USDA Economic and Biophysical Simulations Models Useful for Assessing the Impact of Bioenergy Production

REAP is the **R**egional **E**nvironment and **A**griculture and **P**rogramming model developed by the USDA Economic Research Service. REAP is a price-endogenous mathematical programming model that incorporates the assumptions of neoclassical economics, supplemented by the best available estimated behavioral and biophysical relationships (e.g., for agricultural commodity supply and demand or nitrogen runoff). Many regularly updated data sets—production practices surveys, multiyear baselines, macroeconomic trend projections, and regional resource and land databases—are applied to construct and update REAP. To generate a baseline scenario, disaggregated regional data are used to map the baseline data projections into REAP's smaller units of analysis. The relationships between production practices and environmental performance indicators represented in the model are derived by using biophysical models.
http://www.ers.usda.gov/publications/tb1916/

FARM II is the **F**uture **A**gricultural **R**esources **M**odel **II** developed by the USDA Economic Research Service. FARM II is an integrated modeling framework designed for analyzing global changes related to long-run agricultural and environmental sustainability. FARM II includes a new land and water resources database linked to production of agricultural and forestry commodities according to agro-ecological zones characterized by irrigated or rain-fed production conditions, length of growing seasons, temperature regime, and plant hardiness zones. This database has been incorporated into a computable general equilibrium (CGE) model of the global economy based on the GTAP 7 database modified to reflect FARM II's economic structure. FARM II is in the process of being adapted for the analysis of the implications of a bio-based global economy and it will provide a global framework with links between the agricultural and energy sectors, trade policy, and land and water resource use at a fine spatial scale.
http://www.ers.usda.gov/Briefing/GlobalClimate/Questions/Cceqa3.htm

PEATSim is the **P**artial **E**quilibrium **A**griculture **T**rade **S**imulator developed by the USDA Economic Research Service. PEATSim is a partial equilibrium model that uses MCP to solve discontinuous functions associated with the TRQ schemes under the WTO. PEATSim is able to model domestic policies, including subsidies, price support, and loan rates. Countries included in PEATSim are the United States, European Union, Canada, Mexico, Japan, South Korea, Australia, New Zealand, China, Brazil, Argentina, and a Rest of the World region. PEATSim contains major crop and oilseed markets, oilseed product markets, sugar, livestock, and dairy. The model can be adapted to change or remove domestic policy levers to analyze the impact of biofuel policy changes. The impact of changing tariff and quota levels associated with products in the model can also be assessed. PEATSim has the flexibility to develop scenarios related to the demand for agricultural products for use in biofuels, and account for their byproducts in the feed and livestock sector.

USAGE-ERS is the **U.S**. **A**pplied **G**eneral **E**quilibrium model for the **E**conomic **R**esearch **S**ervice. USAGE is a 500-plus sector dynamic computable general equilibrium model of the United States using the GEMPACK software suite for solving. The model is a modified version for specific applications for agricultural and bioenergy analysis. A number of improvements have been made from the original version for agriculture and biofuels. New data from the Agricultural Resource Management Surveys (ARMS) and from the ERS's own official farm income and productivity accounts was embedded in the USAGE-ERS model, with detailed updates on output and cost for detailed farm commodity activities. Corn-wet milling is distinguished from corn dry-milling activity for the production of ethanol. Farm commodities were further split from their original aggregate (BEA) sectors in the USAGE model. The model interacts with the rest of the world with foreign trade and investment activities. Currently the model is used for incorporating long-term baseline projections and simulating economy-wide impacts from alternative energy policy.

WholeFarm is a computer aided planning system designed by USDA-Agricultural Research Service that optimizes planning decisions by allowing managers to build a specific farm enterprise plans on a field-by-field basis for all crops and livestock components. WholeFarm generates a variety of reports accounting for acreage, rotations, and production histories, along with comprehensive variable and fixed costs analyses for total farm income and expense reports, twelve-month itemized cash flow statement, and in-season cost monitoring. Once the WholeFarm farm plan has been developed, empirical information from crop rotation research can be coupled with the rotation histories to allow producers to obtain mathematically optimized combinations of crops to produce. WholeFarm can help producers decide which crops to plant in which fields that will maximize profits. While the original intent of WholeFarm was to focus on improving crop rotations, numerous other applications have emerged including focusing on regional impacts of changes in farm structures, potential changes in cropping patterns based on climate forecasts, and recently to address the potential of on-farm or local based bioenergy production.

SWAT is the **S**oil and **W**ater **A**ssessment **T**ool, a river basin- or watershed-scale model developed by USDA-Agricultural Research Service to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. SWAT is a physical based model that requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring within the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, and others are directly modeled by SWAT using these input data.
http://www.ars.usda.gov/Research/docs.htm?docid=9793

Auto-calibration Routine for SWAT developed by USDA-Agricultural Research Service applies the multi-objective evolutionary algorithm (MOEA) and Pareto ordering optimization for the auto-calibration of the Soil and Water Assessment Tool (SWAT). The non-dominated sorting genetic algorithm II (NSGA-II) is called in FORTRAN from a parallel genetic algorithm library (PGAPACK) to determine the Pareto optimal solution sets. More than 130 SWAT variables are simultaneously optimized with the calibration routine. The routine allows the production of a useful set of solutions for determining multiple objective trade-offs without degrading the objective criteria. This routine allows for the simultaneous automatic calibration of SWAT water quality and quantity parameters and the application of Pareto optimization in economic decision and policy-making problems related to conflicting objectives.
http://www.blackwell-synergy.com/action/doSearch

PGA-BIOECON is the **P**arallel **G**enetic **A**lgorithm for Computation of **Bio**physical and **Econ**omic Multi-objective Pareto Sets developed by USDA Agricultural Research Service applies a multi-objective evolutionary algorithm (MOEA) and Pareto ordering optimization for the computation of tradeoffs among economic, environmental, and policy efficiency objectives. The algorithm links SWAT to a firm level profit maximization model. The use of a genetic algorithm allows the economic model to calculate the profit maximizing inputs, which are then used to drive the SWAT model to simulate the environmental effects of the firm's decisions. The simplest application is to calculate the trade-offs between farm profit and the environmental quality. The computational framework is general, and any combination of physical and economic could used to specify the objectives. The algorithm is written in the R statistical language, and is implemented for parallel processing, but can also be used with a single processor. Whittaker et al., 2007, A Hybrid Genetic Algorithm For Multi-Objective Data Envelopment Analysis, European J. Operational Research (in press).

EPIC is the Environmental Policy Integrated Climate model. It was originally designed by the USDA-Agricultural Research Service to estimate erosion impacts on crop productivity. Later improvements incorporated functions to simulate environmental processes related to water quality and soil organic carbon dynamics. EPIC predicts the effects of management decisions on soil, water, nutrients and pesticide movements, as well as their combined impact on soil loss, water quality and crop yields for areas with homogeneous soils and management. Twelve plant species can be modeled at the same time, allowing inter-crop and cover-crop mixtures. Simulated processes include tillage effects on surface residue, soil bulk density, and mixing of residue and nutrients in the surface layer; along with wind and water erosion, hydrology, soil temperature, C, N, and P cycling, fertilizer and irrigation effects on crops, pesticide fate, and economics. http://www.brc.tamus.edu/epic/; http://www.public.iastate.edu/~tdc/i_epic_main.html.

An **Integrated Remote Sensing Version** for EPIC was developed by USDA-Agricultural Research Service for optimizing temporal and spatial parameters derived from satellite imagery. The primary application of this technology is to assess crop grain yields and biomass production at local and regional scales that can be extended to soil quality, soil carbon sequestration, and water quality assessments.

WEPP is the **W**ater **E**rosion **P**rediction **P**roject model, a physically-based simulation tool for estimating the effects of land management practices on runoff, soil loss, and sediment yield from hillslope profiles and small watersheds. WEPP was developed by USDA-Agricultural Research Service in cooperation with USDA-Natural Resources Conservation Service, USDA-Forest Service, and USDI-Bureau of Land Management. The model has been successfully applied on croplands, rangelands, forestlands, and construction sites. Both single storm and continuous simulations can be conducted that provide spatial and temporal soil erosion prediction output results in graphical and tabular form. The physical processes accounted for by the tool include climate generation (precipitation occurrence, temperatures, and wind), water infiltration, percolation, and runoff, soil detachment by rainfall and flowing water, sediment transport, sediment deposition, plant growth, residue decomposition, soil disturbed by tillage and consolidation. Types of conservation management that can be evaluate with WEPP include conventional/conservation tillage, crop rotations, mulching, buffer strips and terracing. The model soil loss predictions have been validated in a number of research studies within the U.S. and internationally. Large databases are supplied for climate, soils, management, and topography, which make WEPP east to use in the U.S. A variety of model interfaces are available, including a Windows stand-alone program, the GIS-linked product ArcView/ArcGIS extension – GeoWEPP, and a series of Web-based interfaces for hill slope and GIS-watershed simulations. http://topsoil.nserl.purdue.edu/nserlweb/weppmain.

AGNPS is the **AG**ricultural **N**on-**P**oint **S**ource Pollution Model integrating a system of computer models jointly developed by the USDA-Agricultural Research Service and USDA-Natural Resources Conservation Service to predict non-point source pollutant loadings within agricultural watersheds. AGNPS contains a continuous simulation pollutant loading model (Annualized AGNPS, AnnAGNPS) designed to assess the effects of conservation management practices, the development of total minimum daily load limits, and for conducting risk and cost-benefit analyses. The input programs include a GIS-assisted computer program (TOPAZ-based interface to AGNPS) to develop terrain-based AnnAGNPS cells with all the needed hydrologic and hydraulic parameters calculated from readily available digital elevation models and an input editor to initialize, complete, and revise the input data. Outputs related to soluble & attached

nutrients (nitrogen, phosphorus, and organic carbon) and pesticides are provided. Sediment sources include those by particle size class from sheet & rill, ephemeral gully, classical gully and channel erosion. The model provides the capability to track any pollutant source to any point in the watershed allowing for the assessment of appropriate conservation measures to resolve the particular pollutant problem.
http://www.wsi.nrcs.usda.gov/products/w2q/h&h/tools_models/agnps/index.html

CQESTR is a process-based model developed by USDA-Agricultural Research Service that simulates the effects of climate, crop rotation, and tillage management practices, and soil amendment additions and losses on soil organic carbon (C). CQESTR, pronounced 'sequester', is a contraction of carbon sequestration, meaning carbon storage. It works on a daily time-step and can perform long-term 100-year simulations. Soil organic matter change is computed by maintaining a soil carbon budget for additions as a result of atmospheric carbon dioxide sequestration or added amendments like manure, and organic carbon losses through microbial decomposition. The identity for each organic input is initially maintained as composting residues over a 4-year period after which the organic input loses its identity and is placed into a mature soil organic matter pool in an abrupt step function. Both the composting residues and mature soil organic matter are decomposed daily using an exponential function driven by cumulative heat units with appropriate empirical coefficients for the type of residue, nitrogen content and incorporation into the soil by tillage. The model uses daily time steps to calculate heat units that are initiated for each organic input, typically after harvest of the crop. Other soil amendments are tracked similarly. When soil carbon is decomposed in soil to carbon dioxide, it is normally transported out of the soil in the gaseous phase by dispersion-diffusion and advection in air. A Web application was developed to facilitate inputs, model process execution, and displaying results. CQESTR requires input of initial soil organic matter content for each soil layer of interest, above- and below-ground crop biomass, dates of all residues or organic amendment additions and tillage operations, fraction of pre-tillage residue weight remaining on the soil surface after each tillage, depth of tillage, nitrogen content of residue at decomposition initiation, average daily air temperature expected throughout the period of interest, an approximate date for the first significant rain precipitation event after harvest, number and thickness of soil layers, organic matter content, and bulk density of each layer.

GLYCIM, GOSSYM, **MAIZSIM** and **SPUDSIM** are mechanistic models developed by USDA-Agricultural Research Service simulating soybean, cotton, maize (corn) and potato growth, development and yield, respectively. These models can simulate effects of temperature and CO_2 on photosynthesis. The models simulate light interception, photosynthesis, carbon partitioning in the plant, and two dimensional water and nitrogen uptake and movement in soil. GOSSYM and GLYCIM have seen extensive testing and application at the farm level. MAIZSIM and SPUDSIM are currently under development. Required inputs of these models include daily or hourly radiation and max-min or hourly temperatures, soil water parameters, and plant parameters as well as management information (planting and row spacing). Outputs include biomass and yield components, soil water and nitrogen contents and fluxes. Additionally, MAIZSIM and SPUDSIM can provide information on soil carbon and nitrogen dynamics and energy balances. **MelonMan** is a simple, cultivar specific, cantaloupe phenology model that uses standard weather data to predict leaf appearance, crop developmental stages and final harvest date. **2DSOIL** is a comprehensive, modular, two-dimensional soil simulator that can simulate the major physical, chemical and biological processes in soil. Fully implemented, principles of modular modeling facilitate the addition and replacement of modules makes it make it easy to modify the model and incorporate it into plant models. 2DSOIL was incorporated the new ARS corn (MAIZSIM) and potato (SPUDSIM) models. **2DLEAF** is a comprehensive leaf gas exchange model that includes two-dimensional CO_2, O_2, and water vapor diffusion in the intercellular space schematized according to leaf anatomy, CO_2 assimilation by mesophyll cells, and stomatal movements as a regulating factor. http://www.ars.usda.gov/Research/docs.htm?docid=6339

ALMANAC is the **A**gricultural **L**and **M**anagement **A**lternatives with **N**umerical **A**ssessment **C**riteria model. It is a process-based model designed by the USDA-Agricultural Research Service to simulate competition among plant species, specifically, weeds and crops or complex grassland communities. ALMANAC has recently proved to be a useful tool in simulating potential lignocellulosic biofuel species production, notably *Alamo* switchgrass. ALMANAC has been validated at diverse sites across the U.S. for switchgrass as well as potential sugar-based ethanol crops such as corn and sorghum. ALMANAC simulations provide a useful tool for determining optimal cropping strategies for cellulosic and sugar based ethanol biofuel production across the U.S. The model has been extensively validated for pasture grasses and row crops in a wide range of locations, drought conditions, and plant species. ALMANAC accurately simulated mean crop yields in nine states in the U.S. with diverse soils and climate. When applied to maize at eleven sites and sorghum at eight sites in Texas for the dry conditions of 1998, ALMANAC realistically simulated grain yields. ALMANAC simulates grasses, both in monoculture and polyculture. The model simulates grain and forage yields for a diverse set of ecological sites with two or more competing grass species competing across environmental extremes.
http://www.ars.usda.gov/Research/docs.htm?docid=9760

RZWQM2 is an enhanced version of the UDA-Agricultural Research Service Root Zone Water Quality Model (RZWQM). RZWQM2 simulates the effects of major agricultural management practices on physical-chemical processes and plant growth, and the movement of water, nutrients, and pesticides to runoff and through the crop-root zone to shallow groundwater. The model allows simulation and evaluation of a wide spectrum of management practices, such as no-tillage and residue cover versus conventional tillage; rates, methods, and timings of application of water, fertilizers, manures, and various pesticides; and different crop rotations. RZWQM2 contains special features simulating tile drainage and rapid transport of surface-applied chemicals through soil macropores to deep depths, groundwater, and tile flow. The model daily weather data requirements are maximum and minimum temperature, solar radiation, wind speed, relative humidity, and rainfall. General data requirements include soil texture, soil bulk density, soil hydraulic properties (if known), and management practices. RZWQM2 is a one-dimensional model with a pseudo two-dimensional drainage flow and water table fluctuation. Users have the options of using a generic plant growth model or the DSSAT4.0 plant models. Updated versions of RZWQM2 are delivered through the web at arsagsoftware.ars.usda.gov and is documented in a book, which can be purchased at http://www.wrpllc.com/books/rzwqm.html

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