

**Regional Estimation of Soil Carbon and Other Environmental Indicators
Using EPIC and i_EPIC**

by

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Abstract

Computer models are important tools for assessing regional carbon sequestration and other environmental impacts of agricultural management practices. The Environmental Policy Integrated Climate (EPIC) model is a very flexible model that has been applied for a wide range of field- and regional-scale environmental assessments. Large regional-scale applications of EPIC and similar models can require thousands of runs, resulting in a huge data management task. To address this problem, the Center for Agricultural and Rural Development (CARD) has developed an interactive EPIC (i_EPIC) software package that provides an automated approach to executing large sets of EPIC simulations. Overviews of both the latest EPIC version and the i_EPIC software package are presented, as well as applications using both EPIC and i_EPIC for regional applications conducted by the Resource and Environmental Policy Division of the Center for Agricultural and Rural Development, the Joint Global Change Research Institute of the University of Maryland and the Pacific Northwest National Laboratory, and the Resource Assessment Division of the USDA Natural Resources Conservation Service (NRCS).

Introduction

Resource questions associated with agricultural production are becoming increasingly complex. Decision makers must balance the insurance of a safe food supply versus the need to protect water quality, mitigate carbon loss to the atmosphere, and prevention of other negative environmental externalities. Flexible tools that can provide reliable estimates of economic and/or environmental impacts for a wide combination of cropping and management systems, climatic conditions, soil types, and landscapes are vital to achieving this balance. These tools include simulation models, which can be used for estimating a variety of environmental indicators at the field, watershed, and/or regional scales.

One of the most widely used simulation models for agricultural policy analysis is the Erosion Productivity Impact Calculator (EPIC) model (Williams, 1990; Williams 1995), originally developed by the USDA and now maintained by the Texas A&M Blacklands Research Center. EPIC is a field-scale model that can be adapted to a large range of crop rotations, management practices, and environmental conditions. The original version of the model was primarily designed to assess the impacts of soil erosion on crop productivity (Williams et al., 1984). More recent versions of the model are called Environmental Policy Integrated Climate (Mitchell et al., 1996), reflecting the fact that it has evolved into a tool that can be used to estimate a variety of environmental indicators. Example applications include estimating soil erosion from water (Chung et al., 1999; Phillips et al., 1993) and wind (Potter et al., 1998), climate change impacts on crop yield (Stockle et al. 1992; Brown and Rosenberg, 1999) and soil erosion (Favis-Mortlock 1991; Lee et al., 1996), edge-of-field nutrient losses from fertilizer and/or animal manure applications (Edwards et al. 1994; Bernardos et al., 2001; Chung et al., 2001), edge-of-field losses from pesticide applications (Williams et al., 1992), and soil carbon sequestration (Apezteguía et al., 2002; Izaurralde et al., 2002).

EPIC has also proven adaptable for large regional analyses; examples include estimation of water and wind erosion for the Canadian Prairie Provinces (Izaurralde et al., 1997; Lakshminarayan et al.; 1996), and prediction of nutrient losses and other indicators for the 12-state north central region (Wu and Babcock, 1999; Babcock et al., 1997; Gassman et al., 1998). These regional applications typically require thousands of EPIC simulations, resulting in a formidable management task of the input and output data. Software was initially constructed at the Center for Agricultural and Rural Development (CARD) on a UNIX platform to automate construction of input data, execution of simulations, and storage of desired output data for large sets of EPIC simulations. This initial approach has been refined into a more user-friendly PC-based software package entitled “Interactive EPIC” or *i_EPIC*. The *i_EPIC* software allows the user to handle both input and output data in consistent database structure for EPIC simulation sets numbering in the tens of thousands, as well as providing diagnostic and editing tools via both the database and the windows interface. Overviews of both EPIC and *i_epic* are presented here, with particular emphasis in how EPIC can be executed within *i_epic* to produce regional estimates of soil carbon sequestration. Example applications of the system by CARD’s Resource and Environmental Policy (REP) Division and other user groups are also described.

Overview of EPIC

EPIC is a field-scale model that is designed to simulate drainage areas of up to 100 ha that are characterized by homogeneous weather, soil, landscape, crop rotation, and management system parameters. It operates on a continuous basis using a daily time step and can perform long-term simulations of hundreds of years. A generic crop growth routine is used in the model that facilitates simulation of crop rotations using parameters that have been developed for nearly 100 crops. Up to 12 crops and/or other plants can also be simulated simultaneously, allowing inter-crop, crop-weed, and similar scenarios to be performed. Tillage effects on surface residue, soil bulk density, and mixing of residue and nutrients in the soil plow layer is accounted for in the model; these and other factors are also incorporated into the model's estimations of water and wind erosion. Multiple nutrient and pesticide applications can be simulated in a single simulation, and edge-of-field leaching, runoff, and/or volatilization losses can be output (depending on which chemical is being simulated). Table 1 lists the major components that are included in EPIC1015¹, the latest version of the model.

EPIC1015 includes an improved carbon cycling routine (Izaurralde et al., 2002) that is based on the approach used in the Century model developed by Parton et al. (1994). In this updated routine, carbon (C) and nitrogen (N) compounds are simulated within three soil pools of increasing turnover time: biomass, slow, and passive. However, only two surface litter pools (biomass and slow) are simulated in EPIC1015, instead of the three used in Century. Other differences between EPIC1015 and Century include: (1) using existing EPIC equations to simulate movement of organic material from the surface litter to deeper soil subsurface layers and to calculate C and N transformation rates, and (2) determining crop lignin concentration during a growing season as a sigmoidal function of plant development. Losses of C and N by leaching or gaseous forms are accounted for in EPIC1015, similar to Century. Further details on the EPIC1015 carbon cycling methodology is presented in Izaurralde et al. (2002) and Izaurralde et al. (2001).

At present, the latest publicly released version of the model is EPIC0250. It is anticipated that EPIC1015 will be released in the near future, after further testing of the model is completed. Both versions of the model can be applied in the current i_EPIC software, along with two older EPIC versions as described in the following section.

¹The first digit in 1015 represents the last day of the year that the version was released (i.e., 2001) while the last three digits represent the julian date of the release (i.e., day 15).

Table 1. Major components included in EPIC version 1015^a

Component	Comments	Key inputs or simulated functions
Climate	daily measured and/or generated data can be input	precipitation, max. and min. temperature, solar radiation, windspeed, relative humidity
Management	can simulate many different tillage & fertilizer levels	fertilizer or manure, lime, pesticides, irrigation, drainage, tillage
Hydrology	two options for infiltration; four for evapotranspiration	surface runoff, infiltration, lateral subsurface flow, evapotranspiration, snow melt
Erosion	six options for water erosion	both water and wind erosion are simulated
Nutrients	routines for nitrogen, phosphorus, & potassium	crop uptake, leaching, surface runoff, mineralization, & other processes
Carbon	Century-based routines only in epic1015	biomass, slow, and passive pools are simulated in soil profile
Crop growth	generic routine; very flexible for simulating rotations	crop biomass and yields; inputs developed for ~100 crops
Soil temperature	used in nutrient cycling and hydrology routines	daily average soil temperature
Economics	simple crop budgets	fixed and variable costs

^aComponent categories adapted from those described by Williams (1990).

Overview of i_EPIC

The basic philosophy of the i_EPIC approach is to manage both the input and output data of a large set of EPIC simulations within a single database. This requires converting all existing data from ASCII files and other file formats into ACCESS[®], the database program that has been selected for the i_EPIC system. Thus it is incumbent upon the i_EPIC user to develop methods of processing desired input data into the proper database structure required for i_EPIC.

A general schematic of the data flows for the i_EPIC system are shown in Figure 1. Soil and landscape, climate, cropping system, and management (tillage, fertilizer, etc.) are the main categories of input data. Preprocessing of input data is performed to translate the existing data files into the ACCESS Database format. Twelve tables are constructed that contain the required input data for i_EPIC and EPIC (Table 2); the exact inputs included in some of the tables are dependent on the version of the model being used. Once the input data have been constructed, the entire EPIC simulation set can be executed automatically within i_EPIC. Alternatively, individual runs or subsets of a simulation set can be performed. Output data for each simulation is scanned from standard EPIC output files and stored in the database (Table 2).

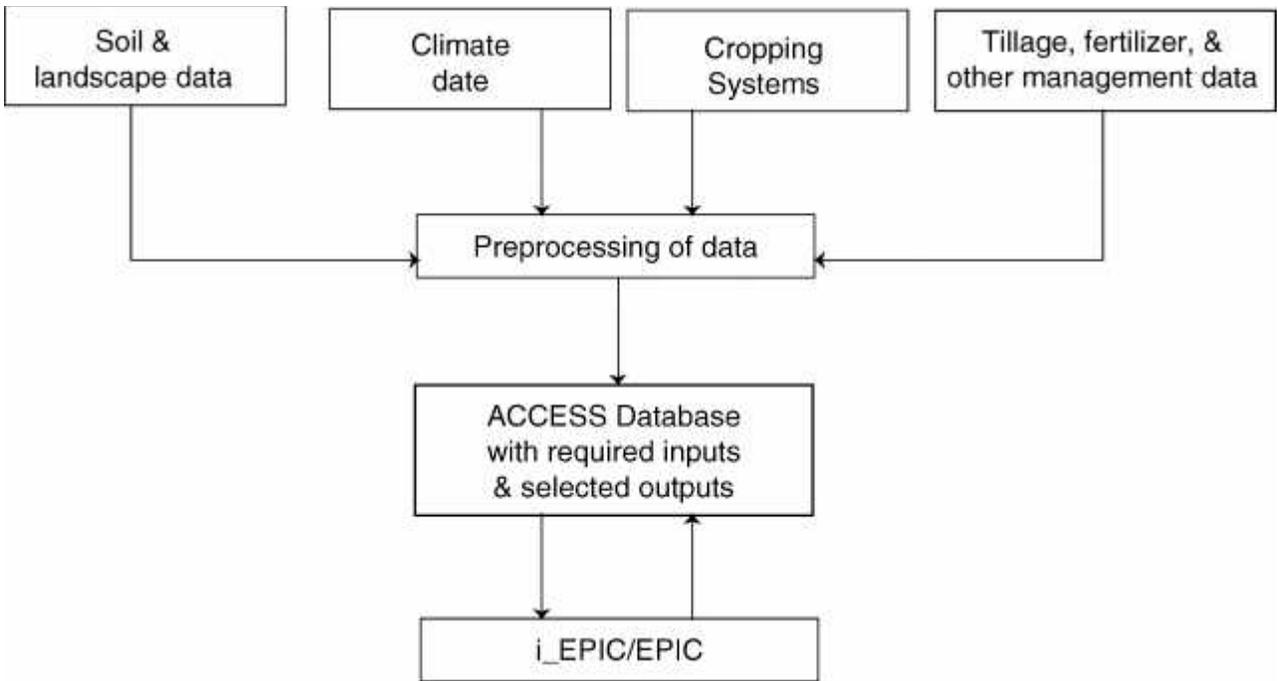


Figure 1. General schematic of the data processing steps required for the I_EPIC system.

Table 2. List of tables required for the ACCESS database used by i_EPIC

Database table	Description	Database links ^a
<u>Input data</u>		
Control records	Characteristics for each EPIC simulation	ID; weather station ID, soil ID
Crops ^b	Standard EPIC crop parameter file	-
Fertilizer ^b	Standard EPIC fertilizer characteristics file	-
Field operations	Operation schedules for APEX opsc files	ID
Management	Management data for APEX subarea files	ID
Operations ^b	Standard EPIC machinery operations file	-
Parameters ^b	Standard EPIC miscellaneous parameter file	ID
Pesticides ^b	Standard EPIC pesticide characteristics file	-
Soil layers	Soil layer data required by subarea	Soil ID
Soils	Soil name; misc. soil data by subarea	Soil ID
Weather	Weather station; miscellaneous weather data	Weather station ID
Weather by month	Monthly weather and wind statistics	Weather station ID
Output variables	15 variables that user can select for annual output	ID
<u>Output data</u>		
Output ^c	Average annual results for four variables	ID
Output Annual	Annual results for up to 45 output variables	ID
Output Annual Crop Yields	Annual yields for simulated crops in each run	ID
Output Soil Carbon Nitrogen	EPIC1015 output file with C and N results	ID

^aCodes used to link files relationally in database; ID is the ID number for each EPIC simulation.

^bThe specific variables and the total number of variables can vary for these files between EPIC versions; they are not directly linked within the relational structure of the ACCESS database, but are linked into each EPIC simulation (e.g., the crops table via crop ID within the field operations table).

^cThis table is essentially nonfunctional at present.

The i_EPIC software is accessible on-line by going to <http://www.public.iastate.edu/~elvis> and clicking on i_EPIC . Similar software can also be obtained for the Century model and Soil and Water Assessment (SWAT) model (Arnold et al., 1998) via the same webpage². Two versions of the i_EPIC software can be downloaded, one based on ACCESS 97 and the other on ACCESS 2000³. Some documentation is provided on the website such as definitions of toolbar button functions, a limited set of frequently asked questions, a history of modifications to the code, and structure of the data tables. At least partial documentation is provided for all of the database tables, which can include the names used in the ACCESS tables for each variable, the equivalent EPIC variable name, the units (if applicable), the type of variable (integer, etc.), and a description or comment. The control records is a key table that contains data that define the characteristics of a each EPIC simulation including the crop rotation, soil type, weather station ID, and location (latitude and longitude). Some of the fields in this table are not actual EPIC inputs; several of these pertain to information that is part of the National Resources Inventory (NRI) Database (Nusser and Goebel, 1997; <http://www.nrcs.usda.gov/technical/NRI>) which is a valuable source of data for regional analyses. Data that are not used in EPIC are identified as “Not passed to EPIC” in the comments for each field.

At present, four different versions of EPIC (5300, 8120, 0250, and 1015) can be executed within i_EPIC. The executable for each of the EPIC versions is included with the i_EPIC download, except for EPIC1015 (which will be incorporated into the download at a future point). The on-line documentation is oriented towards the 02050 and 1015 versions, but any of the four versions can be successfully executed within the system providing that the ACCESS tables are filled with the correct inputs. This is an especially critical step regarding the miscellaneous parameter file (Parameters Table) because the values, definitions, and number of these parameters are in constant flux between versions. There has also been changes in some of the other input files, mostly in the form of additional new variables. For example, several new variables were added to the Operations Table for EPIC1015 which are highlighted in red in the on-line documentation, as well as a few other new variables in other tables. One option that is available to help ensure that the correct inputs are used for a specific version is to first import a set of input files known to work in that version into i_EPIC, using the i_EPIC import function (under file on the toolbar menu). These imported inputs can then be used as a guide for constructing the inputs for a larger simulation set. A final point to remember is that the ACCESS tables include all the inputs used in all four EPIC versions; those inputs that are not relevant to a specific version are ignored when performing simulations with that version.

Once a database has been constructed, it can be read into i_EPIC using a standard Windows read function. The next step is to choose “configuration” (under file on the toolbar), which allows the user to pick one of the four EPIC versions that can be run with the program. The user can then elect to run a single EPIC simulation, a subset consisting of multiple runs, or the entire simulation set. The option is also provided to modify some of the input variables via several pop-up screens. Other diagnostic tools for individual simulations provide the ability to plot a timeline of operations or to obtain a listing that highlights different operation categories in

² Both i_Century and i_SWAT can be downloaded and used as desired; however, development of these two software packages lag that of i_EPIC and thus are less reliable.

³ It is recommended that users work only with the version of i_EPIC that works with ACCESS 2000 because the ACCESS 97 version has not been updated in over two years.

specific colors. Post-simulation diagnostic tools are also provided that allow the user to plot selected outputs for a single simulation or for multiple simulations.

Manipulation of inputs can also be performed in the ACCESS Database, prior to reading it into i_EPIC. This is in fact a more flexible option that allows the user to change one or more variables for part or all of a complete simulation set. Output diagnostics in the form of queries and simple statistics can be performed in ACCESS; porting the output data into other software packages such as Excel provides additional post-simulation processing options.

Example Applications

The i_EPIC software has been used by the CARD Resource and Environmental Policy (REP) Division primarily to support analyses performed for part or all of the 12-state north central region. At least two other extensive applications of the software have been performed. The first is a national assessment of agricultural practices for selected crops by the USDA-NRCS Resource Assessment Division (RAD). The second is an ongoing project in which hundreds of “farm models” are being developed by Joint Global Change Research Institute (JGCRI) to simulate the impacts of agricultural production practices across the globe under current and alternative climate conditions. Examples of how EPIC and I_EPIC are being used by each of these three research groups are presented here.

CARD Application

The applications of i_EPIC by the REP Division of CARD have been performed in the context of the Regional Agricultural Policy System (RAPS), an integrated economic and environmental modeling system (Figure 2) developed for the 12-state north central region (Babcock et al., 1997; Gassman et al., 1998). The modeling framework is constructed around the 1992 and/or 1997 NRI databases⁴, which provides baseline landuse and other data for over 366,000 “points” (typically representing areas consisting of hundreds of hectares) for the region (Figure 3). The subset of agriculturally relevant points are used to define the specific soil type, landscape, crop rotations, other landuse (Conservation Reserve Program (CRP) and pastureland), tillage, tile drainage, and irrigation that are simulated in the modeling system. A second key source of input data is the USDA Economic Research Service (ERS) 1990-95 Cropping Practices Survey (CPS), which provides information on machinery budgets and associated costs. Climate and soil layer data are input into the system from other databases. A baseline is usually performed as the first step of analyzing one or more policy scenarios. The next step is then to impose an alternative scenario(s) on the Discrete Choice Economic Model, which estimates production costs and returns, as well as producer’s decisions regarding tillage practice, crop rotation, or shifting cropland into CRP land for all the NRI points included in the analysis⁵. These decisions are then incorporated into the EPIC simulations for the NRI points for the same scenario⁶. The EPIC simulations are performed using i_EPIC, after the required input data has been entered into the ACCESS Database tables as previously described.

⁴The landuse mix is based on either the 1992 or 1997 NRI; a link back to the 1992 NRI is needed when using the 1997 NRI to access tillage and tile drainage data that are not included in the 1997 NRI.

⁵The economic model essentially assumes that each NRI point is a farm.

⁶Century would be applied the same way; NRI points with similar soils, etc. are clustered together for SWAT.

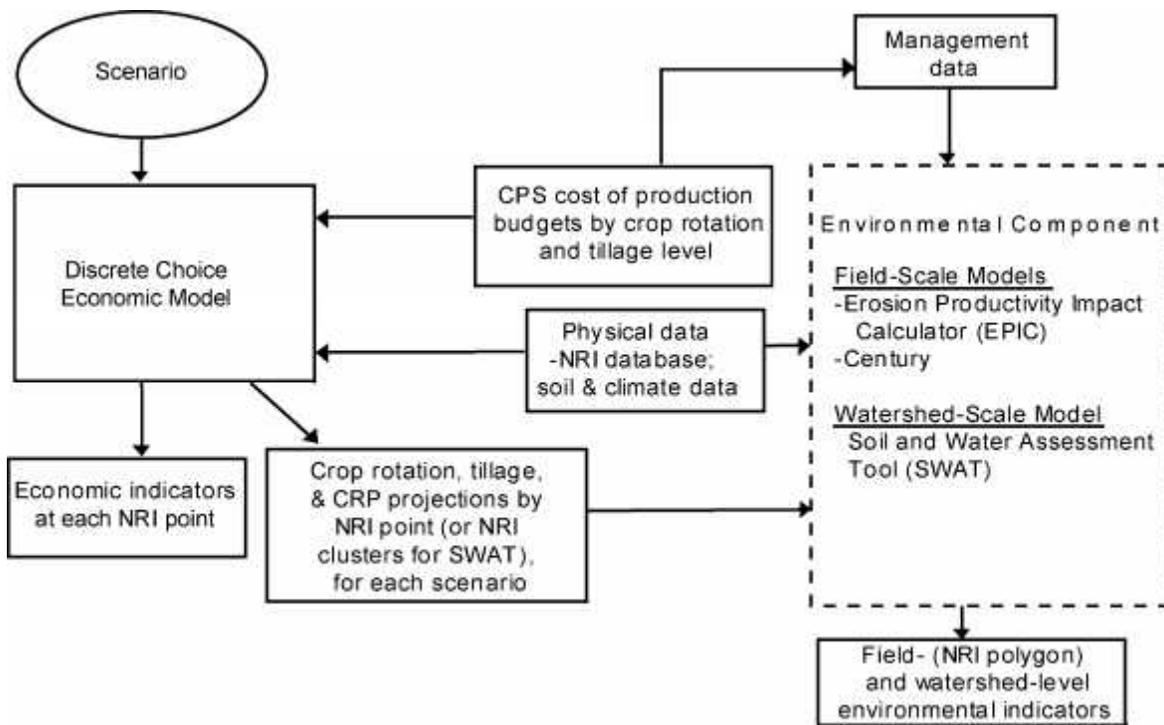


Figure 2. Schematic of the Regional Agricultural Policy System (RAPS)

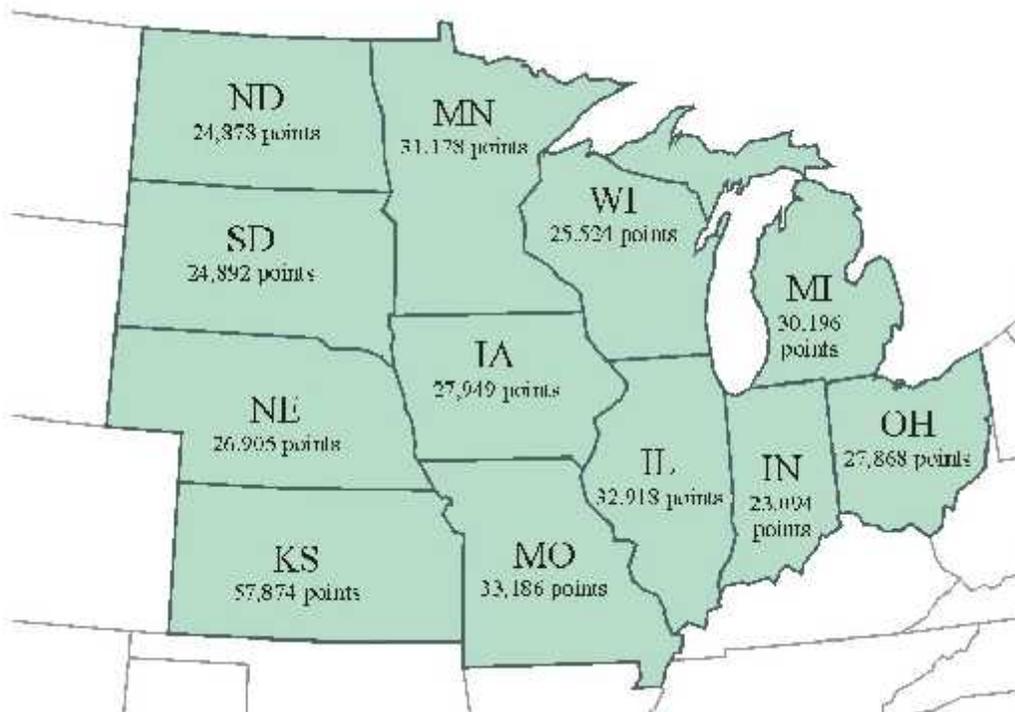


Figure 3. Total NRI points in each of the north central states

An example application is described here in which three sets of 30-year EPIC1015 simulations were executed using i_EPIC for over 15,000 cropland relevant NRI points in Iowa. This was a partial application of the RAPS system, which did not include the economic model. An initial baseline was simulated for the first set of EPIC runs in which the model assumptions were based on NRI data for each point, including a mix of different tillage levels (ranging from no-till to conventional tillage). Two additional simulation sets were then performed that assumed: (1) all the NRI points were managed with conventional tillage, and (2) all the NRI points were managed with no-till. The soil carbon levels for each of these scenarios were then compared against the baseline, to ascertain the impacts on carbon sequestration trends of all producers in Iowa shifting into either of the two different tillage extremes. The differences between the baseline and the conventional tillage scenario (Figure 4) and the baseline and the no-till scenario (Figure 5) are plotted using “NRI polygons”, which are the smallest spatial areas that can be derived from the publicly available versions of the NRI. The results show that a total shift into conventional tillage results in a nearly universal loss of carbon relative to the baseline; in contrast, a total shift into no-till results in positive soil carbon gains for virtually the entire state as compared to the baseline. The only exceptions are a few small polygons for both scenarios (it is not clear why these polygons did not follow the overall predicted trends). The results shown in Figures 4 and 5 are consistent with general expectations that no-till will provide enhanced soil carbon benefits over other tillage options for most conditions.

NRCS Application

The NRCS Resources Assessment Division has incorporated i_EPIC into a modeling system they have developed to perform assessments of different cropping systems and management practices for agricultural areas across the entire 48 contiguous U.S. states. The NRI is again a key database for this system, providing soil type, cropping system, and other data required to perform the simulations. The initial application of the system involved executing nearly one million EPIC0250 simulations for an array of fertilizer, tillage, and monoculture cropping system treatments, in combination with different soil and climate conditions. Soil and climate “clusters” have been created for the system, in which statistically similar soils and climates are clustered together and ultimately represented by a single soil or climate for the actual analysis (and thus greatly reducing the number of required simulations). The processing of the climate data transcended state boundaries and resulted in 66 contiguous climate areas as shown in Figure 6. The soil clustering process was based on the soil types identified for each NRI point and was performed on a state-by-state basis; exact plotting of these clusters is difficult because they are not always contiguous. In total, 7,309 unique soil-climate cluster combinations have been developed for the NRCS modeling system. However, the total number of homogeneous resource areas is about 35,000, when cropping systems and other factors are accounted for. Code has been developed to translate all of the required data needed for the EPIC simulations into the proper ACCESS Database format, so that the EPIC runs can be executed with i_EPIC.

An example output of the system is shown in Figure 7 for changes in estimated losses of labile P between 1992 and 1997, based on changes in the landuse mix that occurred between the 1992 NRI and 1997 NRI. The results are aggregated to U.S. Geological Survey (USGS) 8-digit watersheds, one of the spatial units included in the NRI. The western areas shown in Figure 6 were not included for this analysis. A complete national assessment has been performed with the

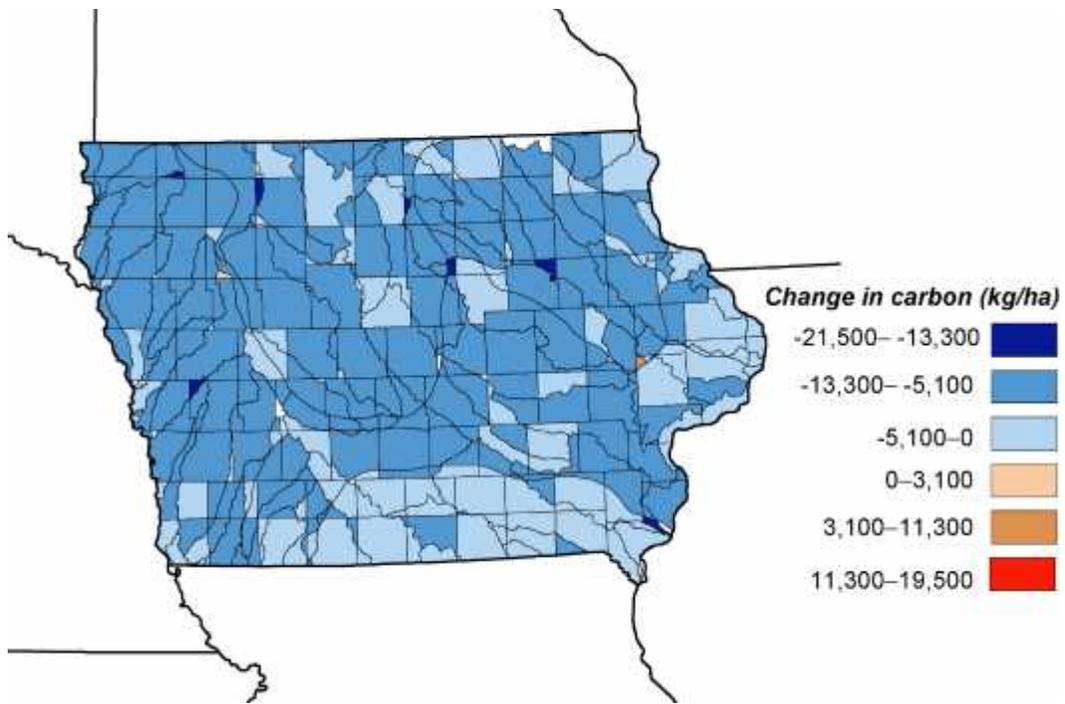


Figure 4. The change in soil carbon by NRI polygon for the EPIC1015 conventional tillage scenario as compared to the baseline set of simulations.

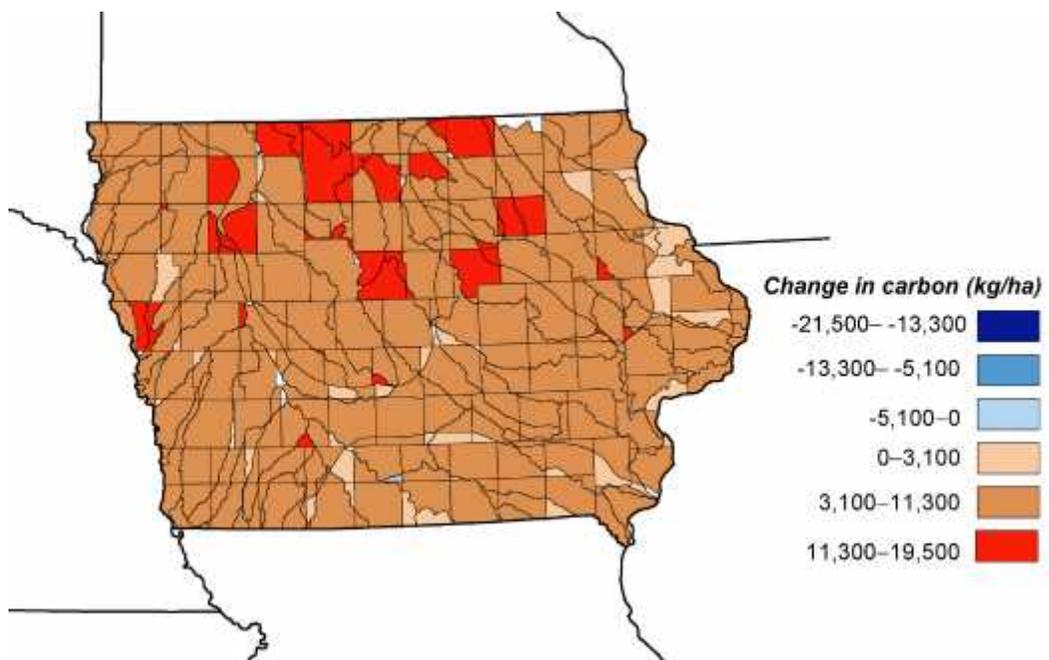


Figure 5. The change in soil carbon by NRI polygon for the EPIC1015 no-till scenario as compared to the baseline set of simulations.

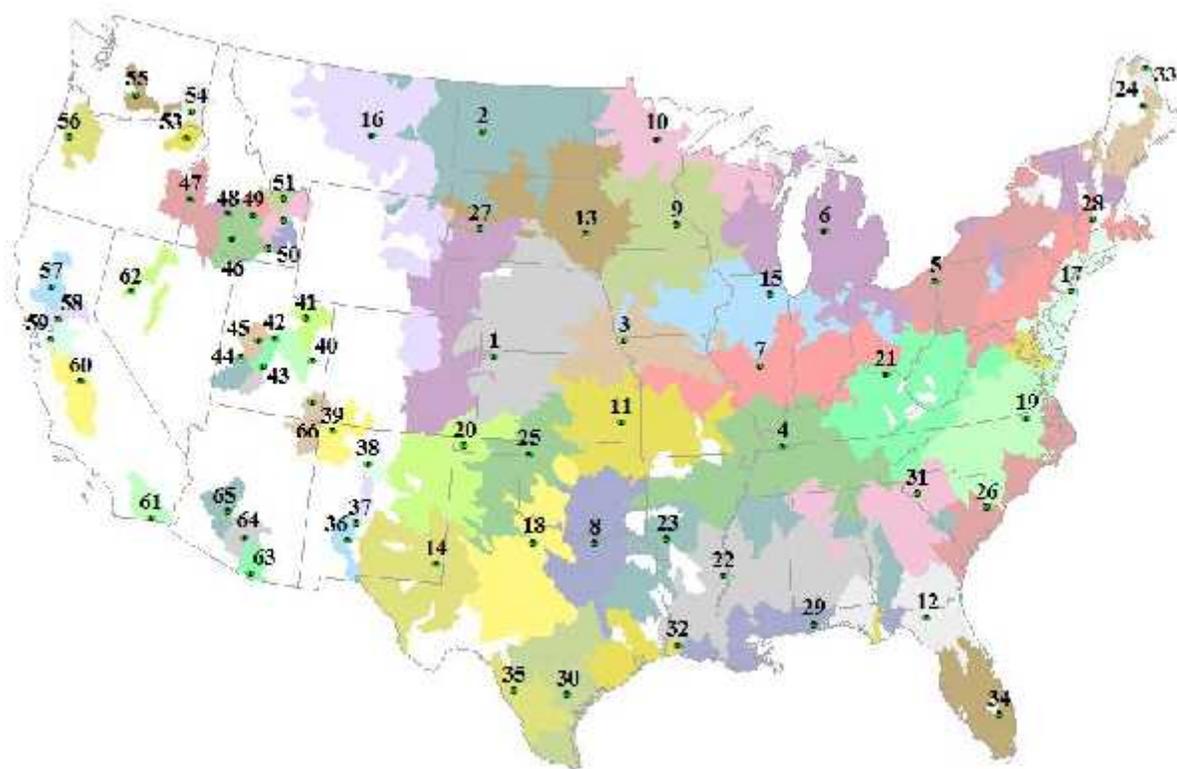


Figure 6. The 66 climate clusters developed for the NRCS modeling system (little or no land is cropped in the crops included in the study in the non-numbered white areas).

system that produced a suite of edge-of-field erosion and nutrient (nitrogen and phosphorus) indicators based on 30-year simulations of all combinations of management, soils, etc.

Development of the NRCS system is a continually evolving process. At present, the system is being configured to perform a national assessment with EPIC0250 of Comprehensive Nutrient Management Plans that the NRCS will be conducting for a significant portion of U.S. livestock operations. A key aspect of this study is that the environmental impacts of nitrogen and phosphorus in applied manure will also be accounted for. The RAD researchers are also planning to perform other future analyses with EPIC1015.

JGCRI Example

Researchers at the Joint Global Change Research Institute are developing a set of “farm models” (EPIC1015 simulations) that will allow analysis of variations in management, cropping systems, and climate conditions for the major agricultural production regions across the globe. The initial step involves identifying sources of soil and climate information that contain the data required for EPIC1015. As shown in Figure 8, over four hundred farm models have been constructed so

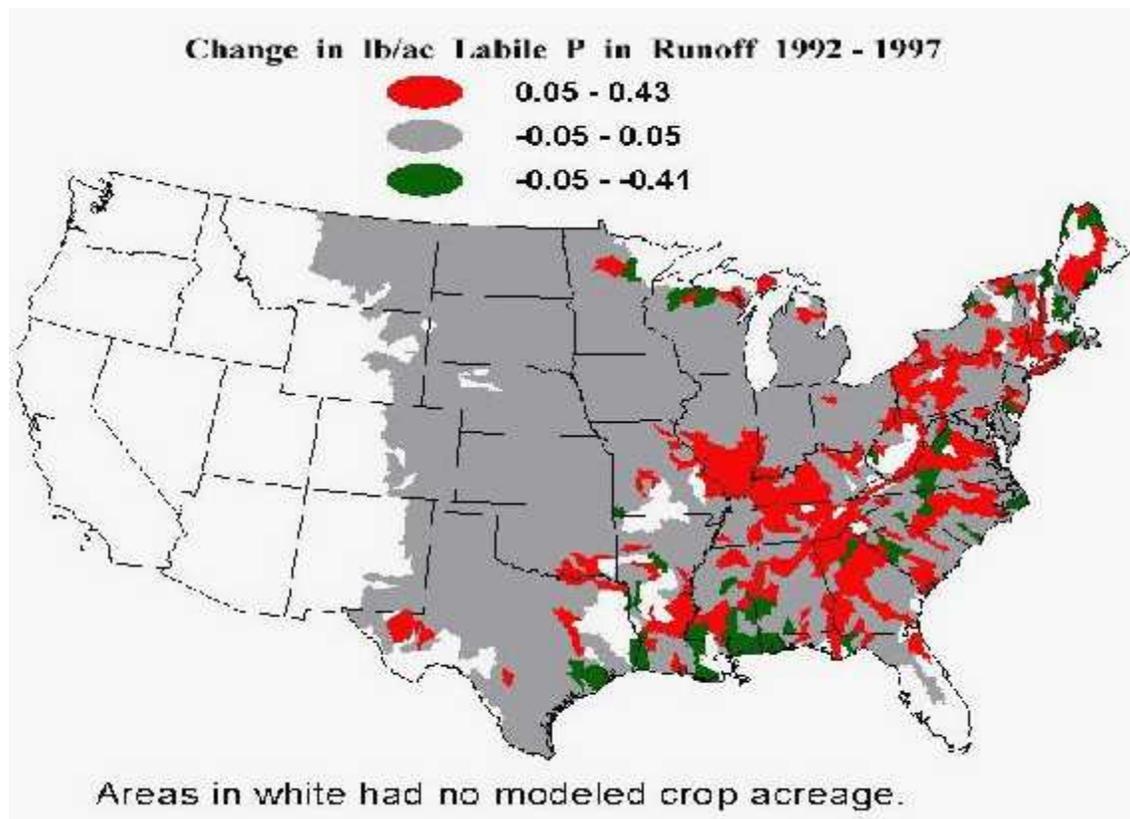


Figure 7. Change in labile P between 1992 and 1997 for cropped areas simulated by NRCS RAD researchers using EPIC0250 (western areas were not included in this analysis).

so far (green squares) and sufficient climate data is available to allow the development of approximately 1,500 more farms (blue triangles). These EPIC1015 farm models are intended to represent conditions typical of the regions they are located in.

The data for each of these farms is being loaded into the proper ACCESS format to allow the simulations to be performed with i_EPIC. To date, efforts have focused on simulating baseline climate and other conditions for different types of crops for the existing farm models. For example, preliminary results are shown in Figure 9 for 30-year average dryland wheat yields predicted with EPIC1015 for the 400 plus farm models. Development of the baseline scenarios for each farm has included contacting researchers in about 20 different countries to determine the best assumptions for tillage, fertilizer and other management inputs. Validation studies of the baseline conditions with measured data have also been initiated for two areas in Argentina.

Future efforts will focus on performing a range of alternative climate, management, and or cropping system scenarios with the complete set of EPIC1015 farm models. Modification of management and other inputs within the i_EPIC framework will allow rapid assessments of different scenarios.

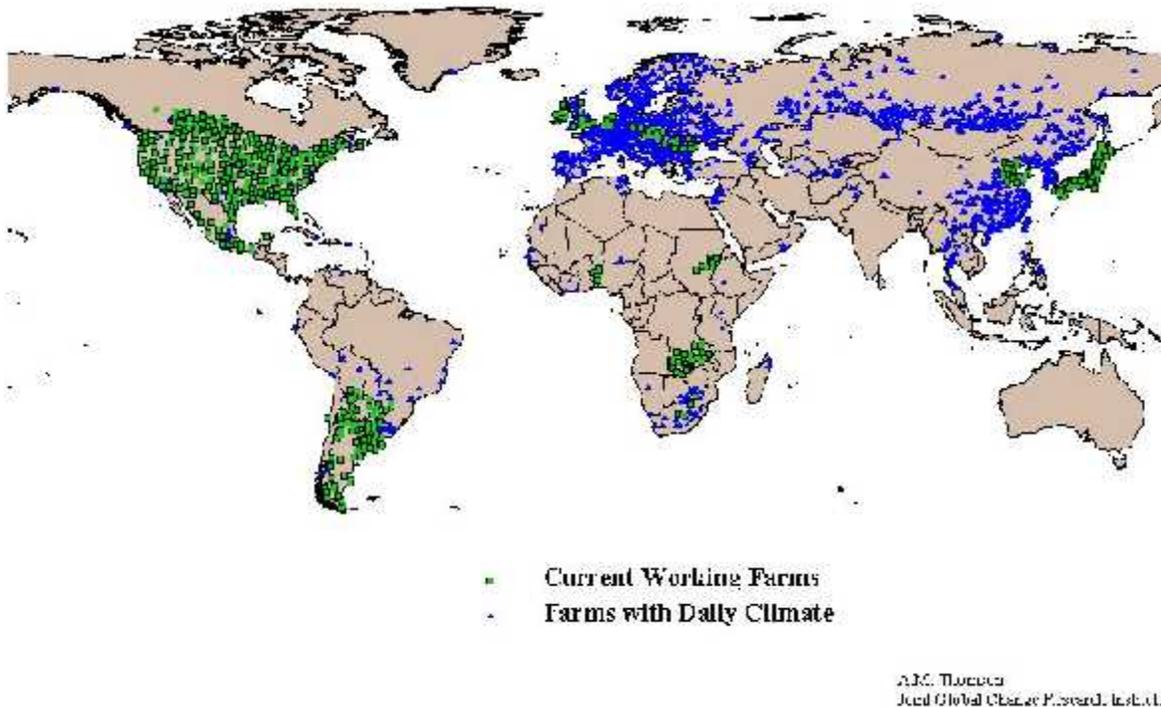


Figure 8. Location of JGCRI farm models (green squares) and potential models (blue triangles).

Conclusions

The *i*_EPIC software package has proven to be a robust tool for managing large sets of EPIC simulations for regional analyses of soil carbon changes, nutrient and erosion losses, and other environmental indicators in response to variations in management practices, cropping systems, climate inputs, and soil types. The software can be freely downloaded by anyone who has internet access. It is anticipated that *i*_EPIC and supporting on-line documentation will continue to evolve, which hopefully will facilitate even easier use of the software in the future. It is also expected that EPIC1015 will be released for general public use in the near future. This EPIC version will allow enhanced applications of the model for those users who are interested in incorporating improved soil carbon sequestration impacts within their regional assessments.

Preliminary dryland wheat yields: 30 year averages for baseline runs.

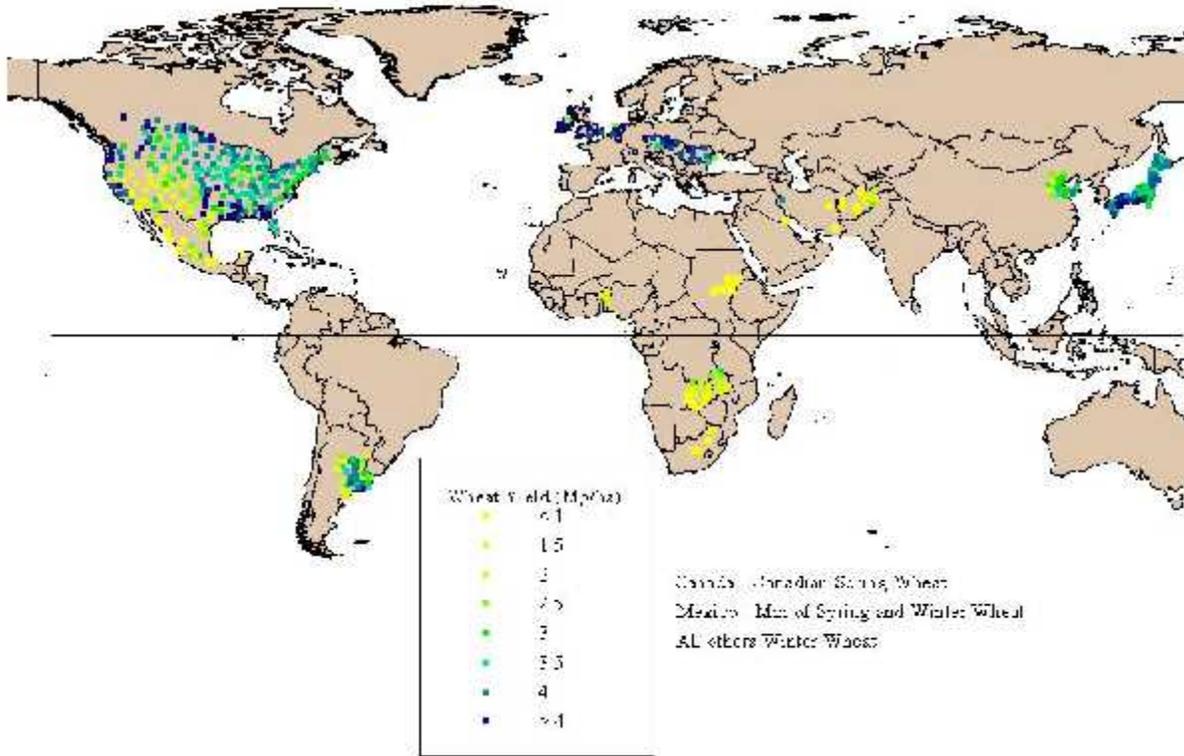


Figure 9. Dryland wheat yields estimated with the JGCRI EPIC1015 farm models for baseline Climate, soil, and management conditions.

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