Journal of Environmental Management 201 (2017) 388–396

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Bacterial mobilization and transport through manure enriched soils: Experiment and modeling

N. Sepehrnia [a, c, *], L. Memarianfard [b], A.A. Moosavi [b], J. Bachmann [c], G. Guggenberger [c], F. Rezanezhad [d]

[a] Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran
[b] Department of Soil Science, College of Agriculture, Fars Science and Research Branch, Islamic Azad University, Marvdasht, 74715-181, Iran
[c] Institute of Soil Science, Leibniz Universität Hannover, Herrenhäuser Str. 2, D-30419, Hannover, Germany
[d] Ecohydrology Research Group, Water Institute and Department of Earth and Environmental Sciences, University of Waterloo, Waterloo, Canada

A R T I C L E I N F O

Article history:
Received 29 April 2017
Received in revised form
2 July 2017
Accepted 3 July 2017
Available online 8 July 2017

Keywords:
Fecal coliform
Attachment rate
Detachment coefficient
Straining
Soil contamination
Water pollution

A B S T R A C T

A precise evaluation of bacteria transport and mathematical investigations are useful for best management practices in agroecosystems. In this study, using laboratory experiments and modeling approaches, we assess the transport of bacteria released from three types of manure (cow, sheep, and poultry) to find the importance of the common manures in agricultural activities in soil and water pollution. Thirty six intact soil columns with different textures (sandy, loamy, and silty clay loam) were sampled. Fecal coliform leaching from layers of the manures on the soil surface was conducted under steady-state saturated flow conditions at 20 °C for up to four Pore Volumes (PVs). Separate leaching experiments were conducted to obtain the initial concentrations of bacteria released from the manures (*Co*). Influent (*Co*) and effluent (*C*) bacteria concentrations were measured by the plate-count method and the normalized concentrations (*C*/*C0*) were plotted versus PV representing the breakthrough curves (BTCs). Transport parameters were predicted using the attachment/detachment model (two-kinetic site) in HYDRUS-1D. Simulations fitted well the experimental data ($R^2 = 0.50–0.96$). The attachment, detachment, and straining coefficients of bacteria were more influenced by the soils treated with cow manure compared to the sheep and poultry manures. Influent curves of fecal coliforms from the manures (leached without soil) illustrated that the poultry manure had the highest potential to pollute the effluent water from the soils in term of concentration, but the BTCs and simulated data related to the treated soils illustrated that the physical shape of cow manure was more important to both straining and detachment of bacteria back into the soil solution. Detachment trends of bacteria were observed through loam and silty clay loam soils treated with cow manure compared to the cow manure enriched sandy soil. We conclude that management strategies must specifically minimize the effect of fecal coliform concentrations before field application, especially for the combination of poultry and cow manures, which has higher solubility and tailing behavior, respectively. Interestingly, the addition of sheep manure with all three soils had the lowest mobilization of bacteria. We also suggest studying the chemistry of soil solution affected by manures to present all relevant information which affect bacterial movement through soils during leaching.

1. Introduction

Contaminated surface and subsurface water is the main cause of much disease, death, and human disaster (Collins and Rutherford, 2004; Goss and Richards, 2007). Water pollution can be the consequence of natural factors and anthropogenic activities (WHO/UNICEF, 2010). What is clear is the difficulty of access to safe drinking water in a world where an estimated 7.10 billion people are living and at least 1.5 billion people solely depend on groundwater resources for drinking water (Schinner et al., 2010; WHO/UNICEF, 2010; World Resources Institute, 2000).

The animal manures contain various pathogens some of which

* Corresponding author. Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran.
E-mail address: n.sepehrnia@ag.iut.ac.ir (N. Sepehrnia).

http://dx.doi.org/10.1016/j.jenvman.2017.07.009
0301-4797/

are host-adapted and, therefore, not a health risk for humans. Others can produce infection in humans and are thus termed zoonotic (*i.e.*, can cause human diseases). The more common zoonotic pathogens in manure include *Campylobacter, Cryptosporidium parvum*, *Escherichia coli 0157:H7*, *Giardia lamblia, and Salmonella*. Risks from manure-associated pathogens can arise when runoff, spills, or infiltration enable microorganisms to reach surface water or groundwater, or when land-applied manure, or irrigation water impacted by manure, comes into contact with food crops. The level of risk to humans depends on many factors such as the absolute number of microbes and their infectious doses in conjunction with their behavior in the environment; *i.e.*, how readily the microorganisms are transported through the environment and how long they remain infectious (Smith and Perdek, 2004; EPA, 2013).

Bacterial pollution of water has been inhibited or is being inhibited in many countries, but water quality issues are still considered as major and even hidden problems for many water resources worldwide (Foppen, 2002; Sepehrnia et al., 2014). In most villages people keep their domestic animal wastes and/or their solid and liquid household waste near their homes. Further, in some cases, there is a short distance between pit latrines and extraction wells (Foppen, 2002). These circumstances are the consequence of social and economic issues, or due to unawareness of people with respect to factors supporting pathogenic bacteria transport. The greatest prevalence of waterborne and food borne gastrointestinal illness, even those caused by zoonotic pathogens, are attributable to human fecal contamination, although agricultural sources have been implicated in a number of cases. With current surveillance, the degree to which manure-related pathogens may be involved in outbreaks is poorly understood, mainly due to difficulties in identifying etiologic agents, and because the sources of contamination in conjunction with cases of illness remains unreported (EPA, 2013). The bacteria, most of which can contaminate waters, are *coliforms* and have a manure origin (EPA, 2013). Fecal coliforms are used as indicators of enteric pathogenic organisms in aquatic environments. These indicators can illustrate/warn if the water bodies meet criteria of sanitary standards for drinking water sources (Payment, 1989).

On the other hand, soil is the main barrier through which bacteria must pass to reach ground water. Hence, soil properties can play an important role in bacterial mobilization and retention by sorption or filtration (Forslund et al., 2011; Gagliardi and Karns, 2000; Sepehrnia et al., 2014; Tufenkji, 2007). Bacterial transport is affected by properties of the cells, the porous medium, and the transporting solution (Aislabie et al., 2001; Banks et al., 2003; Becker et al., 2004; Sepehrnia et al., 2014; Tazehkand et al., 2008). Numerous bacterial studies have shown that soil texture is one of the most important soil properties controlling bacterial transport (Gagliardi and Karns, 2000; Gerba and Bitton, 1984; Unc and Goss, 2004). In this context it is suggested that movement will be greater in coarse-textured than in fine-textured soils, and that soil pore size distribution will primarily affect movement of bacteria and protozoa through the soil, but not of viruses due to their considerable smaller size (McGechan and Lewis, 2002). Because pore size distribution is closely related to particle size distribution, Gargiulo et al. (2007) concluded that particle size significantly influenced bacterial transport and retention. They observed BTC tailing was prominent for all fine sand columns due to stronger *E. coli* adsorption in fine sand, while *E. coli* recovery in leachate from coarse sand was significantly higher than for fine sand columns. Knappett et al. (2008) stated that small changes in grain size can possibly increase pore-throat straining which substantially impacts bacteria-sized microsphere removal. Accordingly, Mosaddeghi et al. (2009) illustrated via undisturbed columns experiments that more bacteria could be transported through sandy clay loam compared to loamy sand.

However, high temporal and spatial variability of bacterial transport through soil makes this subject one of the most complicated and difficult problems in agricultural, hydrological and environmental research. To reach a quantitative assessment and to evaluate the accuracy of experimental data before developing management strategies, mathematical models are useful and widely used to prove the consistency of measured or predicted bacteria transport processes with respect to governing factors. Adequate models provide an assessing tool to elucidate important factors that control microbial concentrations in water reservoirs (Guber et al., 2005; Pang et al., 2008; Shelton et al., 2003; Tufenkji, 2007). Therefore, two objectives are investigated in this study: i) the estimation of transport parameters using HYDURS1-D to assess the combination of soil texture and manure effects on bacterial transport: ii) the evaluation of bacteria release, in tendency, from different manures, which are common in agricultural activities of many countries.

2. Material and methods

2.1. Soil sampling and laboratory experiments

Three types of soils including sandy (Typic Xeropsamment), loam (Typic Haploxerept) and silty clay loam (Typic Haploxerept) were collected from a field site in Marvdasht, 45 km north of Fars province in Iran. The climate of the region is semi-arid with a mean annual temperature of 16.7 °C and precipitation of 263 mm.

Thirty-six intact soil columns were collected from the three soils using PVC cores with dimension of 16 cm diameter and 35 cm height representing depths of 0–30 cm in the soil profile. Thus, the height of soil samples were 30 cm in the columns which means the first 5 cm of all columns was left empty to serve as water reservoir during leaching experiments. Adjacent disturbed soil samples were collected from 0 to 35 cm depths to determine the average of basic chemical and physical properties.

Soil textures were determined according to Bouyoucos (1936), particle density by pycnometer method (Black and Hartge, 1986), mean weight diameter (MWD) of aggregates by wet-sieving method (Yoder, 1936), bulk density by core sampling method (Black and Hartge, 1986), and total porosity calculated using measured bulk density and particle density data. The pH and electrical conductivity (EC) of soil samples were measured by pH-meter and EC-meter in a saturated paste and in 1:5 soil:water suspensions (Rhoades, 1996; Sims, 1996). Total organic carbon was determined by the wet-digestion method (Walkly and Black, 1934). The cation exchange capacity was measured by ammonium-saturation and exchange method (Page et al., 1992).

2.2. Manure treatments as sources of fecal coliform

Fresh cow (*Bos taurus*), sheep (*Ovis aries*) and chicken (*Gallus gallus domesticus*) manures were used as the source of fecal coliforms. The manures were air dried in shade for 48 h and sieved through a 2-mm sieve to obtain uniform particle size. After measuring the water content by the gravimetric method (Gardner, 1986), the sieved manure was kept refrigerated for 24 h (4 °C). Chemical properties of the manures were determined by the methods described for soil samples.

2.3. Adjustment of water flux for column experiments

The experiment setup was similar to that described in Mosaddeghi et al. (2009) and Sepehrnia et al. (2014). Soil columns were leached according to the times required for the percolation of