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Research Brief

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Phosphorus Transport in Soil During Water Infiltration

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During rainfall following application of phosphorus (P)-laden fertilizer or animal manure to most soils, sorption interactions tend to heavily retard the inward movement of P molecules during water flow. However, excessive application tends to create conditions conducive to P penetration during periods of intense rainfall. Penetration into a soil column was investigated during constant-flux infiltration of P-laden aqueous solutions with a range of high concentration C_0 and two imposed liquid flux L.

Observed results were simulated using a model that describes both transient water flow during unsaturated conditions and convective-dispersive solute transport. Richards' equation was used to describe water flow, and a parallel 2-site nonlinear, kinetic mechanism was used to describe P sorption. The mechanism was assumed to follow n^{th}-order, Freundlich-type reversible kinetics with an instantaneous reaction occurring in type-I sites and a slow kinetic reaction occurring in type-II sites.

Aqueous P solutions with a range of C_0 (as KH_2PO_4) were applied at constant flux L to columns of air-dry soil from the spodic horizon of a Myakka fine sand. C_0 in influent solutions ranged from 100 to 800 g m^{-3}. Low and high influx of 0.20 and 1.0 in/h, respectively, were much smaller than the saturated hydraulic conductivity K_{sat} of 26.1 in/h, assuring that water unsaturation would occur in the soil.

Stirred batch experiments with soil-solution-ratios (8) ranging from 1.0 to 6.4 Mg m^{-3} were conducted to obtain sorption rate coefficients. During the initial stages of sorption in the batch experiments, solution phase concentrations (C) of P decreased due to a very fast apparent sorption reaction, which slowed down with time. For a large equilibration time, the observed Freundlich sorption isotherm was $S_{eq} = 67.6\ [C_{eq}]^{0.378}$ with C_{eq} and S_{eq} given in units of g/m^3 and g/Mg, respectively. This nonlinear relationship provided a S_{eq}/C_{eq} ratio which decreased by only 3.6-fold from 3.85 to 1.06 as C_0 increased by 8.0-fold from 100 to 800 g/m^3. This ratio decrease implies enhanced P mobility in soil during water flow.

The sorption submodel satisfactorily described the nonequilibrium reaction for the batch experiments, but rate coefficients varied with 8. These results imply that the sorption submodel assumptions were overly simplistic.

Distributions of water content 2 with depth in the soil columns (Fig. A) reveal flat transmission zones occurring behind sharp wetting fronts for each flux rate. Cumulative infiltration for all cases was 8.4 cm. As expected, the higher fluid influx resulted in higher 2 in the unsaturated transmission zone since L < K_{sat} . An inverse technique was applied to the terminal 2 distributions in order to obtain saturated hydraulic conductivity and parameters in van Genuchten's analytical function for water retention. These optimized parameters were used in simulations for water flow.

Experimentally-determined sorption rate coefficients described P transport in the column experiments for the higher (Fig. B) but not for the slower influx. Hence, calibration of rate coefficients was necessary for describing P transport during the slower flux. This difference in rate coefficients with L indicates that chemical sorption reactions in the soil were more complex than the simple mathematical description provided in the transport model. Terminal distributions of P concentrations in solution (C) and sorbed (S) phases reveal minimal and maximal P penetration with C_0 = 100 and 800 g/Mg, respectively. P penetration into the soil was enhanced with increasing C_0 due to nonlinear sorption behavior. In all cases, terminal solute fronts occurred well behind the terminal wetting front due to retardation.

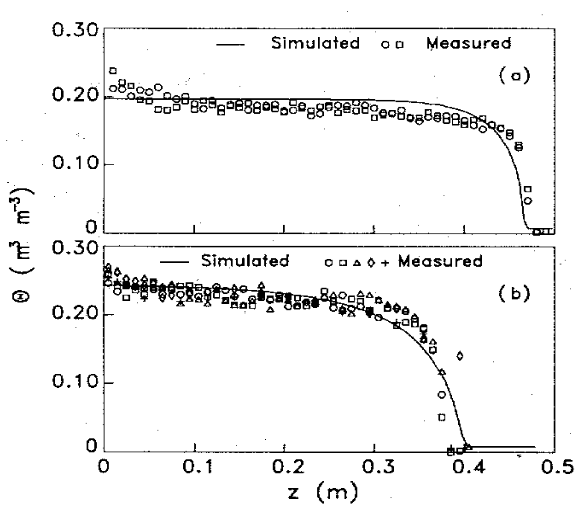

Fig. A. Terminal water content distributions with depth for 2 constant-flux infiltrations: a.) 0.20 and b.) 1.0 in/h (Fig. 3 in Chen et al. 1993)

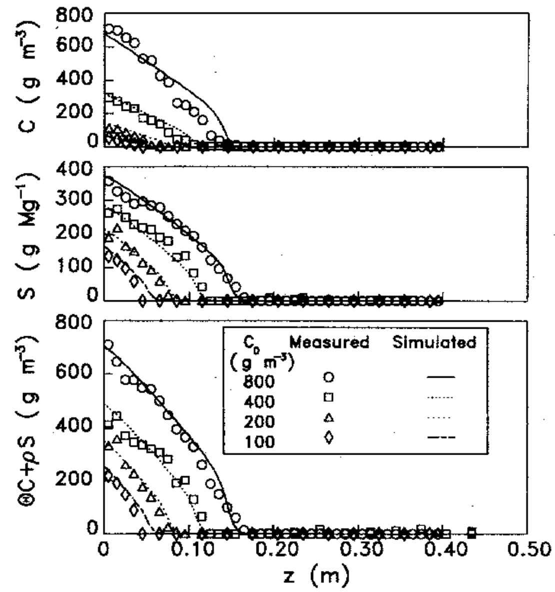

Fig. B. Observed (points) and simulated (lines) terminal P distributions in solution C, sorbed S, and combined phases of soil for water flux of 1.0 in/h (Fig. 4 in Chen et al. 1993)

Penetration of P in the soil was also observed to be greater for the higher flux L with smaller residence time due to increased P mobility resulting from enhanced sorption kinetics. Thus, P entry into this soil during rainfall following fertilizer or waste disposal depends upon both P concentration in the solution phase C_0 and rainfall intensity L.

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