Development and Validation of a 3D Coupled Hydrologic-Biogeochemical Model for Evaluation of the Impact of Water-Table Management on Nitrate Loads from Tile-Drained Agricultural Fields

Basic Information

Title:	Development and Validation of a 3D Coupled Hydrologic-Biogeochemical Model for Evaluation of the Impact of Water-Table Management on Nitrate Loads from Tile-Drained Agricultural Fields
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1. Feng Yue, A.J. Valocchi, R.J. Hudson, 2004, Physically-based 3D hydrologic conjunctive modeling of water flow in tile-drained agricultural fields in Groundwater Quality 2004 Proceedings, 4th International Conference, University of Waterloo, Ontario, Canada.

Problem and Research Objectives

One of the most promising approaches to minimizing nitrate export to rivers draining agricultural watersheds is water table management, or controlled drainage. The Illinois District of the USGS has conducted a field pilot study of the benefits of controlled drainage at an active farm in east-central Illinois. Two adjacent 40-acre plots, one with tile management and the other without, have been instrumented for collecting a variety of data. Modeling is required to fully interpret the field data and to extend the results to conditions on other farms.

The project involves developing and applying sophisticated simulation models to properly quantify the hydrologic and nitrogen cycle fluxes on such sites. Fully 3-D models of subsurface flow and nitrogen processes will be necessary in order to simulate both surface runoff/runon and subsurface flow between the adjacent managed/conventional plots. This will allow us to properly analyze the field data and assess the environmental benefits of water table management.

Methodology

We have been combining two different modeling approaches in order to interpret data previously collected by USGS researchers from the paired set of agricultural fields with and without controlled subsurface drainage.

For hydrologic analysis, we have employed a 3-dimensional model with accurate topography to simulate both surface runoff/runon between the fields and subsurface flow between the two halves of the study sites. These results are being combined with water budgets over both short and long time periods in order to characterize the water fluxes at the site.

For nitrogen cycle modeling, our initial plan was to employ the DRAINMOD model and develop a new model for in studying the field sites, but we have chosen instead to focus on an established model (DSSAT) with excellent and soil and plant process representations. Automatic calibration using the University of Arizona Shuffled-Complex Evolution algorithm has been employed to obtain optimal parameters for Illinois conditions and develop means of predicting N mineralization for sites based on simple soil N test results.

Principal Findings and Significance

3-D Physical Model Development and Testing: Following our previous work updating the hydrologic code in the CHM3D model, further tests of its suitability for application in this study were conducted. The relatively fast Alternating-Direction-Implicit method (ADI) was employed to solve the system of coupled differential equations. We found that the accuracy of ADI is limited to extremely small time steps (~10^{-3} s) when solving variably-saturated subsurface flows. Although the ADI method is known to be reasonably accurate in solving parabolic differential equations, those equations usually contain small diffusion coefficients. The subsurface flow equation is not such a case because the presence of specific storage coefficients on the order of 10^{-6} can results in large "diffusion" coefficients. If large time steps are employed, the numerical results with ADI showed strong artificial orientation errors when compared with the analytical solutions of some example problems. We believe this type of error is common the whole family of directional splitting methods. Therefore, in the future we would consider applying another robust numerical solver in the CHM3D model that aims at long term flow simulations.

Hydrologic Modeling of the Ford County Field Site: Hydrologic modeling efforts for the Ford County drainage site include: i) inspection of the field data, ii) analysis of water budgets, and iii) numerical simulations carried out with the integrated hydrology model HydroGeoSphere. i)

Inspection of the Data: The hydrologic data provided by the USGS were compiled and inspected for problems. The main problem that we are aware of is that during some periods, some drainage tiles became full, rendering the flow meter readings invalid. Alternate means of estimating flows are being examined.

ii) *Water budgets*: As an example water budget, we present here results over one time period that we carefully analyzed – Oct. 11-Nov. 14, 2001. The main terms in the budget include precipitation (15.4 cm), evapotranspiration (7.6 cm), drainage discharge (7.7 cm) and soil water storage change (<~2.5 cm), which are balanced to within the margin of error. The cumulative depth of water discharged from the managed side of the field was twice that of the unmanaged side. We are currently pursuing explanations of this counterintuitive result.
iii) *Modeling*: To generate the finite element mesh for the field site, actual topography data were used and all 16 tiles were given a uniform slope and diameter. Simulations were generated for a part of the period of the water balance above. The initial groundwater table was set right below the tile lines and the subsurface boundary fluxes were assumed to be zero everywhere except at tile drain outflow nodes. The critical depth boundary condition was used over the entire surface domain. To make calibration tractable, a uniform set of soil physical properties was employed. The simulated tile discharges from the conventional and controlled fields match the timing of the observed data reasonably well, but tends to underestimate the flow peaks in both fields.

Nitrogen Cycle Modeling of the Ford County Field Site: Nitrogen cycle modeling efforts at the Ford

County drainage site include: i) inspection of the field data and ii) preliminary field N balances.
i) *Inspection of Data:* The chemistry and flow data received from the USGS include nitrate, nitrite and dissolved phosphorous concentrations. Due to gaps in flow and N data records, it is difficult to accurately quantify fluxes from the site. Unfortunately, the data on fertilizer inputs and crop yields were not available due to difficulties in communicating with the owners of the field site. To enable us to estimate the input of inorganic nitrogen to the field via mineralization of organic matter, we measured labile organic N for 120 samples collected from the field. The labile organic N was measured using the new Illinois Soil Nitrogen Test.

ii) Preliminary N Balance: While N export via tile discharge is considerably lower in the managed field, it is likely that subsurface export from the managed field added to the conventional field fluxes of water and nitrate. Our final N balance is pending.

Plant-Soil Model Calibration: A critical part of modeling the effects of water table management on nitrogen fluxes is determining how it affects crop growth and soil N mineralization. Thus, we began working with a well-established plant-soil model (DSSAT). First, the model code was adapted for use in tile-drained fields by incorporating Hooghoudt's equation into the hydrology subroutines. Next, we employed automatic calibration by a genetic algorithm (SCE-UA) to determine optimal parameter values for simulating N mineralization and organic matter decay. We found a significant correlation between the quantity of N in the model's "slow SOM" pool (R^2=0.70, P<0.001) and ISNT measurements in fields where fertilizer rate studies had been conducted. This relationship can be used to develop strong constraints for model calibration at sites where N-rate trials have not been conducted, perhaps even permitting direct estimation of the initial magnitudes of the model N pools from ISNT and total soil C and N measurements. In other words, we expect to be able to accurately predict net mineralization of soil organic N for the Ford County field site by combining the model and ISNT measurements that we have obtained.

Significance: We expect that our final results will show that accounting for losses of N via subsurface flow from fields with water table management will be important for assessing their net environmental impact. In addition, we have developed methods of estimating net mineralization of N in fields by combining measurements of a labile soil N fraction (ISNT) with automatic calibration of a dynamic simulation model (DSSAT). Such results will be highly useful for managing fertilizer application rates in a way that reduces N losses to the environment impacts.