Measurement of Physical and Hydraulic Properties of Cattle Manure with Soil Analysis Techniques

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Introduction

Surface runoff from manure amended areas and from pastures with grazing livestock commonly results in transport of nutrients, pathogens, and organic material to aqueous systems both ground and surface water. Similar to soils, the transport and fate of dissolved nutrients in manure depends on the magnitude and direction of the water flux, primarily affected by the hydraulic gradient, which is the driving force of water flow, and the physical and hydraulic manure properties. From a physical perspective, manure is a heterogeneous, polyphasic, disperse porous medium and can generally be considered as a three-phase system, composed of solid (organic matter), liquid, and gas.

Our study focuses on the fundamental physical and hydraulic characteristics of cattle manure that primarily affect the transport of liquid water and gas within the manure. We used techniques commonly applied in soil science to measure physical properties of fresh cattle manure. This included the determination of the manure dielectric permittivity - volumetric water content relationship with time-domain reflectometry (TDR) and capacitance-based dielectric estimates. A liquid retention curve for cattle manure was determined based on gravimetric measurements and the chilled-mirror dew point technique.

Materials and Methods

Experimental Setup

The GS3 sensors (Decagon Devices, Inc., Pullman, WA) and TDRs (1502B Metallic Cable Tester, Tektronix Inc., Beaverton, OR) were calibrated in six cattle manure samples to establish a generic calibration equation identifying the correlation between the dielectric permittivity (K_a) output from the sensors and the volumetric water contents (θ_v), determined with gravimetric measurements. At the end of the evaporation experiment, the lengths, widths, and volumes of the manure shrinkage were estimated. The final water contents and bulk densities were determined by drying the manure samples at 70 ºC for 48 hours to minimize oxidation of the organic material.

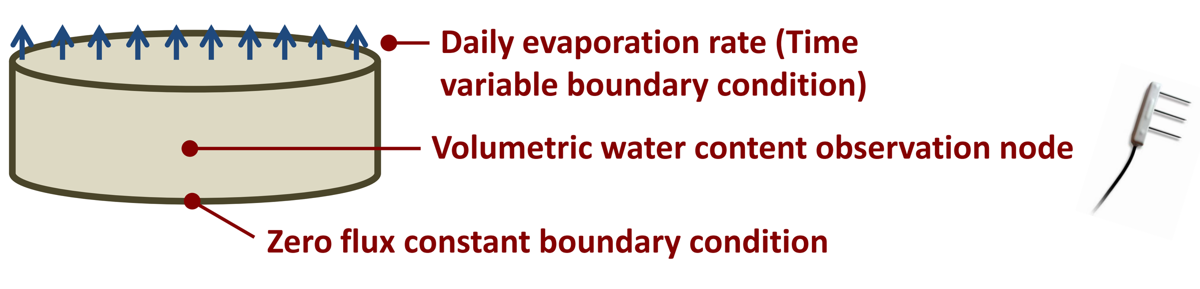
GS3 moisture sensor installed at the center of the calibration ring

Pre-calibrated load cell (ESP-10, Transducer Techniques Inc., Temecula, CA)

We measured water potential of cow manure with the chilled-mirror dewpoint technique (WP4-T, Decagon Devices, Inc., Pullman, WA) to investigate the structural and functional relation between manure volumetric water content (θ_v) and water potential under equilibrium conditions. Three trials of mixed cattle manure samples were examined to generate the water retention curve for cow manure. In each trial, the suite of water potential measurements included six sub-samples prepared from mixed cattle manure samples. The manure samples were equilibrated at a constant room temperature (≈ 22 °C) in a sample holder at various potentials for different time periods allowing the water to evaporate from "as-excreted" conditions until the samples were air dried.

HYDRUS-1D Inverse Numerical Simulation of Evaporation

The van Genuchten-Mualem hydraulic conductivity model (van Genuchten, 1980) was applied in the HYDRUS 1-D inverse simulations with the hydraulic properties obtained from the water retention curve, including residual water content (θ_r), saturated water content (θ_s), parameters α and n in the water retention function, while the saturated hydraulic conductivity (K_s) was assigned as the unknown parameter to be solved for.



Results and Discussion

1. Empirical Calibration Equations for GS3 Moisture Sensors

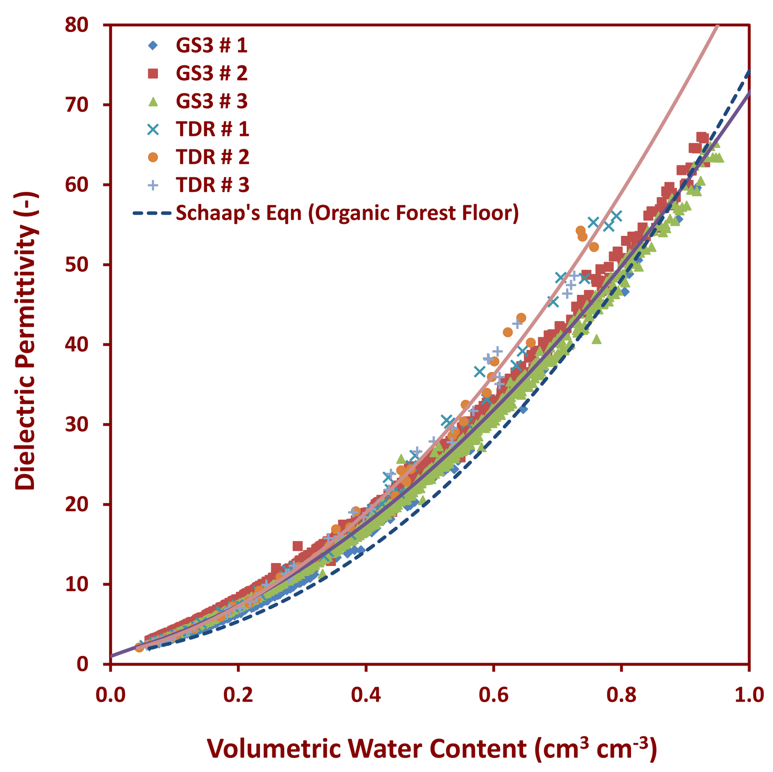


Table 1. Parametric expression and accuracy of the parameters fitted to the measured data to determine the relationship between K_a and θ

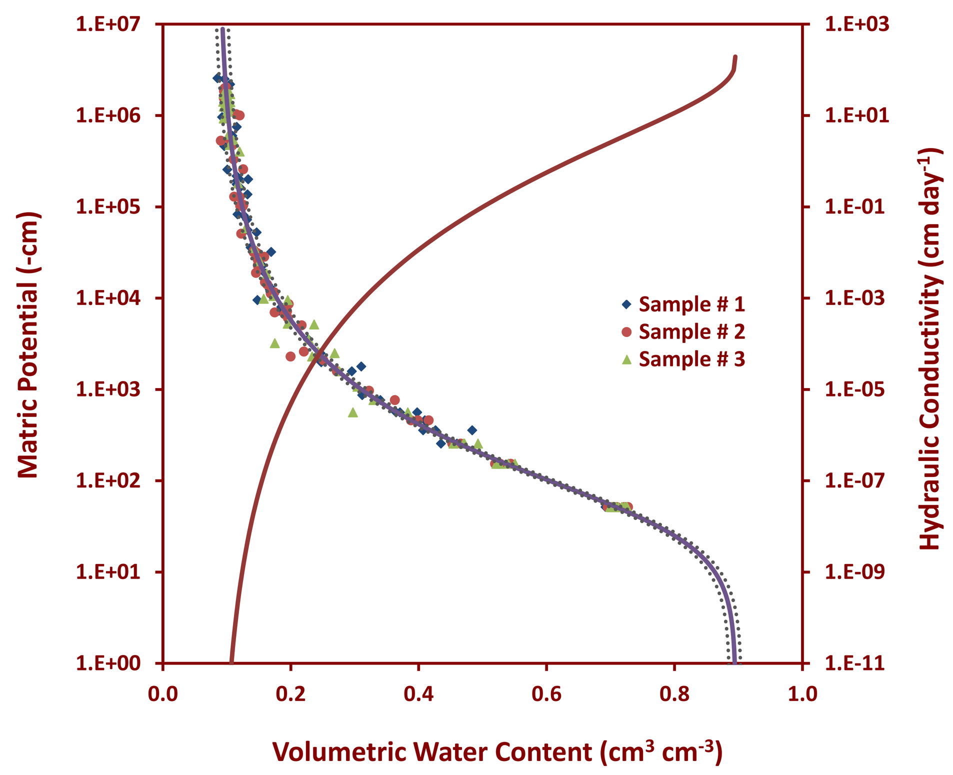
Measurement Technique	Coefficients $\theta = \left(A\sqrt{K_a} - B\right)^C$ A	B	C	n	RMSE (cm³ cm⁻³)	R^2
GS3 - Dairy manure	0.136	0.150	1.061	2579	0.0125	0.982
TDR - Dairy manure	0.121	0.130	0.990	135	0.0120	0.987
GS3 - Non-mineral soils†	0.118	0.117	1.000	-	-	-
TDR (Schaap et al., 1997) - Organic forest floor material	0.133	0.146	0.885	505	-	0.963

† Potting soils, perlite, and peat moss at salinities ranging from 0 to greater than 4 dS/m.

2. Water Retention Equation for Cattle Manure

Table 2. Model parameters obtained from fitting the van Genuchten parametric expression to the measurement data

Parameters	
θ_r (cm³ cm⁻³)	0.0869
θ_s (cm³ cm⁻³)	0.895
α (cm⁻¹)	0.027
n	1.391
m	0.281
N	210
R^2	0.9966

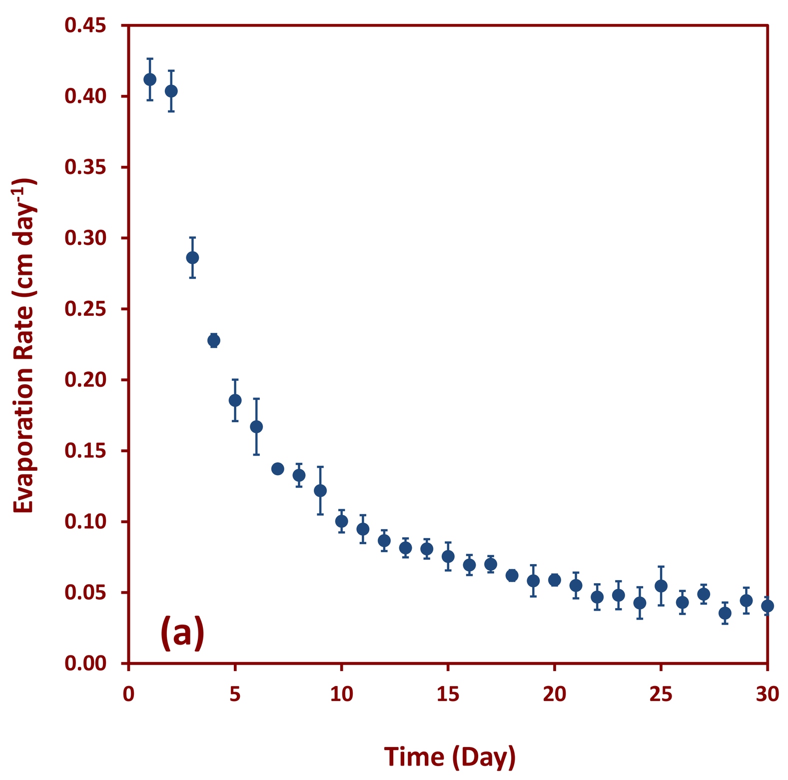


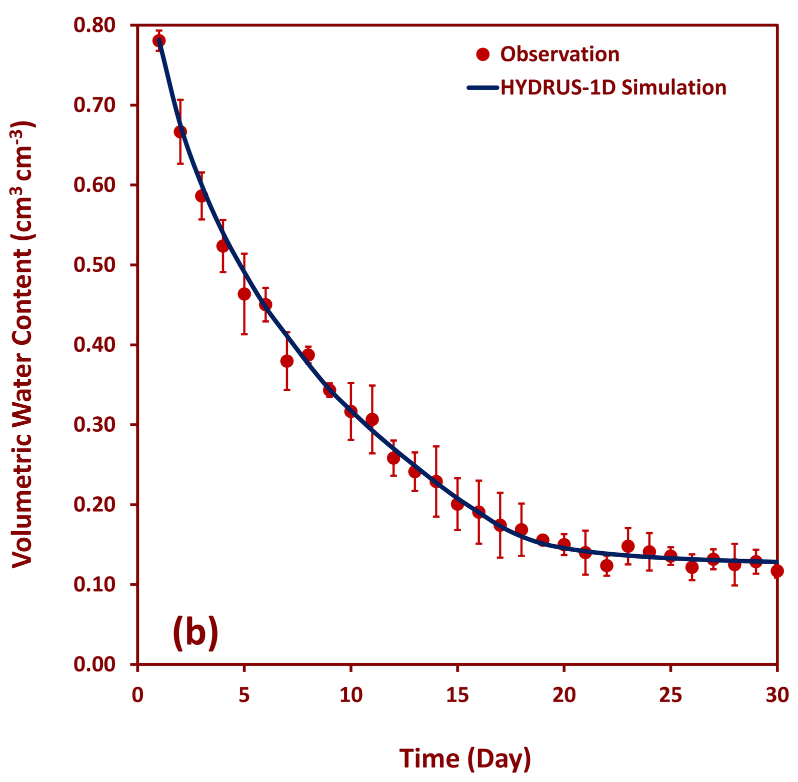
The experimental water retention data were analyzed by fitting the van Genuchten hydraulic model (van Genuchten, 1980):

$$\Theta(\psi_m) = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[\frac{1}{1 + (\alpha|\psi_m|)^n}\right]^m$$

where: Θ is the degree of saturation, ψ_m is the matric potential [-cm], θ is the volumetric water content [cm³ cm⁻³], θ_s and θ_r are the saturated and residual water contents [cm³ cm⁻³], respectively, while α, m, and n ($m = 1 - 1/n$) are the shape parameters related to the bubbling pressure and pore-size distribution.

3. Saturated Hydraulic Conductivity and Unsaturated Hydraulic Conductivity Function





(a) Evaporation rates monitored from the evaporation experiment of three dairy manure samples in a constant room temperature at 22 ºC. (b) Comparison between the measured and simulated volumetric water contents from the HYDRUS-1D inverse solution.

Table 3. Statistical summary of non-linear least-squares analysis from estimation of the saturated hydraulic conductivity (K_s).

Parameter	Value (cm day⁻¹)
Saturated hydraulic conductivity (K_s)	194.19
Number of measurements (N)	90
Standard error coefficient (SE)	56.88
Lower 95% confidence limit	81.173
Upper 95% confidence limit	307.20

Numerical modeling of transient water flow in cattle manure, as a porous medium, requires an accurate estimation of a number of hydraulic parameters, including the water retention curve, saturated hydraulic conductivity, and unsaturated hydraulic conductivity function. Overall, the presented research uses soil analysis techniques to determine physical and hydraulic properties of cattle manure. The evaporation process simulation derived using the HYDRUS-1D inverse model provides strong support for the hypothesis that Richards equation can describe hydrodynamic processes taking place in dairy manure relevant to natural drying processes. However, the effects of manure's surface crust formation and shrinkage, likely to occur variably under field conditions, potentially modify the retention and hydraulic conductivity functions. Ongoing studies of these effects will allow us to determine if Richards equation is valid to characterize the unsaturated flow associated with these conditions.

Acknowledgments

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