Effects of cattle manure on erosion rates and runoff water pollution by faecal coliforms

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Abstract

The large quantities of slurry and manure that are produced annually in many areas with intensive animal production could be an important source of organic matter and nutrients for agriculture. However, the benefits of waste recycling may be partially offset by the risk of water pollution associated with runoff from the fields to which slurry or manure has been applied. In this paper, the effects of cattle manure application on soil erosion rates and runoff and on surface water pollution by faecal coliforms are analysed. Rainfall simulations at a rate of 70 mmh^{-1} were conducted in a sandy loam soil packed into soil flumes (2.5m long*1m wide) at a bulk density of 1400 kg m^{-3}, with and without cattle slurry manure applied on the surface. For each simulation, sediment and runoff rates were analysed and in those simulations with applied slurry, presumptive faecal coliform (PFC) concentrations in the runoff were evaluated. The application of slurry on the soil surface appeared to have a protective effect on the soils, reducing soil detachment by up to 70% but increasing runoff volume by up to 30%. This practice implies an important source of pollution for surface waters especially if rainfall takes place within a short period after application. The concentrations of microorganisms (presumptive faecal coliforms (PFCs)) found in water runoff, ranged from 1.9*10^4 to 1.1*10^6 PFC 100 mL^{-1}, depending on the initial concentration in the slurry, and they were particularly high during the first phases of the rainfall event. The result indicates a strong relationship between the faecal coliforms transported by runoff and the organic matter in the sediment.

Keywords: runoff rates, sediment rates, cattle manure, faecal coliforms, rainfall simulation

Introduction

The large quantities of slurry and manure that are produced annually in many areas with intensive animal production could be an important resource of organic matter and nutrients. Recycling these wastes via land application could lead to improvements in physical properties of soil, such as soil porosity, structure and water holding capacity (León-González et al., 2000; Ourédraogo et al., 2001; Nyamangara et al., 2001). For this reason, the application of faecal wastes could be beneficial for soil conservation (Pinamonti and Zorzi, 1996), especially in degraded soils and soils susceptible to erosion, although the response to soil amendment is soil-site specific. 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, especially if rainfall occurs shortly after application.

The contamination of surface waters with pathogenic micro-organisms transported from fields to which livestock slurries and manure have been applied is a serious environmental concern because it may lead to humans being exposed to such micro-organisms via several routes: 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).

The aim of this work was to evaluate the effects of cattle manure application on soil erosion rates and runoff and on the detachment and transport of faecal coliforms.

Material and methods

The study was performed in the laboratory. A sandy loam soil, classified as Lamellic Ustipsamment (Soil Survey Staff, 1999), sampled at Bedfordshire, (UK) was used throughout the experiments. The soil was passed through a 9.5 mm sieve and packed into soil flumes (2.5 m long x 1 m wide and 30 cm deep) at a bulk density of 1400 kg m^{-3}, set at a 5 % slope. The flumes are designed to separate overland flow from water that has infiltrated the soil. Surface runoff generated along the slope flows into a collection chamber at the end of the flume and then through an outlet hose from which discharges could be measured and samples taken for analysis. Water percolating through the soil was able to drain freely from the flume thus avoiding the creation of saturated conditions (Fig 1).

In order to increase soil surface moisture conditions, one day prior to each runoff experiment, the erosion plot was exposed to simulated rainfall whilst protected with fabric to avoid soil detachment. Simulated rainfall was applied to the plots at an intensity of 70 mm h^{-1} for 45 minutes using a pressure irrigation sprinkler. 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. The intensity used in the simulation was high enough to produce runoff, which became constant after 15 minutes. This intensity corresponds to the 15-min intensity for a 20-year return period storm.

For each simulation runoff samples were taken every five minutes. Runoff volumes (including water and sediment) were determined using calibrated measuring cylinders. Sediment concentration in runoff was determined in 1-L aliquots of runoff, which were then decanted and dried at 105ºC, and then weighed. The organic matter content in the sediments collected in runoff was determined for each sample by weight after ignition in a furnace at 550 °C for 4h of an aliquot (Nelson and Sommers, 1996). The results were expressed in grams of organic matter per ? runoff volume. Two simulations and three replications of each analysis were done.

In similar plots, cattle slurry was spread onto the soil surface at a rate of 30 Mg ha^{-1} (7.5 kg/plot) which is below the maximum recommended value (MAFF, 1998). Slurry application was done by hand but just left on the surface, simulating the way in which it could be applied by farmers with machinery. The dry solids content of the slurry ranged from 8-24%. In this case, simulated rainfall was applied to the plots within 24 h of the slurry application. Runoff samples were collected and managed in the way described above to determine sediment and organic matter concentration. In addition, aliquots of 300 mL were collected in sterile bottles to determine the number of PFCs in the runoff following serial dilution according to the membrane filter procedure (method nº: 9222D, APHA, 1998). The analysis was done within two hours of the end of the rainfall simulation and each sample was analysed in triplicate.

Prior to application the number of PFCs present in the slurry was also enumerated. Ten grams of moist slurry was added to 200 mL of sterile water and placed on a mechanical shaker for 20 min. This solution was also serially diluted prior to the membrane filtration.

A statistical analysis (Duncan’s mean test and one–way analysis of variance) of total runoff volume, average sediment concentration in runoff recorded during the 45 min rainfall, final constant runoff rates and final sediment concentration was done to evaluate significant differences between treated and untreated soils, using the Multi range test- Statgraphics 5.1 program.

Results and Discussion

Runoff rates and sediment concentrations

For the untreated plots runoff started 3 minutes after the beginning of the rainfall and became constant 25 minutes later at a rate of 9 Lmin^{-1}. However, when the slurry was applied on the surface, runoff increased faster in the first phase of the storm, and reached a maximum discharge of 13 Lmin^{-1}, which represents a depth of 4.7 mm. At the peak 80% of the rainfall ran off. (Fig.2). Total runoff collected during the 45min simulation was 58 ± 4 L in untreated soils and 105 ±5 L in treated soil, on average .

Regarding the soil sediment concentration in runoff, for untreated soils the quantity of material eroded increased during the first part of the trial until it reached a constant value of about 100 g/min, which represented a maximum sediment concentration of about 10 gL^{-1} (Fig. 3), and an erosion rate of about 0.45 Mg ha^{-1}. A significant linear relationship between soil losses and runoff was observed.

For the treated soils, however, the eroded material behaved differently. The highest erosion rates were at the beginning of the experiment and subsequently decreased until rates of about 3 g/L were reached. Total sediment in runoff collected during the 45 min period of simulated rainfall was 30 g in treated soils vs. 346 g in untreated soils, which represented average sediment concentration in runoff of 2.0 g/L vs. 7.6 g/L. Significant differences were confirmed between treated and untreated soils. Table 1 shows the average value and its standard deviation and the ANOVA.

The application of slurry on the soil surface appeared to have a protective effect on the soils, reducing erosion but increasing runoff. The repacked soils used in these experiments are likely to have lower (probably-but they could also be higher) infiltration rates than undisturbed soils due to a loss of structure. Nevertheless, the flumes were prepared in an identical way for each run and therefore we conclude that the differences observed are due to the treatment effect.

Effect of simulated rainfall on transport of organic matter and micro-organisms

Organic matter concentrations associated with the sediment collected in the runoff were generally higher in the first 20 minutes of the experiment and declined gradually as the simulation proceeded (Fig. 4). There were not big differences between simulations. Similar trends were obtained in the three replications.

The PFC concentrations found in the runoff water, ranged from 1.9×10^4 to 1.1×10^6 PFC 100 mL^{-1}, depending on the initial concentration in the slurry (for the three simulations they were: 5112, 3118 and 11697 FC/g of slurry, respectively), but even during the stages where the concentrations were lower they were always at least one order of magnitude higher than the European standard (2000/100 mL) given for bathing waters. The analysis suggests that faecal coliforms were very mobile in the first fifteen minutes of the experiments but that this rate of transport declined rapidly as the simulation progressed.

There were similarities in the pattern of transport of PFCs and organic matter, i.e. a decrease in concentration as the experiment proceeded but there was not a good correlation with total soil loss. There is still a lack of understanding of the way in which the micro-organisms are transported: for example the proportions adsorbed to mobile and/or immobile sediments or moving in the flow (Yeghiazarian and Montemagno, 2000) or the influence of applying livestock waste on the surface or incorporating the wastes into the soil (Quinton, et al., 2003). So, more research is necessary in this area. But the results indicate that bacterial transport is more likely to be linked to the slurry organic matter particles than to the soil particles. There was a linear relationship between PFCs and organic sediment (Fig. 5). However, the linear relationship observed between PFCs and organic matter had different slope and intercept values for each experimental run, which could be due to the differences in the original concentrations in the slurry or other factors not yet elucidated.

Conclusions

The application of slurry and manure to the fields has implications for erosion processes. When manure is applied on the soil surface, the quantity of eroded material decreases but runoff can increase by up to 30%.

This practice implies an important source of pollution for surface waters. If rainfall takes place within a short period after application, faecal coliforms in runoff waters reach high concentrations, especially during the first phases of the rainfall event. This may cause an increase in the concentration of faecal coliforms in surface water, which could exceed the standards for bathing water quality by more than one order of magnitude. The distribution patterns of PFCs during the rainfall show that most of them are transported in association with organic matter particles rather than linked to the soil or suspended in water.

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Table 1. Average values and ANOVA of total runoff (TRU: total runoff in untreated soils; TRT: total runoff in treated soils), sediment concentration in total runoff (SCRU: total sediment in runoff for untreated soils; SCRT: total sediment in runoff for treated soils), final runoff rates (FRRU: final runoff rates for untreated soils; FRRT: final runoff rates for treated soils) and final sediment concentration in runoff (FSCRU: final sediment concentration in runoff for untreated soils; FSCRT: final sediment concentration in runoff for treated soils).

	Average ± stad. Deviation	F	p value
TRU (L)	58.4 ± 4.2	48.6	*0.0022
TRT (L)	105.0 ± 4.7		
SCRU (g/L)	7.5 ± 0.9	42.73	*0.0073
SCRT (g/L)	2.0 ± 0.4		
FRRU (L/min)	2.69 ± 0.08	29.17	*0.0001
FRRT (L/min)	1.84 ± 0.02		
FSCRU (g/L)	97.0 ± 1.4	152.19	*0.0011
FSCRT (g/L)	1.91 ± 0.03		

* Statistical significant difference between means at 95% confidence level.

Figure captions

Fig.1 Diagram representing the flume type used for the rainfall simulation

Fig. 2. Runoff volume evolution along the rainfall simulation for the slurry treated (RVT) and untreated soils (RVU). (Each line corresponds to one simulation S1-S2-S3)

Fig. 3. Sediment concentration evolution along the rainfall simulation for slurry treated (SCRT) and untreated (SCRU) soils. (Each line corresponds to one simulation S1-S2-S3)

Fig. 4. Evolution of the organic sediment concentration with time for the different simulations of treated soils (simulations S1-S2-S3).

Fig. 5. Evolution of the faecal coliforms lost from the soil along the time in each simulation (simulations S1-S2-S3).

Fig.6. Relationship between FC 100 mL^{-1} and the organic matter content in the sediment for each simulation (simulations S1-S2-S3).

Fig. 1

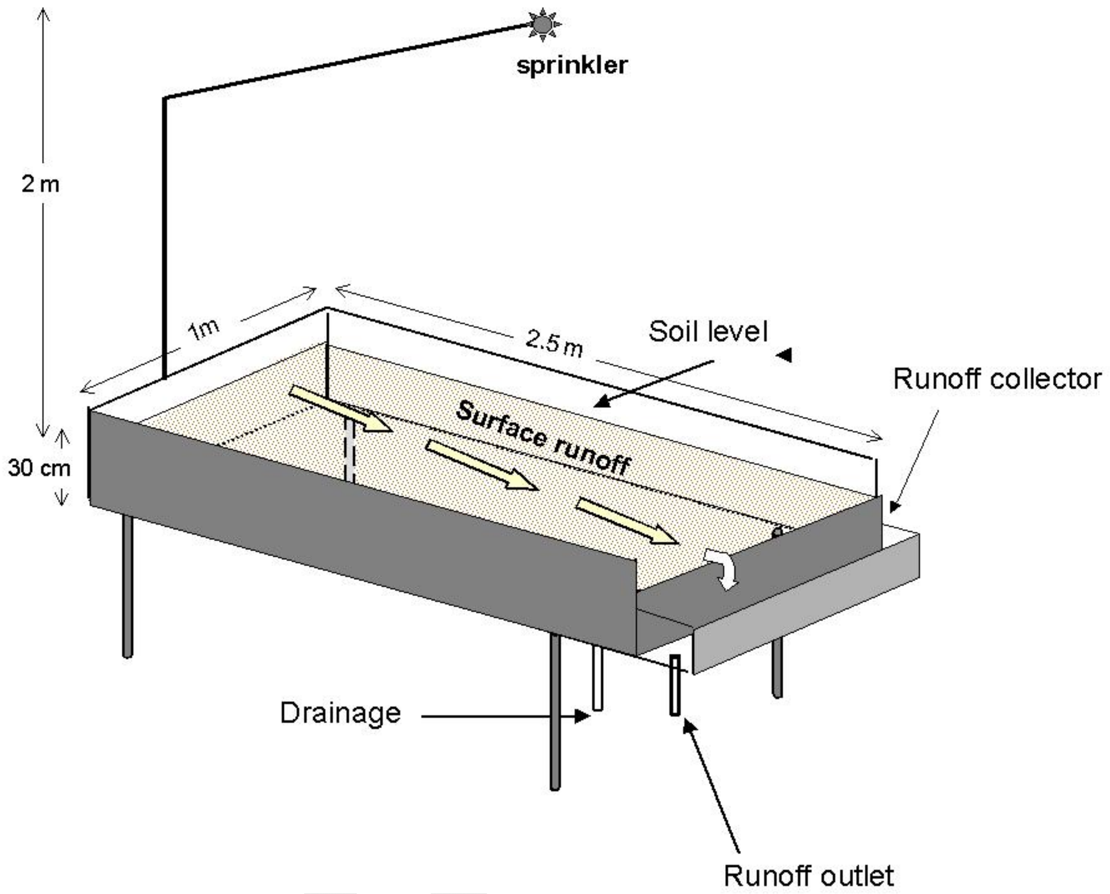

sprinkler
2 m
1m
2.5 m
Soil level
Runoff collector
Surface runoff
30 cm
Drainage
Runoff outlet

Fig. 2 ALLfIGURES NEED THICKER LINES ESPECIALLY ON AXIS

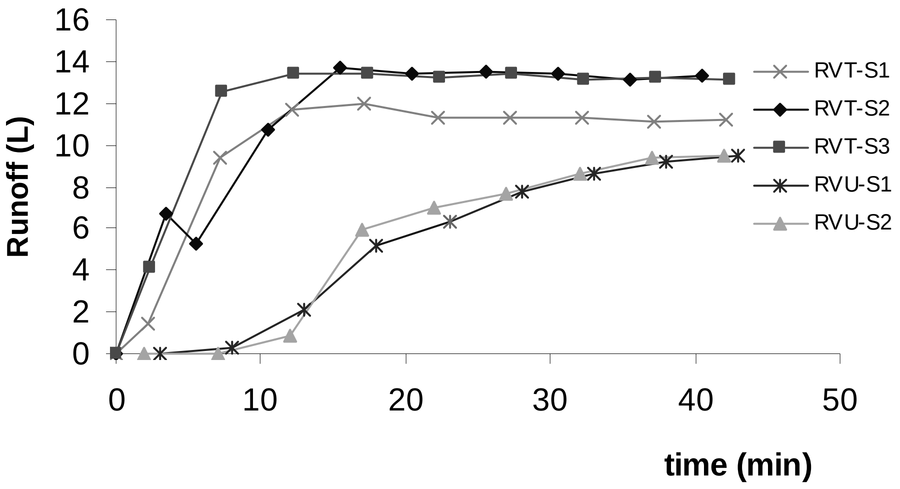


Fig. 3

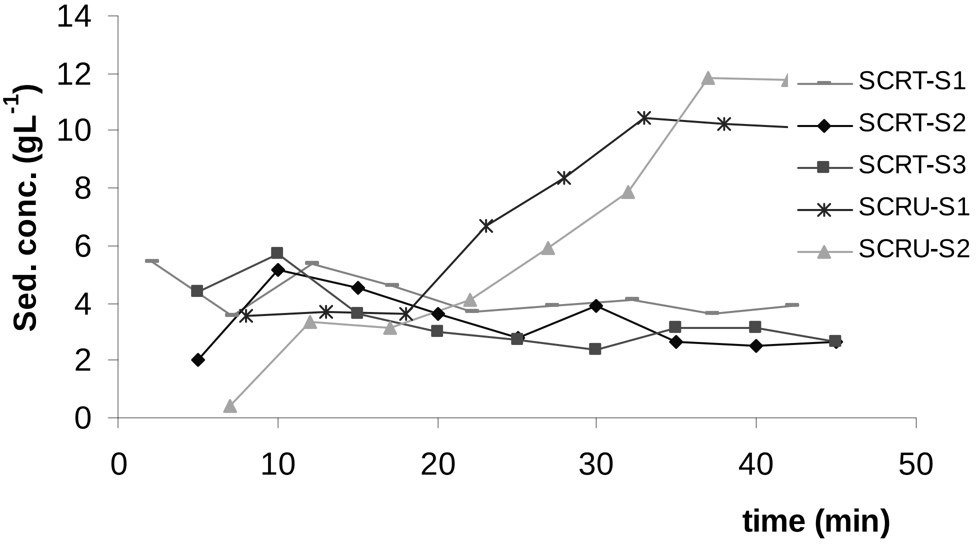


Fig. 4.

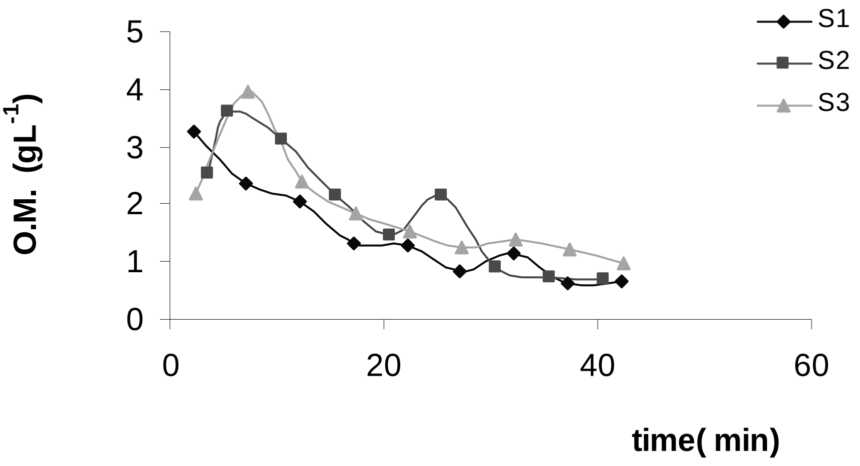
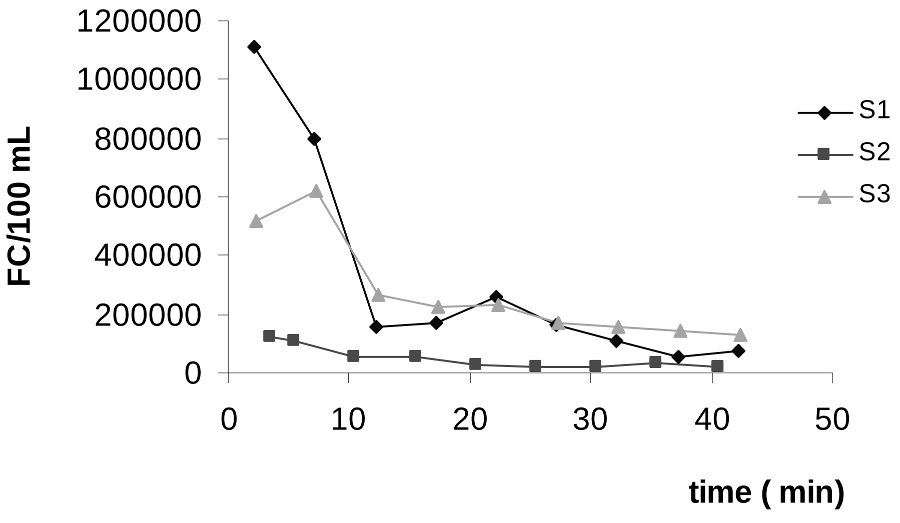
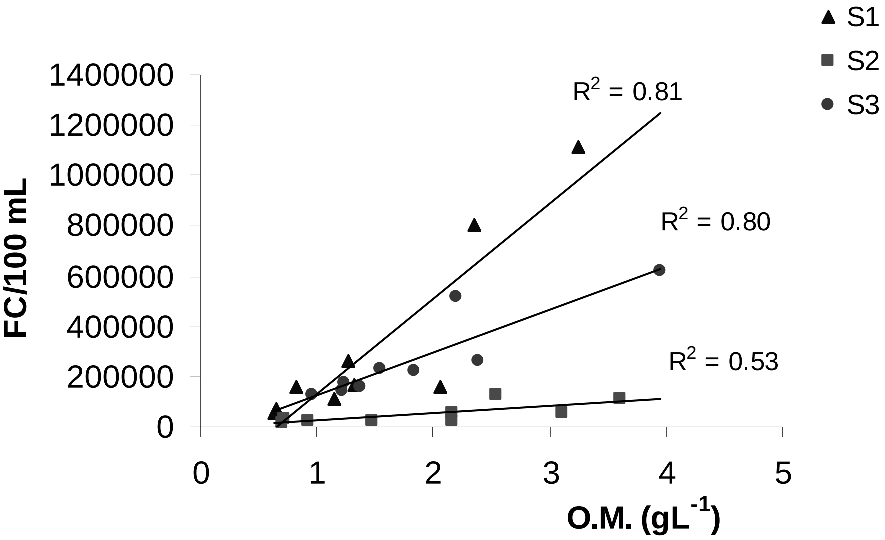

O.M. (gL^{-1})
5
4
3
2
1
0
0
20
40
60
time(min)
S1
S2
S3

Fig. 5.


FC/100 mL
1200000
1000000
800000
600000
400000
200000
0
0
10
20
30
40
50
time (min)
S1
S2
S3

1m

Fig. 6


S1
S2
S3
R^2 = 0.81
R^2 = 0.80
R^2 = 0.53
FC/100 mL
1400000
1200000
1000000
800000
600000
400000
200000
0
0
1
2
3
4
5
O.M. (gL^{-1})