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The erosion-productivity impact calculator (EPIC) model: a case history

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SUMMARY

Beginning in 1981, a mathematical model called the erosion-productivity impact calculator model (EPIC) was developed to determine the relation between soil erosion and soil productivity throughout the U.S.A. By 1985 the model was ready for use in the RCA (1977 Soil and Water Resources Conservation Act) analysis. Between 15000 and 20000 EPIC simulations of 100 years each were performed as part of the 1985 RCA analysis. After the RCA analysis, model refinement and development continued and EPIC has been applied to a number of agricultural management problems. For example, EPIC is capable of dealing with decisions involving drainage, irrigation, water yield, erosion (wind and water), weather, fertilizer and lime application, pest control, planting dates, tillage, and crop residue management. Example applications include: (i) 1988 drought assessment; (ii) soil loss tolerance tool; (iii) Australian sugarcane model (AUSCANE); (iv) pine tree growth simulator; (v) global climate change analysis, and (vi) farm level planning.

INTRODUCTION

The erosion-productivity impact calculator (EPIC) model† (Williams *et al.* 1984) was developed to assess the effect of soil erosion on soil productivity. Urgent need for such a model was identified as a result of the 1977 Soil and Water Resources Conservation Act (RCA). The Act required the Secretary of Agriculture to appraise soil and water resources and to make long-range policy decisions on the use and protection of these resources. With development of plans to implement RCA, it became obvious that no reliable method existed for quantifying the costs of soil erosion or the benefits from soil erosion research and control.

The United States Department of Agriculture (USDA) held a workshop in February 1980 to discuss ways of improving understanding of the crop yield-soil loss relationship. A USDA national soil erosion – soil productivity research planning committee was appointed. The committee documented what was known about the problem, identified what additional knowledge was needed, and outlined a research approach for solving the problem (Williams *et al.* 1981). One of the most urgent and important needs outlined in the research approach was the development of a mathematical model for simulating erosion, crop production, and related processes. Thus a national Agricultural Research Service (ARS) erosion-productivity modelling team was organized and began developing the model during 1981.

The objectives were to develop a model that is: (i) physically based and capable of simulating the processes involved simultaneously and realistically using readily available inputs; (ii) capable of simulating hundreds of years, if necessary, because erosion can be a relatively slow process; (iii) applicable to a wide range of soils, climates, and crops encountered in the U.S.A., and (iv) efficient, convenient to use, and capable of assessing the effects of management changes on erosion and soil productivity. The resulting model called EPIC is composed of physically based components for simulating erosion, plant growth, and related processes, plus economic components for assessing the cost of erosion, determining optimal management strategies, etc. A brief model description, some applications, and recent developments are presented here.

MODEL DESCRIPTION

The components of EPIC can be placed into nine major divisions for discussion: hydrology, weather, erosion, nutrients, soil temperature, plant growth, tillage, plant environment control and economics. A detailed description of the EPIC components was given by Williams *et al.* (1990*a*). A brief description of each of the nine components is presented here.

(*a*) ***Hydrology***

(i) *Surface runoff*

Surface runoff from daily rainfall is predicted using a procedure similar to the CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) runoff model, option one (Knisel 1980; Williams &

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† The EPIC computer program is available from: J. R. Williams, USDA-ARS, 808 East Blackland Road, Temple. Texas 76502, U.S.A.

Nicks 1982). Like the CREAMS model, runoff volume is estimated with a modification of the Soil Conservation Service (SCS) curve number method (USDA Soil Conservation Service 1972). The curve number estimates runoff as a function of rainfall amount, soil type, land management and soil-water content. The curve number varies nonlinearly from the 1 (dry) condition at wilting point to the 3 (wet) condition at field capacity and approaches 100 at saturation. The EPIC model also includes a provision for estimating runoff from frozen soil.

Peak runoff rate predictions are based on a modification of the Rational Formula (Lloyd-Davis 1906). The runoff coefficient is calculated as the ratio of runoff volume to rainfall. The rainfall intensity during the watershed time of concentration is estimated for each storm as a function of total rainfall using a stochastic technique. The watershed time of concentration (time required for surface runoff to travel from the most distant point to the watershed outlet) is is estimated by using Manning's Formula (Manning 1891) considering both overland and channel flow.

(ii) *Percolation*

The percolation component of EPIC uses a storage routing technique to predict flow through each soil layer in the root zone. Downward flow occurs when field capacity of a soil layer is exceeded if the layer below is not saturated. The downward flow rate is governed by the saturated conductivity of the soil layer. Upward flow may occur when a lower layer exceeds field capacity. Movement from a lower layer to an adjoining upper layer is regulated by the soil water to field capacity ratios of the two layers.

Percolation is also affected by soil temperature. If the temperature in a particular layer is 0 °C or below, no percolation is allowed from that layer.

(iii) *Lateral subsurface flow*

Lateral subsurface flow is calculated simultaneously with percolation. Flow is partitioned between percolation and lateral subsurface as a function of land slope and saturated conductivity.

(iv) *Evapotranspiration*

The model offers four options for estimating potential evaporation: Hargreaves & Samani (1985); Penman (1948); Priestley–Taylor (1972); and Penman–Monteith (Monteith 1965). The Penman and Penman–Monteith methods require solar radiation, air temperature, wind speed, and relative humidity as input. If wind speed, relative humidity, and solar radiation data are not available, the Hargreaves or Priestley–Taylor methods provide options that give realistic results in most cases. The model computes soil and plant evaporation separately as described by Ritchie (1972).

(v) *Snow melt*

The EPIC snow-melt component is similar to that of the CREAMS model (Knisel 1980). If snow is present, it is melted on days when the maximum temperature exceeds 0 °C, using a linear function of temperature. Melted snow is treated in the same way as rainfall for estimating runoff and percolation, but rainfall energy is set to 0.0 and peak runoff rate is estimated assuming uniformly distributed rainfall for a 24 h duration.

(*b*) ***Weather***

The weather variables necessary for driving the EPIC model are precipitation and air temperature. If the Penman methods are used to estimate potential evaporation then solar radiation, wind speed and relative humidity are also required. Of course, wind speed and direction are also needed when wind erosion is simulated. If daily precipitation, air temperature, and solar radiation data are available, they can be input directly to EPIC. Otherwise, EPIC provides options for simulating various combinations of the five weather variables.

(i) *Precipitation*

The EPIC precipitation model developed by Nicks (1974) is a first-order Markov chain model. Thus input to the model must include monthly probabilities of receiving precipitation if the previous day was dry and if the previous day was wet. Given the wet-dry state, the model determines stochastically if precipitation occurs or not. When a precipitation event occurs, the amount is determined by generating from a skewed normal daily precipitation distribution. The amount of daily precipitation is partitioned between rainfall and snowfall by using average daily air temperature.

(ii) *Air temperature and solar radiation*

The temperature-radiation model developed by Richardson (1981) was selected for use in EPIC because it simulates temperature and radiation values that exhibit the expected correlation between one another and rainfall. Daily maximum and minimum temperature and solar radiation are generated from a multivariate normal distribution. Details of the multivariate generation model were described by Richardson (1981). The dependence structure of daily maximum temperature, minimum temperature and solar radiation was described by Richardson (1982*a*).

(iv) *Wind*

The wind simulation model was developed by Richardson (1982*b*) for use in simulating wind erosion with EPIC. The two wind variables considered are average daily wind velocity and direction. Average daily wind velocity is generated from a two-parameter γ distribution. Wind direction expressed as radians from north in a clockwise direction is generated from an empirical distribution specific for each location.

(v) *Relative humidity*

The relative humidity model simulates daily average relative humidity from the monthly average by using a triangular distribution. Triangular coordinates are set to produce higher relative humidities on rainy days, lower values on dry days, and to preserve the long-term monthly average.

(*c*) *Erosion*

(i) *Water*

The EPIC water erosion model simulates erosion caused by rainfall and runoff and by irrigation (sprinkler and furrow). To simulate rainfall–runoff erosion, EPIC contains three equations: the USLE (Wischmeier & Smith 1978), the MUSLE (Williams 1975), and the Onstad–Foster modification of the USLE (Onstad & Foster 1975). Only one of the equations (user-specified) interacts with other EPIC components.

The three equations differ only in their energy factors: USLE uses rainfall; MUSLE uses runoff; and the Onstad–Foster equation uses both rainfall and runoff. The rainfall factor is the product of total rainfall energy of the storm and the maximum 0.5 h intensity. The runoff factor is the product of peak runoff rate and runoff volume.

The hydrology model supplies estimates of runoff volume and peak runoff rate. To estimate the daily rainfall energy in the absence of time-distributed rainfall, the model distributes rainfall rates exponentially. This allows simple substitution of rainfall rates into the USLE equation for estimating rainfall energy. The maximum 0.5 h rainfall intensity is simulated stochastically by using long-term maximum monthly 0.5 h rainfall amounts. The soil erodibility factor is estimated as a function of soil texture and organic content. The crop management factor is evaluated with a function of above-ground biomass, crop residue on the surface, and the minimum C factor for the crop. Other factors of the erosion equation are evaluated as described by Wischmeier & Smith (1978). A non-linear function of topsoil coarse fragment content is used to adjust the erosion estimates.

(ii) *Wind*

The Manhattan, Kansas wind erosion equation (Woodruff & Siddoway 1965), was modified by Cole *et al.* (1982) for use in the EPIC model. The original equation computes average annual wind erosion as a function of soil erodibility, a climatic factor, soil ridge roughness, field length along the prevailing wind direction, and vegetative cover. The main modification of the model was converting from annual to daily predictions to interface with EPIC.

Two of the variables, the soil erodibility factor for wind erosion and the climatic factor, remain constant for each day of a year. The other variables, however, are subject to change from day to day. The ridge roughness is a function of a ridge height and ridge interval. Field length along the prevailing wind direction is calculated by considering the field dimensions and orientation and the wind direction. The vegetative cover equivalent factor is simulated daily as a function of standing live biomass, standing dead residue, and flat crop residue. Daily wind energy is estimated as a non-linear function of daily wind velocity.

(*d*) *Nutrients*

(i) *Nitrogen*

The amount of NO_3—N in runoff is estimated by considering the topsoil layer only. The NO_3—N concentration is reduced as an exponential function of water flowing through the layer. The average concentration for a day can be obtained by integrating the exponential function to give NO_3—N yield and dividing by volume of water leaving the layer (runoff, lateral flow, and percolation). Amounts of NO_3—N contained in runoff, lateral flow, and percolation are estimated as the products of the volume of water and the average concentration.

Leaching and lateral subsurface flow in lower layers are treated with the same approach used in the upper layer, except that surface runoff is not considered. When water is evaporated from the soil, NO_3—N is moved upward into the top soil layer by mass flow.

A loading function developed by McElroy *et al.* (1976) and modified by Williams & Hann (1978) for application to individual runoff events is used to estimate organic N loss. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield (sediment delivered to the watershed outlet), and enrichment ratio (organic N concentration in sediment or organic N concentration in soil surface).

Denitrification, one of the microbial processes, is a function of temperature and water content. Denitrification is only allowed to occur when the soil water content is 90% of saturation or greater. The denitrification rate is estimated using an exponential function involving temperature, organic carbon, and NO_3—N.

The N mineralization model is a modification of the PAPRAN mineralization model (Seligman & van Keulen 1981). The model considers two sources of mineralization: fresh organic N associated with crop residue and microbial biomass and the stable organic N associated with the soil humus pool. The mineralization rate for fresh organic N is governed by C:N and C:P ratios, soil water, temperature, and the stage of residue decomposition. The N associated with the soil humus pool is divided into two pools (active and stable). Mineralization occurs only in the active pool, but N is allowed to flow very slowly from the stable to the active pool. Mineralization is estimated as a function of organic N mass, soil water and temperature.

Like mineralization, immobilization is simulated with a modification of the PAPRAN model. Immobilization is a very important process in EPIC because it determines the residue decomposition rate, and residue decomposition has an important effect on erosion. The daily amount of immobilization is computed by subtracting the amount of N contained in the crop residue from the amount assimilated by the microorganisms.

Crop use of N is estimated by using a supply and demand approach. The daily crop N demand is estimated as the product of biomass growth and optimal N concentration in the plant. Optimal crop N concentration is a function of growth stage of the crop. Soil supply of N is limited by mass flow of NO_3—N to the roots. Actual N uptake is the minimum of supply and demand.

Fixation of N is an important process for legumes. Daily N fixation is estimated as a fraction of daily plant N uptake. The fraction is a function of soil NO_3 and water content and plant growth stage. N fixation occurs if the root zone NO_3 content is greater than 300 kg ha^{-1} m^{-1}. The fraction is allowed to increase to 1.0 as the root zone NO_3 content is lowered to 100 kg ha^{-1}† m^{-1}. The fraction decreases linearly from 1.0 to 0.0 as soil water increases from 85% of field capacity to saturation. Below 85% of field capacity, the fraction reduces linearly to zero at wilting point. Also, fixation only occurs during the period between 15 and 75% of crop maturity.

To estimate the N contribution from rainfall, EPIC uses an average rainfall N concentration at a location for all storms. The amount of N in rainfall is estimated as the product of rainfall amount and concentration.

(ii) *Phosphorus*

The EPIC approach to estimating soluble P loss in surface runoff is based on the concept of partitioning pesticides into the solution and sediment phases as described by Leonard and Wauchope (Knisel 1980). Because P is mostly associated with the sediment phase, the soluble P runoff is predicted using labile P concentration in the top soil layer, runoff volume, and a partitioning factor. Sediment transport of P is simulated with a loading function as described in organic N transport.

The P mineralization model developed by Jones *et al.* (1984*a*) is similar in structure to the N mineralization model. Mineralization from the fresh organic P pool is governed by C:N and C:P ratios, soil water, temperature, and the stage of residue decomposition. Mineralization from the stable organic P pool associated with humus is estimated as a function of organic P weight, labile P concentration, soil water, and temperature. The P immobilization model also developed by Jones *et al.* (1984*a*) is similar in structure to the N immobilization model.

The mineral P model was developed by Jones *et al.* (1984*a*). Mineral P is transferred among three pools: labile, active mineral and stable mineral. When P fertilizer is applied, it is labile (available for plant use). However, it may be quickly transferred to the active mineral pool. Simultaneously, P flows from the active mineral pool back to the labile pool (usually at a much slower rate). Flow between the labile and active mineral pools is governed by temperature, soil water, a P sorption coefficient, and the amount of material in each pool. Flow between the active and stable mineral P pools is governed by the concentration of P in each pool and the P sorption coefficient.

Crop use of P is estimated with the supply and demand approach described in the N model. However, the P supply is predicted by using an equation based on plant demand, labile P concentration, and root mass.

(*e*) ***Soil Temperature***

Daily average soil temperature is simulated at the centre of each soil layer for use in nutrient cycling and hydrology. The temperature of the soil surface is estimated by using daily maximum and minimum air temperature and snow, plant, and residue cover for the day of interest plus the four days immediately preceding. Soil temperature is simulated for each layer using a function of damping depth, surface temperature, and mean annual air temperature. Damping depth is dependent upon bulk density and soil water.

(*f*) ***Crop Growth Model***

A single model is used in EPIC for simulating all the crops considered (corn, grain sorghum, wheat, barley, oats, sunflower, soybean, alfalfa, cotton, peanuts, potatoes, durham wheat, winter peas, faba beans, rapeseed, sugarcane, sorghum hay, range grass, rice, casava, lentils and pine trees). Of course, each crop has unique values for the model parameters. Energy interception is estimated as a function of solar radiation and the crop's leaf area index. The potential increase in biomass for a day is estimated as the product of intercepted energy and a crop parameter for converting energy to biomass. The leaf area index is simulated with equations dependent upon heat units, the maximum leaf area index for the crop, a crop parameter that initiates leaf area index decline, and five stress factors.

Crop yield is estimated using the harvest index concept. Harvest index increases as a nonlinear function of heat units from zero at planting to the optimal value at maturity. The harvest index may be reduced by water stress during critical crop stages (usually between 30 and 90% of maturity).

The fraction of daily biomass growth partitioned to roots is estimated to range linearly from 0.4 at emergence to 0.2 at maturity. Root weight in a soil layer is simulated as a function of plant water use within that layer. Root depth increases as a linear function of heat units and potential root zone depth.

The potential biomass is adjusted daily if one of the plant stress factors is less than 1.0 using the product of the minimum stress factor and the potential biomass. The water-stress factor is the ratio of actual to potential plant evaporation. The temperature stress factor is computed with a function dependent upon the daily average temperature, the optimal temperature, and the base temperature for the crop. The N and P stress factors are based on the ratio of accumulated plant N and P to the optimal values. The aeration stress factor is estimated as a function of soil water relative to porosity in the root zone.

Roots are allowed to compensate for water deficits in certain layers by using more water in layers with adequate supplies. Compensation is governed by the minimum root growth stress factor (soil texture and bulk density, temperature, and aluminum toxicity). The soil texture – bulk density relationship was developed by Jones (1983).

(*g*) ***Tillage***

The EPIC tillage component was designed to mix nutrients and crop residue within the plow depth, simulate the change in bulk density, and convert standing residue to flat residue. Other functions of the

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† 1 hectare = 10^4 m^2.

tillage component include simulating ridge height and surface roughness.

Tillage operations convert standing residue to flat residue by using an exponential function of tillage depth and mixing efficiency. When a tillage operation is performed, a fraction of the material (equal the mixing efficiency) is mixed uniformly within the plow depth. Also, bulk density is reduced as a function of mixing efficiency, bulk density before tillage, and undisturbed bulk density. After tillage, bulk density returns to the undisturbed value at a rate dependent upon infiltration, tillage depth, and soil texture.

(*h*) *Plant environment control*

(i) *Drainage*

Underground drainage systems are treated as a modification to the natural lateral subsurface flow of the area. Simulation of a drainage system is accomplished by reducing the travel time in a specified soil layer.

(ii) *Irrigation*

The EPIC user has the option to simulate dryland or irrigated agricultural areas. Sprinkler or furrow irrigation may be simulated and the applications may be user specified or automatic. With the automatic option, the model decides when and how much water to apply. The user must input a plant water stress level or a soil water tension value to trigger automatic irrigation, the maximum volume applied per growing season, and the minimum time interval between applications.

(iii) *Fertilization*

The EPIC model provides two options for applying fertilizer. With the first option, the user specifies dates, rates, and depths of application of N and P. The second option is more automated, the model decides when and how much fertilizer to apply. The three required inputs are: (i) a plant stress level to trigger nitrogen fertilizer application; (ii) the maximum N application per growing season, and (iii) the minimum number of days between applications. At planting time, the model takes a soil sample and applies enough N and P to bring the concentrations in the root zone up to the concentration level at the start of the simulation. Additional N may be applied during the growing season.

(iv) *Lime*

The EPIC model simulates the use of lime to neutralize toxic levels of aluminum in the plow layer. Two sources, KCl-extractable aluminum in the plow layer and acidity caused by ammonia-based fertilizers, are considered. When the sum of acidity due to extractable aluminum and fertilizer N exceeds 4 t ha^{-1}, the required amount of lime is added and incorporated into the plow layer.

(v) *Pesticides*

The effects of insects, weeds, and diseases are expressed in the EPIC pest factor. Crop yields are adjusted by multiplying the daily simulated yield by the pest factor (ranges from 0 to 1).

(*c*) *Economics*

The crop budgets are calculated by using components from the Enterprise Budget Generator (Kletke 1979). Inputs are divided into two categories: fixed and variable. Fixed inputs include depreciation, interest or return on investment, insurance, and taxes on equipment, land, and capital improvements (terraces, drainage, irrigation systems, etc.). Variable inputs are defined as machinery repairs, fuel and other energy, machine lubricants, seed, fertilizer, pesticides, labour, and irrigation water.

MODEL OPERATION

EPIC is a fairly comprehensive model developed specifically to estimate the long-term relationship between erosion and productivity (E/P). As the E/P estimate may require simulating many processes that take place over hundreds of years, computing efficiency was a primary consideration in EPIC development. Thus the model operates on a daily time step and uses the simplest and most efficient components available that will give adequate results.

The drainage area considered by EPIC is generally small ($\approx$ 1 ha) because soils and management effects are assumed to be spatially homogeneous. In the vertical direction, however, the model is capable of working with any variation in soil properties, the soil profile being divided into a maximum of 10 layers whose thicknesses can be varied. When erosion occurs, soil is removed from the surface, thus thinning the top layer. To maintain a constant top layer thickness of 10 mm, the second layer is thinned by the eroded thickness and the top layer properties are adjusted by interpolation (according to the distance the first layer is moved into the second layer). When the second layer thickness becomes zero, the top layer starts moving into the third layer, etc.

The crop parameter table contains information needed for simulating the production of 22 crops. The table can be expanded to include any number of crops without increasing the computer program storage requirements. Any combination of the 22 crops in rotations (up to 10 years) may be simulated. As many as three crops may be grown during one calendar year.

MODEL VALIDATION

The EPIC model has been tested in various ways. Several components were tested and reported in the literature (Knisel 1980; Williams 1982; Cooley & Williams 1983; Smith *et al.* 1984; Renard & Williams 1983; Nicks *et al.* 1990; Cole *et al.* 1982; Jones *et al.* 1984*b*; Kiniry *et al.* 1990; Williams *et al.* 1989). The Soil Conservation Service (SCS) performed numerous tests before the model was used for the 1985 RCA analysis. Seventeen major land resource areas in the U.S. were selected for these tests. Appropriate SCS experts inspected the EPIC simulations to determine if the results were reasonable and if the model was generally reliable. Several deficiencies were discovered, and the model was modified to overcome them. The tests were repeated after the model was revised. These simulations were carefully inspected by appropriate SCS experts before the model was declared ready for the RCA runs. The 13000 RCA simulations (of 100 years each) performed during 1984 and 1985 covered the entire U.S. Besides this extensive testing and application in the U.S., the model is being used internationally in research and in management.

MODEL APPLICATIONS

Putman *et al.* (1988) described details of the RCA EPIC application. Erosion-productivity relations were developed throughout the U.S. and supplied to SCS as part of the RCA analysis. As this major application, the model has been used in solving a variety of problems. Some of the most important applications include:

(i) The 1988 drought assessment, EPIC was used in a real time mode to estimate drought effects on U.S. crop production. The model provided most likely and extreme crop yield predictions to the USDA World Agricultural Outlook Board three times during the growing season.

(ii) A soil loss tolerance tool, soil loss tolerance can be defined as the maximum average annual soil loss rate at which productivity can be maintained at an acceptable level.

(iii) Australian sugarcane model (AUSCANE), Jones *et al.* (1989) modified EPIC for application to sugarcane. AUSCANE simulates sugarcane yields and sucrose content under a wide range of climatic conditions, soil properties, and management.

(iv) Pine tree growth simulator, Farmer (1988) expanded the EPIC crop growth model to include pine trees. She evaluated the model's predictive ability and sensitivity to soil and climatic conditions.

(v) Global climate change analysis, SCS and ARS (Robertson *et al.* 1990) used EPIC to estimate the effect of temperature, precipitation, and CO_2 changes on crop yield at several U.S. locations. Also, cooperative work with the Texas Agricultural Experiment Station and Resources for the Future is underway to evaluate CO_2 and climate change effects on crop productivity, hydrology, and irrigation and nutrient requirements.

(vi) Conservation planning, Benson *et al.* (1990) applied EPIC to SCS farm level conservation planning. They found that EPIC provided more comprehensive farm plans than the conventional methods.

(vii) Furrow diking, Williams *et al.* (1990*b*) showed the model's furrow diking component at 23 locations in Louisiana, New Mexico, Oklahoma and Texas. EPIC showed which soils and climates were best suited to furrow dikes and that furrow diking reduced erosion and conserved water.

EPIC DEVELOPMENTS SINCE RCA

An interactive data entry system, EASE (Entry and Assembly System for EPIC), is available to aid in building EPIC data sets.

The model can be used with a wide variety of mainframe and PC computers.

Inputs are readily available. Also, the model is designed to run on minimum data sets when some inputs are missing.

The weather data may be inputted or generated. Almost any combination of inputting and generating weather variables is possible. Also, a weather variable may be inputted for part of the simulation and generated for the remainder.

The same weather sequence may be repeated for any number of simulations at the same site or a new weather sequence may be generated for each simulation.

Daily, monthly, or annual output may be specified. Also, the output increment may be set for any number of days (N days) or any number of years (N years). For example, it may be desirable to see outputs every 5 days for detailed comparisons of crop growth data. It is also possible to operate the N-day print interval during the growing season only. The N-year interval is quite useful for long-term simulations involving slow processes like pine tree growth.

Output variables may be selected, or standard output is available.

The EPIC farm equipment table contains data for about 50 types of equipment for use in simulations. Any type of farm equipment may be added to the table, or existing equipment data may be modified.

Weather generation parameters are available for about 8000 locations. EASE automatically inserts these parameters into the EPIC data set for the site selected.

Data are available for 737 soils. EASE automatically inserts the selected soils data into the EPIC data set.

Components were added to EPIC for simulating furrow diking and water table dynamics.

The percolation component was modified to provide potential upward movement when field capacity is exceeded.

The crop growth model was modified to increase sensitivity of yield to drought stress.

A method for estimating winter wheat vernalization requirement was added.

A multiperiod operation mode was added for convenience in establishing relations between erosion and productivity.

An automatic soil layer splitting scheme was developed to provide better soil and description, especially when thick subsurface layers are exposed.

A special operating mode was added for estimating crop yield probability distributions by using static soil properties and a variety of weather sequences.

The flexibility of weather variable input was increased to allow real time simulation for 1988 drought assessment.

A seed germination component was added.

The simulation of manure application and cycling was added.

New components were added for simulating effects of climate and CO_2 changes. The Penman–Monteith method for estimating potential evapotranspiration was installed because of its sensitivity to climate and CO_2 through stomatal and aerodynamic resistance terms. Also, the energy-biomass relation was altered to account for variation in CO_2. A new flexible operation scheduling scheme was developed for use in simulating changes in growing season brought about by climatic change.

A plant competition growth model was developed to simulate weeds and a crop, intercropping or range and pasture grasses.

A soil compaction component was added, and early plant growth was governed by seed bed condition (mainly bulk density).

A more detailed root growth model was developed and added recently.

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