Simulation of Greenhouse Gas Emissions after Land Application of Cattle Manure

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ABSTRACT

Land application of cattle manure is a cost effective source of nutrients and organic matter for crop production. However, emissions of greenhouse gases after land application contribute to air pollution impacting public health and welfare. Knowledge of gas transport mechanisms in manure-amended soils is an important part of predicting gaseous emissions from land application practices. A predictive empirical model was developed based on detailed numerical simulations of wetting and drying processes in manure using HYDRUS-1D. Similar to the principle of soil respiration, the fundamental model parameters, considered in gas production from land application of manure, include water content, temperature, and soil/manure characteristics. Because of the temperature dependency of gas transport processes, heat transport was also included in the simulations. The model was calibrated and validated based on field measurements of gaseous emissions after surface application of four different manure sources (i.e. dairy manure, beef manure, dairy compost, and beef compost). Soil / manure moisture contents were monitored during the course of measurements using dielectric sensors. The developed model provides improved means for estimation of greenhouse gas emissions from land-applied manure, based on the physical and thermal soil and manure properties.

THEORETICAL CONSIDERATIONS

Measuring Gas Flux (J_g) in Closed Dynamic Chambers:

Calculation of the gas flux with the closed dynamic chamber system (with correction for temperature and pressure) is as follows.

$$J_g = \frac{P \cdot V}{P_s \cdot R \cdot S \cdot (273.15 + T)} \cdot \frac{\partial C}{\partial t}$$

where P is the measured ambient pressure, V is the total system volume, P_s is the standard pressure, R is the gas constant, S is surface area of the chamber over the emission source, T is the temperature (ºC), C is the gas concentration, and t is the observation time.

Modeling of Gas Transport and Production:

The HYDRUS-1D software package (Šimunek et al., 2008) includes a module for simulating carbon dioxide (CO_2) transport in soils, considering diffusion in both liquid and gas phases and convection in the liquid phase as transport mechanisms. The one-dimensional CO_2 transport is described by the mass balance equation (Šimunek and Suarez, 1993; Suarez and Šimunek, 1993):

$$\frac{\partial C_T}{\partial t} = -\frac{\partial}{\partial z}\left(J_{da} + J_{dw} + J_{ca} + J_{cw}\right) - Qc_w + S$$

where C_T is the total volumetric concentration of CO_2; J_{da} is the CO_2 flux caused by diffusion in the gas phase; J_{dw} is the CO_2 flux caused by dispersion in the dissolved phase; J_{ca} is the CO_2 flux caused by convection in the gas phase; J_{cw} is the CO_2 flux caused by convection in the dissolved phase; S is the CO_2 production/sink term; and Qc_w is the dissolved CO_2 removed from the soil by root water uptake (negligible in our study). This uptake term assumes that when plants absorb water, dissolved CO_2 is also removed from the soil-water system.

The CO_2 production (S) is considered as the sum of the production by microorganisms (γ_s) and the production by plant roots (γ_p - negligible in our study)

$$S = \gamma_s + \gamma_p$$

$$\gamma_s = \gamma_{s0}\prod_i f_{si} \quad \text{and} \quad \gamma_p = \gamma_{p0}\prod_i f_{pi}$$

$$\prod_i f_i = f(z)f(h)f(T)f(c_a)f(h_\phi)f(t)$$

where the subscript s refers to soil microorganisms and subscript p refers to plant roots. γ_0 is the optimal CO_2 production at 20ºC under optimal water and CO_2 concentration conditions. The reduction coefficients are represented by z (depth), T (temperature), h (pressure head or water content), c_a (CO_2 concentration), and t (time).

THEORETICAL CONSIDERATIONS

Soil and Cattle Manure Hydraulic Parameters:

The soil-hydraulic function of van Genuchten (1980) using the statistical pore-size distribution model of Mualem (1976) was implemented to obtain a predictive equation for the unsaturated hydraulic conductivity function in terms of soil and manure water retention parameters. The van Genuchten's water retention parameters and hydraulic conductivities used in the simulations are listed in the table below.

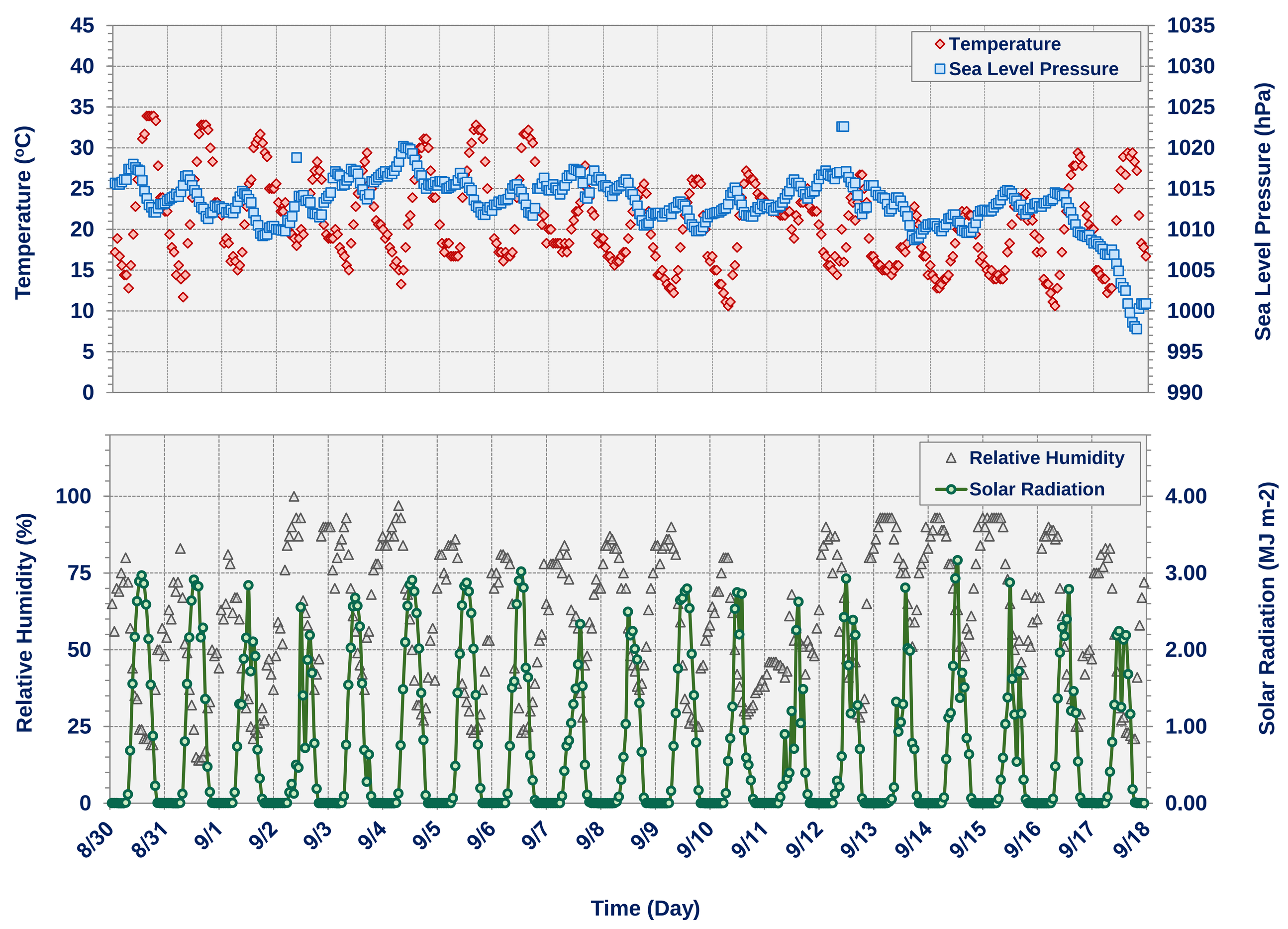
Medium	van Genuchten model parameters†					
	Θ_r	Θ_s	α	n	m	K_s
	($cm^3\ cm^{-3}$)	($cm^3\ cm^{-3}$)	(cm^{-1})			($cm\ d^{-1}$)
Cattle manure	0.087	0.895	0.027	1.391	0.281	190
Millville silt loam	0.097	0.428	0.012	1.916	0.479	65.73

† Θ_r = residual water content; Θ_s = saturated water content; α, m, and n = shape parameters related to the pore-size distribution; and K_s = saturated hydraulic conductivity

EXPERIMENTAL SETUP

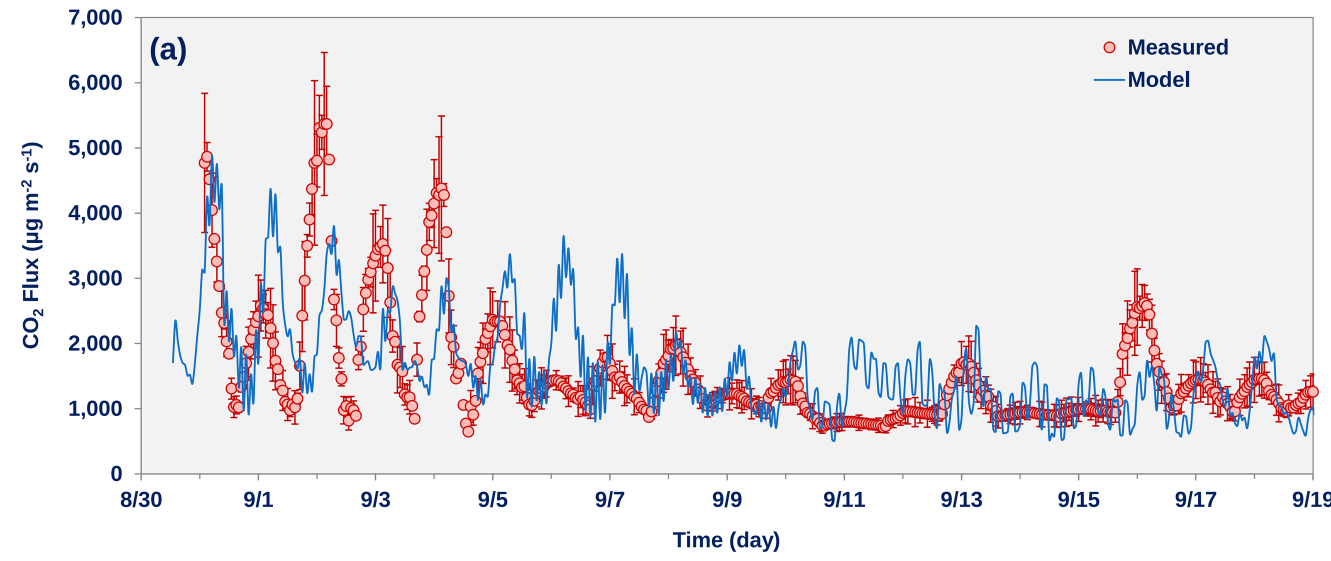
Manure surface application (2.5 cm) plots were set up at Greenville Research Farm (central coordinates: 41° 45' 58.5" N 111° 48' 41.9" W) in North Logan, UT during Aug. and Sept. 2013 to quantify gaseous emissions. The soil / manure moisture content sensors were inserted into the surface to a depth of 5 cm. A multiplexed automated chamber system was employed for evaluation of manure management practices. The Figure below shows a closed dynamic chamber measuring gas buildup to estimate emissions from soil surface-applied manure.

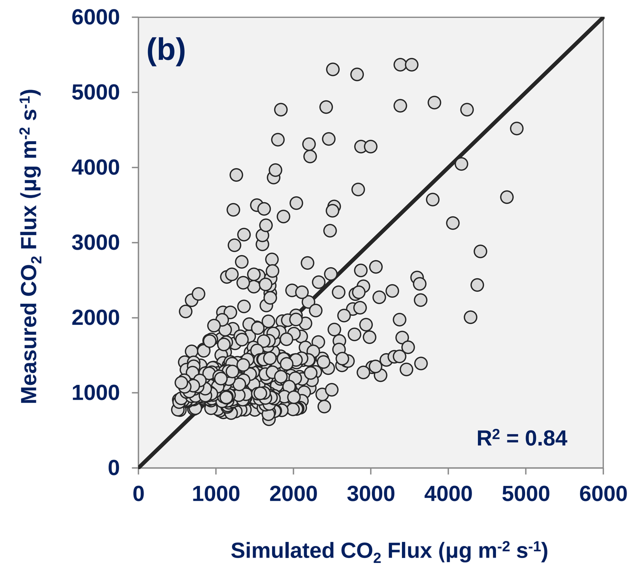
In addition to gas emissions, primary meteorological factors affecting evaporation, including temperature, atmospheric pressure, relative humidity, and solar radiation were monitored (below).

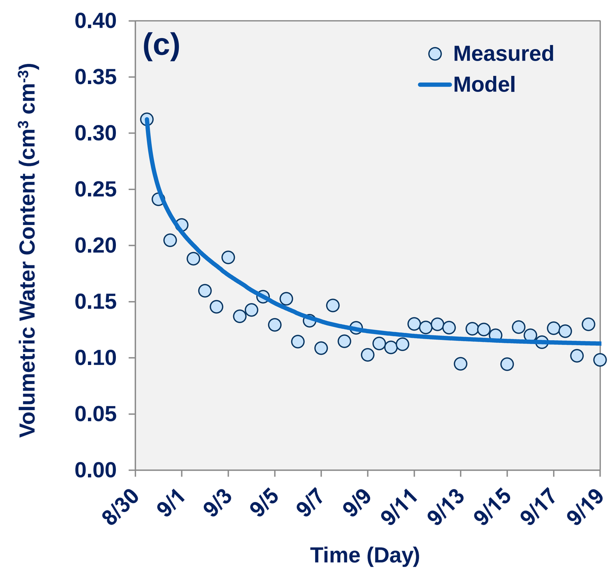


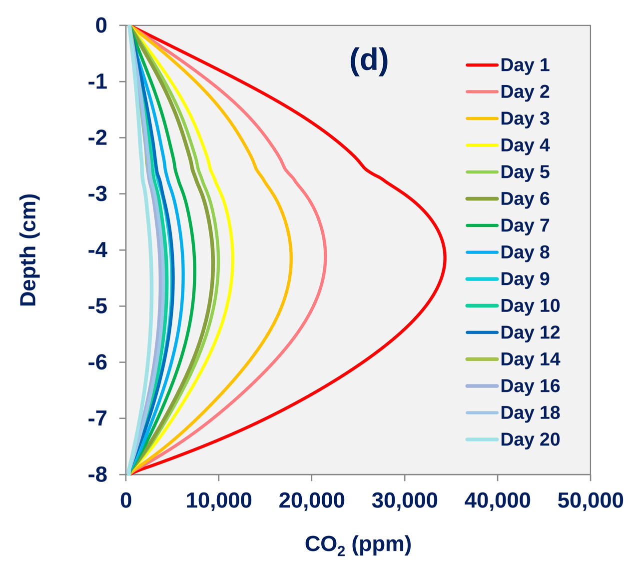
RESULTS AND DISCUSSION

Figure (a) shows a good agreement between measured and modeled CO_2 fluxes for surface application of cattle manure on Millville silt loam. The coefficient of determination R^2 was 0.84 as illustrated in Figure (b). The large deviations between the measured and modeled CO_2 fluxes were observed at the beginning of drying stage when the water content was rapidly changing as shown in Figure (c). The measurements are presented in hourly values to investigate variations in gas emissions related to changes in temperature. Figure (c) shows the comparison of the predicted and measured daily water contents approximately at 5 cm depth. Figure (d) shows the simulated CO_2 concentrations in the profile during the course of experiment.









In this study, we presented a model development to investigate gas (i.e. CO_2) emissions from land application of cattle manure using HYDRUS-1D. The accuracy of the model is limited by the assumption that the gas production by microorganisms is identical in all materials. The concept of model development can be further used for investigation of other gaseous compounds and greenhouse gases emitted from manure.

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