the process may be modelled in the future. Furthermore, our findings indicate that the transport of faecal microorganisms is correlated to the transport of organic sediment particles. The number of PFCs per unit of organic sediment transported varied considerably from one experiment to another. The range of faecal coliform concentrations in the runoff from these experiments ($6.0 \times 10^3 – 1.1 \times 10^6$ PFC 100 ml^{-1}) represents a very significant risk to surface water pollution.

The contradictory evidence in the literature over whether or not the incorporation of slurries and manures reduces the faecal pollution of water courses appears to be due to the survival of bacteria once applied to the soil. Our view is that where possible slurries and manures should be incorporated since this reduces the risk of movement in overland flow, thus reducing the risk of water pollution. Since it is likely that pathogenic bacteria will survive within the soil after application, all steps should be taken to reduce the pathogenic content of the manure or slurry prior to application.

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Table 1. Particle size distribution of the Cottenham series soil used in the experiments

Soil property	Value
Percent coarse sand (>600µm)	1.7
Percent medium sand (212 - 600 µm)	44.9
Percent fine sand (63 - 212 µm)	36.3
Percent silt (2 - 63 µm)	9.7
Percent clay (<2µm)	5.9

Table 2 Mean total runoff, mineral and organic sediment loss from the incorporated and surface applied slurry treatments during a 45 minute sampling period ± standard deviation (* indicates significant difference [p<0.1])

	Incorporated	Surface
Mean total runoff (L)	105 ± 7	101 ± 10
Mean total mineral sediment eroded (g)	1023 ± 546*	148 ± 29*
Mean total organic sediment eroded (g)	126 ± 20*	199 ± 20*

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Fig 6. Relationship between the concentrations of presumptive faecal coliform and organic sediment in the runoff from the surface applied experiments.

Fig. 1. Diagrammatic representation of the soil flume used in the experiments.

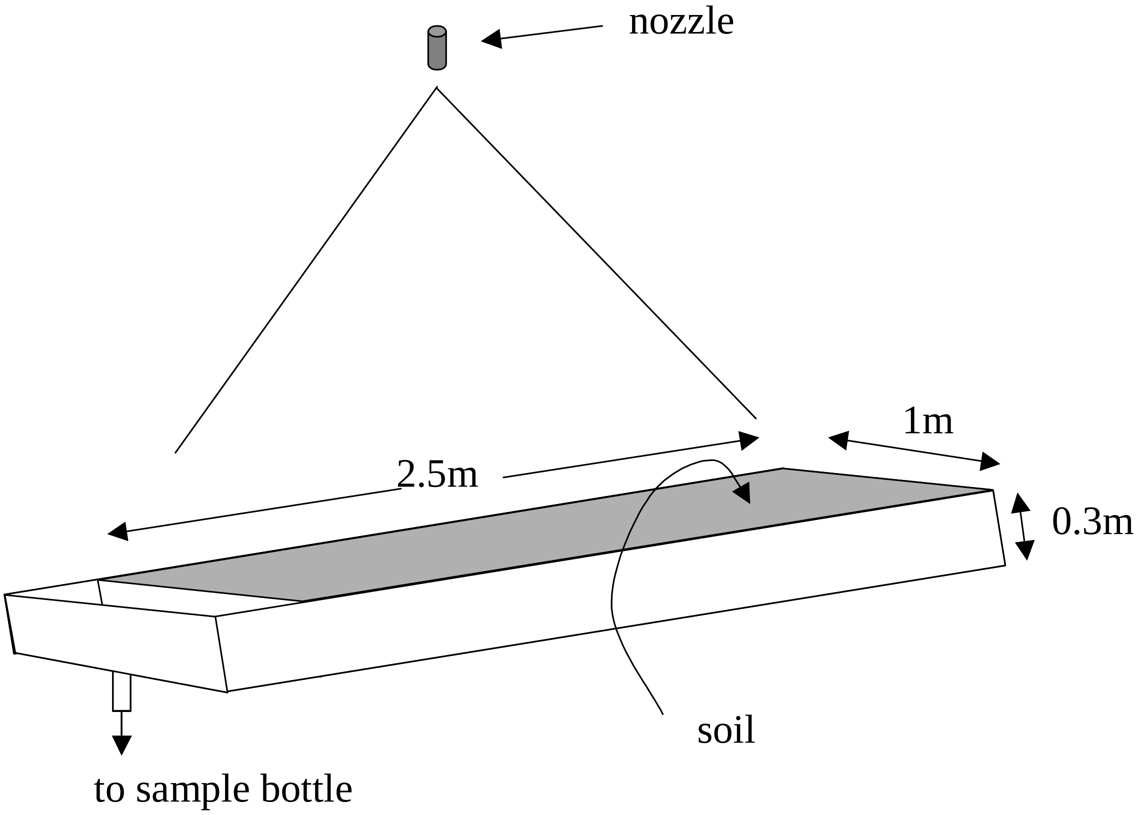


Fig 2. Mineral sediment lost from the soil slope for the incorporated and surface applied slurry treatments.

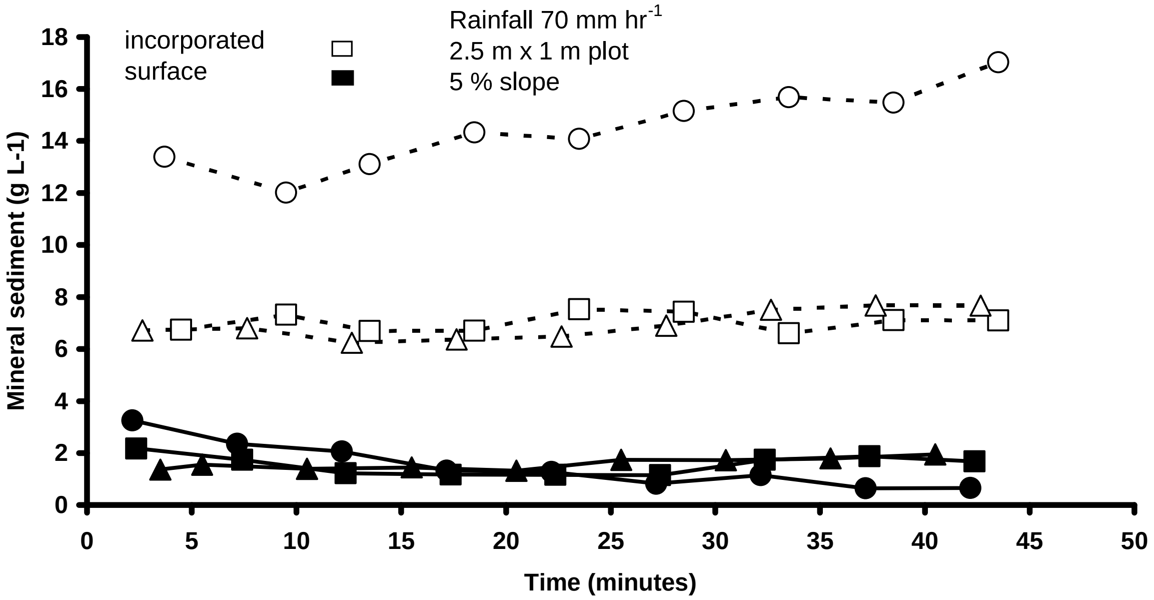


Fig 3. Organic sediment lost from the soil slope for the incorporated and surface applied slurry treatments.

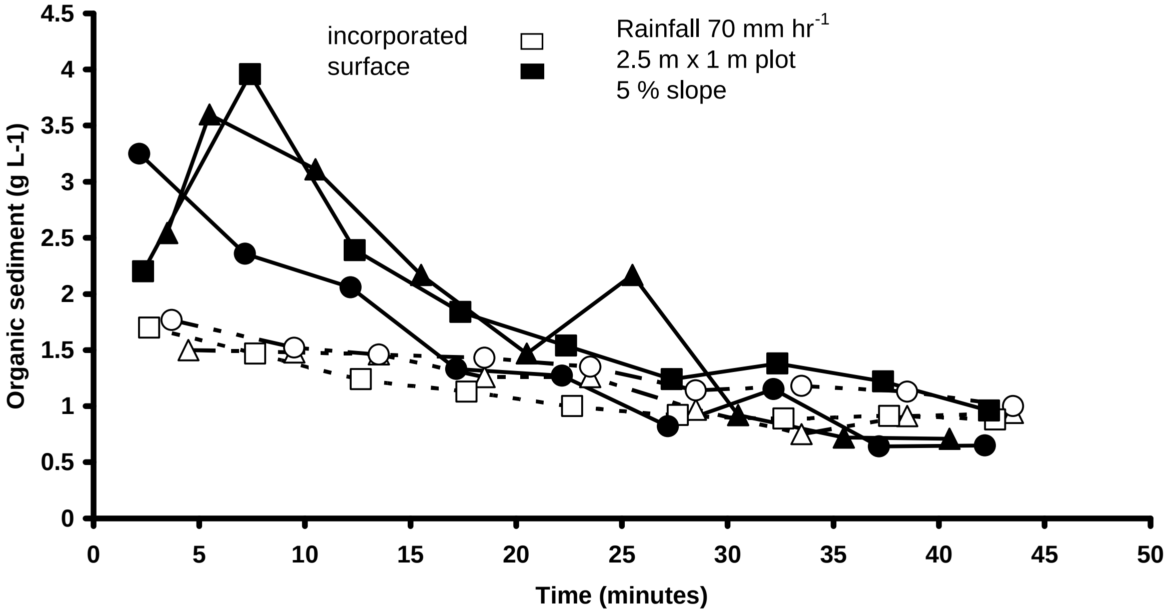


Fig 4. Normalised presumptive faecal coliforms lost from the soil slope for the incorporated and surface applied slurry treatments.

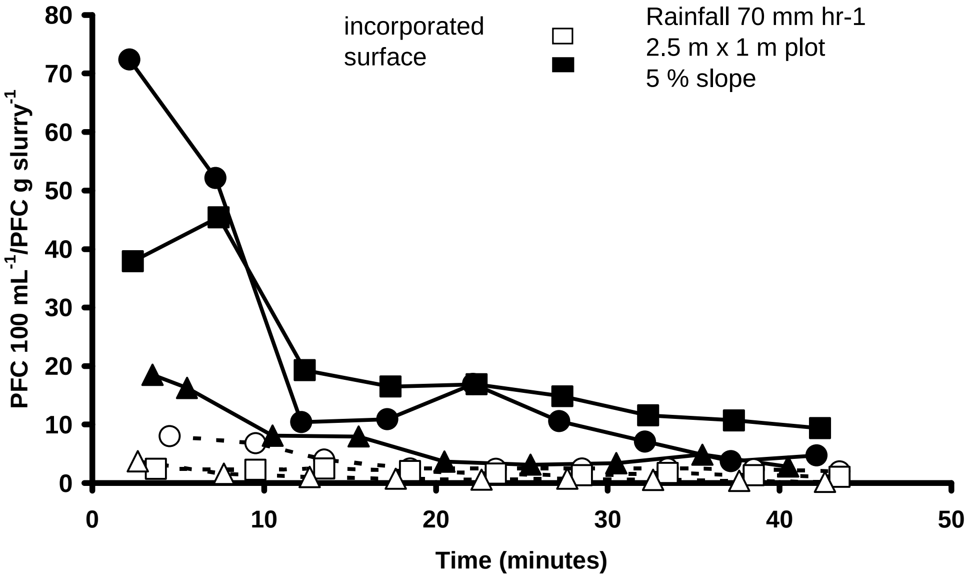
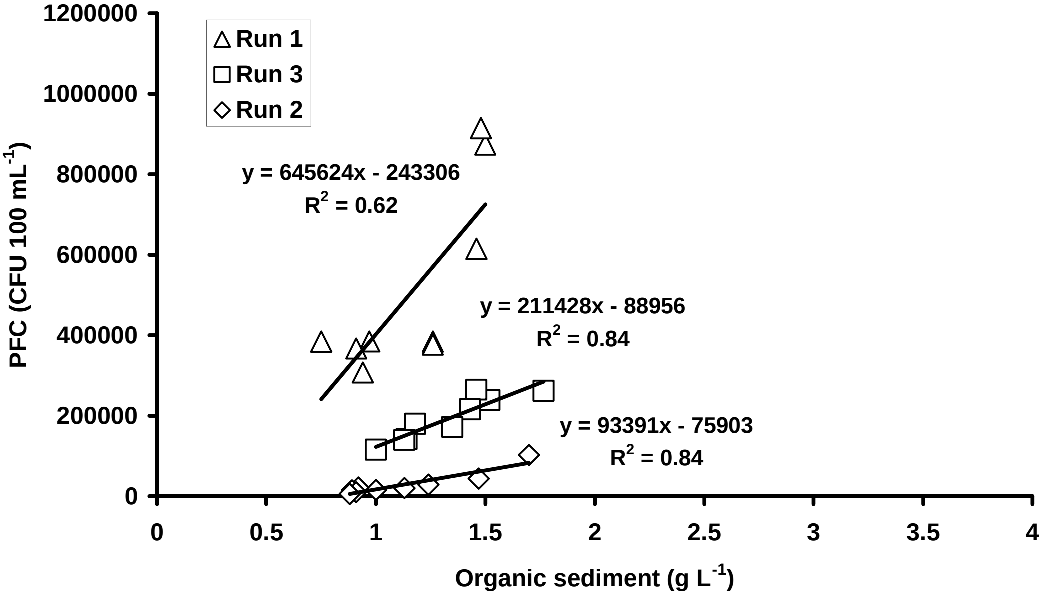


Fig 5. Relationship between the concentrations of presumptive faecal coliform and organic sediment in the runoff from the incorporated experiments



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