
Transport of *Escherichia coli*, Chloride and Nitrate through Disturbed and Undisturbed Soil Columns

T. Johnson and E. de Jong.

Saskatchewan Center for Soil Research, University of Saskatchewan, Saskatoon, SK,
S7N 5A8.

Abstract

Current livestock production techniques often require the surface application of large quantities of manure. In 1996 Saskatchewan had 2.8 million cattle and 0.9 million hogs, conservative estimates suggest that this number of cattle and hogs produce approximately 60 000 Mg of manure day⁻¹. This number is expected to be even higher today, and would certainly be much higher if other livestock such as poultry were included. The most common disposal method for this manure is application on or in the soil. The growing environmental awareness of our society, coupled with the increased number of large-scale livestock production facilities, has greatly increased concerns regarding ground water quality. These concerns are caused by the potential for nitrate and pathogenic microorganisms such as *Escherichia coli* (*E.coli*) to be leached from the soil surface into ground water.

The objective of this research was to characterize the transport of *E.coli* and nitrate through soil. Experiments involved leaching *E.coli*, nitrate, chloride and potassium through disturbed soil columns under saturated and unsaturated conditions. Transport through undisturbed columns was also studied in saturated conditions. Effluent from these columns was analyzed, both chemically and microbiologically. Results of this analysis showed that *E.coli* can be preferentially transported through both disturbed and undisturbed soil columns.

Introduction

The most common contaminant identified in groundwater is nitrogen in the form nitrate (NO₃⁻). This contamination is often the result of over fertilization and the deposition of sewage on or in the surface soil (Kehew et al., 1998; Gangbazo et al., 1995; Freeze and Cherry 1979). Nitrate present in groundwater can pose serious health risks to humans and animals. As a result of these health risks, groundwater containing NO₃⁻ at

levels above 45 mg L^{-1} is considered unfit for consumption by human infants, and waters containing NO_3^- in excess of 450 mg L^{-1} are unsuitable for livestock consumption (Freeze and Cherry 1979).

Another concern associated with the disposal of sewage on, or in the soil involves the question of how far and how fast pathogenic bacteria and viruses can travel in the soil and groundwater flow systems. Feces excreted by livestock contain bacterial populations ranging from 10^6 to 10^8 CFU g^{-1} . Although many of these organisms are innocuous, pathogens such as *Salmonella*, *Campylobacter* and *E.coli* O157 are frequently excreted in high concentration, and have been associated with diseases in humans (Whipp et al., 1994). For cattle the excretion of feces with a high concentration of *Campylobacter* and *E.coli* O157 appears to be a periodic event, which lasts for one or two months, occurring in the spring and sometimes in the fall (Stanley et al., 1998 a,b). Wang (1996) reported that during these events the *E.coli* O157 population in feces ranges from 10^2 to 10^5 CFU g^{-1} . As a result of these high pathogen concentrations, humans could become infected with one or more of these agents by ingesting as little as $100 \mu\text{g}$ of contaminated feces (Jones, 1999).

When manure is applied to land it is assumed that the soil can act as a living filter which has the ability to purify itself through biological processes. However numerous field and laboratory tests have shown that once applied, microorganisms can migrate through significant distances of soil (Abu-Ashour et al., 1994 Gannon et al., 1991a,b,c; Rahe et al., 1978; Wollum et al., 1978). Disease outbreaks resulting from fecal contamination in both drinking and recreational waters have been reported (Keene et al., 1994; Greenberg et al., 1992; Swerdlow et al., 1992; Thornley and Bos 1985).

Despite evidence of fecal pathogen contamination of surface and groundwater resulting from livestock wastes few studies have been conducted to examine the transport of fecal pathogens through in loam textured soil. For this reason the following project was undertaken.

Material and Methods

The soils used in these experiments were taken from a field (NW 25-33-10 W3) on the Carr farm located near the town of Laura in west central Saskatchewan. The field is a gently sloping Elstow soil, a Dark Brown soil formed on lacustrine parent material (Ellis et al., 1968).

Soils used in experiments with disturbed structure were collected from a soil pit in a mid slope position. The soil used for the A horizon columns, came from the top 14 cm of this pit, while C horizon soil came from 42-55 cm depth. Horizon delineation was determined through visual observations. Particle size analysis conducted on this soil (Table 2) shows that it is silty loam to loam textured.

Table 2. Physical properties of soil

Horizon	Depth	Texture	Organic carbon	Inorganic carbon	Air dry water	33 kPa water	1500 kPa
A	0-14 cm	Silt loam	2.7 %	0.04	2.63	28.0	16.2
B	14-42	Silt loam	1.8	0.01	2.39	24.4	13.1
C	42 +	Loam	0.8	0.05	2.56	24.1	13.7

Disturbed columns were prepared by air drying the soil and sieving through a 2 mm screen. Soil was then poured into 140 mL syringes, which were 15 cm long and 4 cm in diameter and packed to an airdry bulk density of approximately 1.1 g cm^{-3} . All columns were with filled 130 mL of air dry soil and placed in a cold room at 4°C . Undisturbed soil columns were extracted from the same midslope position as the soil in the disturbed experiments. Columns were obtained by sliding a clear plastic sleeve into a specialized metal coring tube attached to a hydraulic sampler. The core tube was then pushed into the soil and an intact core was obtained. Columns were left in the clear plastic sleeve, sealed at both ends with watertight caps and stored in the shade until the completion of sampling. The columns were 5.8 cm in diameter and averaged 95 cm in length and 2.6 kg in weight at the time of sampling. After sampling all columns were stored in a cold room at 4°C prior to their use.

Once in the fridge, the columns were pre-leached with approximately 6 pore volumes of a 1mmol/L CaCl_2 leaching solution in order to bring the salt concentration to a steady state. At the completion of pre-leaching, a 6ml pulse containing *E.coli*, Cl^- , and NO_3^- was applied to the soil surface. This pulse was prepared by combining a 1 ml *E.coli* suspension (approx. 2.5×10^6 CFU) with a 5 ml salt solution containing 0.025 mol/L KCl and 0.025 mol/L KNO_3 . Once this pulse had completely infiltrated the leaching solution was reapplied. Leaching continued until approximately 10 pore volumes of leachate had been collected. Effluent samples were then analyzed to determine concentrations of *E.coli* (CFU/ml) as well as NO_3^- and Cl (moles/L). After 10 pore volumes of effluent had been collected from the columns the leaching was terminated and the columns were cut into sections and sampled, in order to determine the *E.coli* distribution with in the soil.

Results and Discussion

Results of the effluent analysis showed that Cl^- and NO_3^- are both transported in the same manner and acted as conservative tracers in these experiments conducted at 4°C . In unsaturated columns the Cl^- and NO_3^- moved at approximately the same speed as the soil water, however in disturbed saturated conditions preferential flow resulted in transport velocities for Cl^- and NO_3^- that were up to 1.3 times those of the water. In undisturbed columns the Cl- and NO_3^- peaks occurred even earlier. Chloride and NO_3^- breakthrough data from the disturbed columns were fit to an analytical solution of the convection-dispersion equation (CDE) to calculate the various parameters required to solve the CDE. Unfortunately the undisturbed columns could not be analyzed by this procedure, as the effects of preferential flow were so pronounced that the data could not be fit to the CDE.

E. coli concentrations in the effluent were 2 to 3 orders of magnitude lower and far more variable than those of Cl^- and NO_3^- . However often relatively high *E. coli* concentrations occurred well before the Cl^- or NO_3^- peaks, and remained at relatively high concentrations long after Cl^- and NO_3^- had returned to background values. Although the relative *E. coli* concentrations in the leachate were low, the actual *E. coli* concentration in the leachate frequently reached very high levels (5300 CFU mL^{-1} in a disturbed column and 1200 CFU mL^{-1} in an undisturbed columns). *E. coli* concentrations of this order would be of serious concern if they reached ground water. Analysis of the soil after leaching showed that in both the disturbed and undisturbed columns the highest *E. coli* concentrations occurred in the top few cm of soil, giving rise to concerns regarding overland flow of water and *E. coli*. A review of Cl^- tracer movement in the field from which the soil for the experiments was collected shows that *E. coli* contamination of ground water from manure application to knolls and mid-slopes is unlikely. However an increased risk exists in depressional areas due to both increased leaching rates and possible deposition of *E. coli* in soil eroded from adjoining hill slopes.

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