BELOW-GROUND PROCESSES IN THE ARS COTTON MODEL

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Abstract

The second generation cotton model (SGCM) was designed as an expandable modular crop simulator. The paper presents an outline of the essential features of the below-ground component based on the two-dimensional soil and root process simulator 2DSOIL. New modules developed specifically for SGCM, and modules under development are described.

Model Description

The second generation cotton model (SGCM) was designed as an expandable crop simulator capable of accommodating existing knowledge on cotton crop growth and development, of including new knowledge as it becomes available, and of including new management actions as they are introduced. The modularity paradigm (Reynolds and Acock, 1997) has been chosen to achieve this goal and object-oriented programming was used to code the simulator.

A two-dimensional soil representation was selected to simulate below-ground processes. The soil profile between two mid-row positions is divided into cells with a grid formed by vertical and horizontal lines. Soil state variables, such as soil water content, soil temperature, nitrate concentration, root density, etc., are simulated for each of the cells. Other options considered were: (1) a zero-dimensional soil representation, or 'nutrient bucket', in which a single value of nutrient and water content is assigned to the whole soil profile, and (2) a one-dimensional soil representation in which soil is divided into layers, and changes in soil and root status from row to inter-row positions are ignored. The criteria used to select the 2-dimensional soil representation included: (a) ability to account for distributions of water and nutrients within a soil profile, (b) ability to account for differences in properties among soil horizons, and (c) ability to simulate applications of water and chemicals that are asymmetrical with respect to plants, like alternate row irrigation or banded fertilizer application. The zero-dimensional soil representation does not satisfy any of these criteria, and the one-dimensional representation satisfies criteria (a) and (b), but not (c).

A modular structure of the soil simulator was required from the soil simulator to provide the expandability of the soil component in the SGCM. This requirement arose from the wide variety of crop and soil management practices used in cotton production. It was much more practical to have models of management actions in separate modules, added as needed rather than rigidly 'welded' in the simulator.

A modular simulator of soil and root processes in two dimensions, 2DSOIL, satisfied the aforementioned dimension and modularity requirements (Timlin et al., 1996, Timlin and Pachepsky, 1997). This simulator was developed in 1992-1995 specifically to be interfaced with plant models in crop simulators. The sources for 2DSOIL were SWMS_2D from the ARS Salinity Laboratory (Simunek et al, 1992), the crop simulator GLYCIM from the ARS Remote Sensing and Modeling Laboratory (Acock and Trent, 1991), and the soil simulator LIBRA from the Mass and Energy Transport Laboratory (Pachepsky, 1990). 2DSOIL was used in potato, corn, and soybean crop modeling in 1996-1998.

2DSOIL has distinct independent modules, each for a specific soil or root process. Transport processes are simulated for water, nitrate, heat, and carbon dioxide. The boundary interface sets potential water, heat, nitrate, and carbon dioxide fluxes on the soil surface. Simulated root processes are root growth and proliferation, root water uptake, and nitrate uptake. Cation exchange, gypsum dissolution-precipitation, and carbonate-bicarbonate equilibrium are included in chemical simulations. Crop management actions affecting soil are each simulated with a separate module.

Modules in 2DSOIL are independent of each other because they encapsulate their parameters and algorithms as private information. The modules interact by using public information which includes only soil state variables in soil grid cells and time steps. Addition or replacement of modules is very simple because of the minimized coupling of the modules.

Coupling of the soil simulator with the plant simulator is also minimized to provide a manageable model. The concept of carbon traded from shoots for water and nitrogen from roots (Acock and Trent, 1991) is implemented. The shoot simulator obtains the potential total water and nitrogen uptake values from the soil and provides the actual total uptake values and the potential carbon amount available for the root growth. The root simulator provides the potential uptake of water and nitrogen from soil and the actual carbon amount used for the root growth.

2DSOIL was revised, expanded, and re-written in C++ to be used in the SGCM. A grid generator module was developed to relieve the users of selecting grid cell size and position. The module requires input of surface micro-relief parameters such as furrow depth and width and ridge height

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and width to build grids for soil profiles with uneven surfaces. It uses soil data files to accommodate cells within soil horizons. Maximum cell width and minimum cell height have default values that can be modified by users.

A new soil nitrogen transformation module was developed for the SGCM. The SOILN model of Berstrom et al. (1991) was used. This model has a minimum number of pools, and still provides a satisfactory description of nitrogen turnover in soils. Humus, litter, and organic fertilizer pools are subject to mineralization. Litter and organic fertilizer pools are subject to humification and nitrogen immobilization from nitrate and ammonium. The ammonium nitrogen resides in the soil solid phase and may be immobilized or nitrified. Sources of the ammonium nitrogen are mineralization from the three organic matter pools and fertilizer applications. Nitrate nitrogen resides in the soil solution. It can be denitrified or immobilized. Sources of the nitrate nitrogen are nitrification and fertilizer application. Nitrate is taken up by roots, and dead roots replenish the litter pool. All processes but denitrification are simulated with first-order kinetics equations with rate constants dependent on soil temperature and soil water potential.

Root water uptake is driven by differences between soil water potential and apparent leaf water potential. The latter is adjusted hourly to match the shoot transpiration demand set by the new stomatal regulation model Eureka (Acock and Gallardo, in press). Vascular resistances are different for young and mature roots. The effective soil resistance depends on root density and soil water potential.

Root nitrogen uptake is simulated as a combination of passive and active uptake (Huwe and van der Ploeg, 1991; Hansen et al., 1991). Nitrogen is transferred to the root surface by mass flow and diffusion. The diffusion is driven by the difference between soil nitrate concentration and nitrate concentration on the root surface. The latter is set to zero when uptake is limited by nitrogen availability, and is found from the plant nitrogen demand when there is ample nitrogen supply.

The soil process visualization module was developed to take full advantage of the two-dimensional soil representation. Spatial distributions of soil water content, soil water potential, root density, and nitrate and ammonium contents can be shown in color as the simulations progress.

We are incorporating a new convective-dispersive model of root growth and proliferation in two dimensions in SGCM (Acock and Pachepsky, 1996).The propagation of roots is viewed as a result of a diffusion-like gradient driven propagation in all directions and convection-like propagation downward caused by geotropism. Root model equations are solved on the same grid with the same finite-element method as equations of water, solute, heat and gas transport in appropriate modules. Root diffusivity and geotropic proliferation rate depend on soil state variables (soil water potential, temperature, root density, nitrogen content) and soil strength.

Estimating soil hydraulic properties appears to be an important issue for SGCM applicability. We have adopted the NRCS model MUUF (USDA-ARS Grassland Soil & Water Research Lab) which allows estimation of hydraulic properties from soil name or soil map unit for a particular county in a particular state. The MUUF was modified to allow a user to enter his/her own data for soil mechanical analysis, bulk density, and/or organic matter content. We are testing this model for soils of the Cotton Belt.

Other soil modules under development will simulate soil strength, soil potassium, and tillage effects.

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