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The Erosion-Productivity Impact Calculator as Formulated for the Resource Conservation Act Appraisal

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ABSTRACT

The Erosion-Productivity Impact Calculator (EPIC) model measures the effects of erosion on soil productivity and long-range resource capacity. EPIC is a production function model which simulates the interaction among weather, hydrology, erosion, plant nutrients, plant growth, soil, tillage and management, and plant environmental control submodels. This report describes the model briefly, but concentrates on data and information systems developed to support the model for use in the U.S. Department of Agriculture's 1985 appraisal of resource conditions and trends required by the Soil and Water Resources Conservation Act of 1977.

Keywords: Erosion, erosion-productivity, simulation model, process model, weather generator.

PREFACE

The Soil and Water Resource Conservation Act of 1977 (RCA) requires the U. S. Department of Agriculture (USDA) to obtain and maintain information on the current status of soil, water, and related resources of the Nation. A major outgrowth of the appraisal effort is the Erosion-Productivity Impact Calculator (EPIC) model, developed as a cooperative effort of several USDA agencies (the Agricultural Research Service, the Soil Conservation Service, and the Economic Research Service). The EPIC model measures the effects of erosion on soil productivity and long-range resource capacity. This report describes the EPIC model in general terms and documents the information system and assembly procedures developed to apply the model in the 1985 RCA appraisal. Model outputs, analysis, and findings will follow in other reports.

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INTRODUCTION

The Soil and Water Resource Conservation Act of 1977 (RCA) requires the U.S. Department of Agriculture (USDA) to obtain and maintain information on the current status of soil, water, and related resources of the Nation (20). 1/ This information must include a continuing resource appraisal with an updated soil and water conservation program plan at 5-year intervals. The initial 1980 appraisal identified a data gap regarding accurate measurements of the effects of erosion on soil productivity and long-range resource capacity.

USDA responded to this data gap by forming the National Soil Erosion-Soil Productivity Research Planning Committee to document current technology for evaluating erosion/productivity problems, to identify the need for additional information, and to outline a research approach for seeking solutions to the problem. One of the most urgent needs identified was the development of a mathematical model for simulating erosion, crop production, and related processes (34).

In a cooperative effort led by the Agricultural Research Service and supported by the Soil Conservation Service and the Economic Research Service, such a model was developed. The output of this modeling effort is a network of independent but interrelated models and information systems which address specific tasks in the 1985 RCA. These tasks are: 1) to analyze the effects of alternative management and conservation systems on the resource base's productivity for the next 100 years; 2) to estimate the change in production costs for the alternative management and conservation systems analyzed; 3) to evaluate the economics of crop rotation systems, conservation tillage practices, and conservation structure alternatives for reducing erosion; and 4) to provide data on resource productivity, erosion rates, and the impact of erosion on productivity and fertility.

The cornerstone of the modeling system is the Erosion-Productivity Impact Calculator (EPIC) model. Development of the EPIC model has been described at various levels of detail (40). A few model applications have also been described (41). The EPIC Users Manual (38) provides information for applying the model, including the details of assembling input data using an interactive data entry system. Because of the immense data requirements for the RCA, the authors developed a more automated data assembly system and modified some parts

1/ Underscored numbers in parentheses refer to items in the Bibliography.

of the EPIC computer programs (mainly input-output) for the RCA special application.

This report describes details of the RCA data assembly system, the structure of the data sets, and the EPIC modifications required.

GENERAL DESCRIPTION

EPIC's design reflects several complex goals. First, the model should be physically based and capable of simulating the processes involved simultaneously and realistically using readily available inputs. Second, the model should be capable of simulating hundreds of years, if necessary, because erosion-induced productivity impacts can occur slowly. Third, it should be applicable to a wide range of U.S. soils, climates, and crops. Finally, the model should be computationally efficient, convenient to use, and capable of assessing the effects of management changes on erosion and soil productivity (39).

EPIC operates on daily time-steps. Each daily step is initiated by the simulation of a weather day and completed by tracing the impacts of the individual weather day through each of the submodels as well as estimating the interactions among submodels. EPIC tabulates daily outputs (runoff, erosion, plant growth, harvest, and so on) and computes daily balances as inputs to the succeeding day (soil moisture, nutrient levels, biomass, residue, and so on).

Erosion is defined as the detachment and movement of soil or rock fragments by water, wind, ice, or gravity (19). Erosion affects agricultural output in many ways. Soil removed by erosion depletes soil productivity by reducing the thickness of the root zone and the soil moisture-holding capacity, by changing texture and chemical properties as subsoil is mixed with topsoil to maintain a plow layer, by the loss of nutrients and organic matter in the sediment removed, by the change in toxicity in the root zone, and by accelerated runoff which reduces moisture infiltration. Erosion is also an inseparable part of the removal process which involves disruption and delays in agricultural operations and crop growth, damage and destruction of crops and facilities, and increased production costs due to replanting, repeating production practices, and increased use of other production inputs.

Inherent productivity changes, even at high erosion rates, are so gradual that they are essentially immeasurable in a single year. Thus, EPIC's design focuses on estimating the accumulated impact of soil removal over enough years to ensure an adequate sample of expected weather events and statistically reliable estimates of average annual impacts. In other words, EPIC estimates the impact of irrevocable losses in longrun productive capacity. EPIC does not, as yet, address direct damages resulting from storm events.

Although EPIC estimates daily, monthly, and annual changes for many years, it is not a projection model. EPIC interactively simulates the management, environmental and plant growth processes relevant to agricultural production, and the impact of erosion on sustained output. Each of these three processes in the EPIC model has different temporal concepts and assumptions.

EPIC is static with respect to management and technology. A single crop or rotation, tillage practice, conservation measure, crop planting and harvesting date, and machine sequence is specified prior to an EPIC simulation and cannot be varied during a simulation. The level of technology (such as plant genetic material and efficiency, plant varieties, irrigation efficiencies, and so on) is also fixed. The only exception is allowing fertilizer and irrigation water application to be varied as necessary to eliminate plant stress at a prespecified "trigger" level.

The environmental portion of EPIC, as reflected by the weather submodel, is both dynamic and conditionally predictive. EPIC is driven by a stochastic series of daily weather events that initiate the chain reaction and day-to-day change in values of the many physical and chemical processes. These daily weather events, in the aggregate, have the same means, variances, skewness, and sequential correlation as historical weather. Thus, the model is clearly dynamic in the way it simulates daily variability in climate and the impact of this variability on agriculture. While the series of weather days is sequentially correlated within years and generated for many years, there is no statistical relationship among the weather years generated. The synthetic weather series created, therefore, has no relation to forecasting. It may more properly be thought of as a frequency distribution of individual, annual weather events that might occur in a single year with characteristics that preserve daily sequential probabilities, internal correlation, and seasonal characteristics.

EPIC is predictive in the sense that it simulates the sequential, daily physical processes through a frequency distribution of weather events, assuming constant management and technology. Thus, EPIC predicts the estimated soil loss and change in inherent productivity, which might result over a multiyear period composed of weather events drawn from a known frequency distribution.

MODEL COMPONENTS

EPIC is a sophisticated production function model which simulates the interaction of the soil-climate-plant-management processes in agricultural production. EPIC is composed of physically based submodels for simulating weather, hydrology, sheet and rill and wind erosion, plant nutrients, plant growth, soil tillage and management, and plant environment control (fig. 1). Each submodel is linked sequentially and interactively with other submodels.

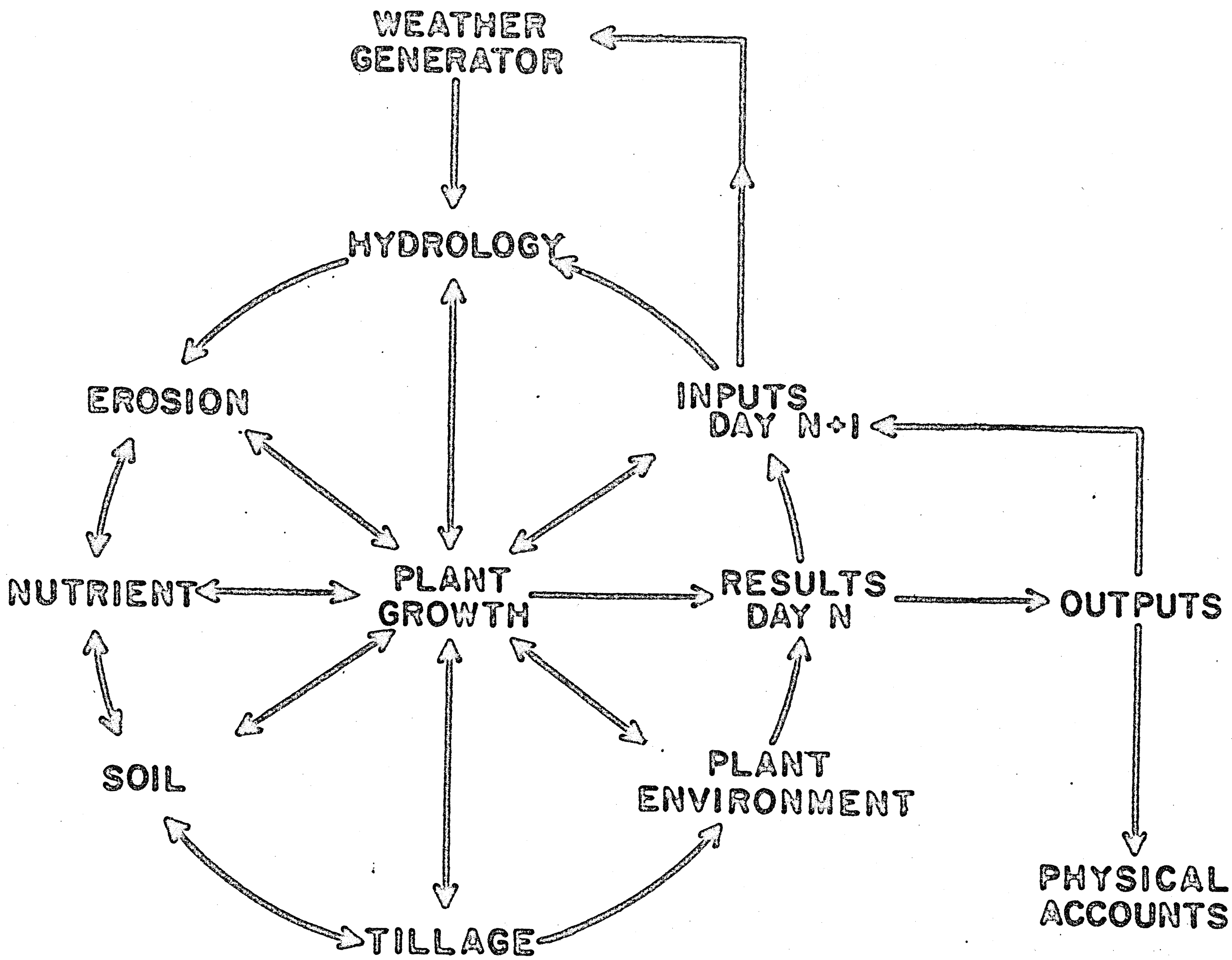
Weather Submodel

The weather parameters required for EPIC simulations are precipitation, air temperature, solar radiation, and wind (fig. 2). Daily precipitation is simulated by a first-order Markov chain model (9). The model uses monthly probabilities of receiving daily precipitation given the wet-dry state of the previous day. The model generates a stochastic series of wet and dry days for the period of simulation based on these historical probabilities.

The amount of any precipitation is generated from a skewed normal daily precipitation distribution. Daily maximum and minimum temperatures and solar radiation are generated from a multivariate normal distribution (14). The system simulates temperature and radiation that exhibit proper correlation between each other and with rainfall (15).

Average daily wind velocity is generated from a two-parameter gamma distribution specific for each location (16). The weather submodel components and the required data base for weather generation are developed in a model

Figure 1--System linkage diagram



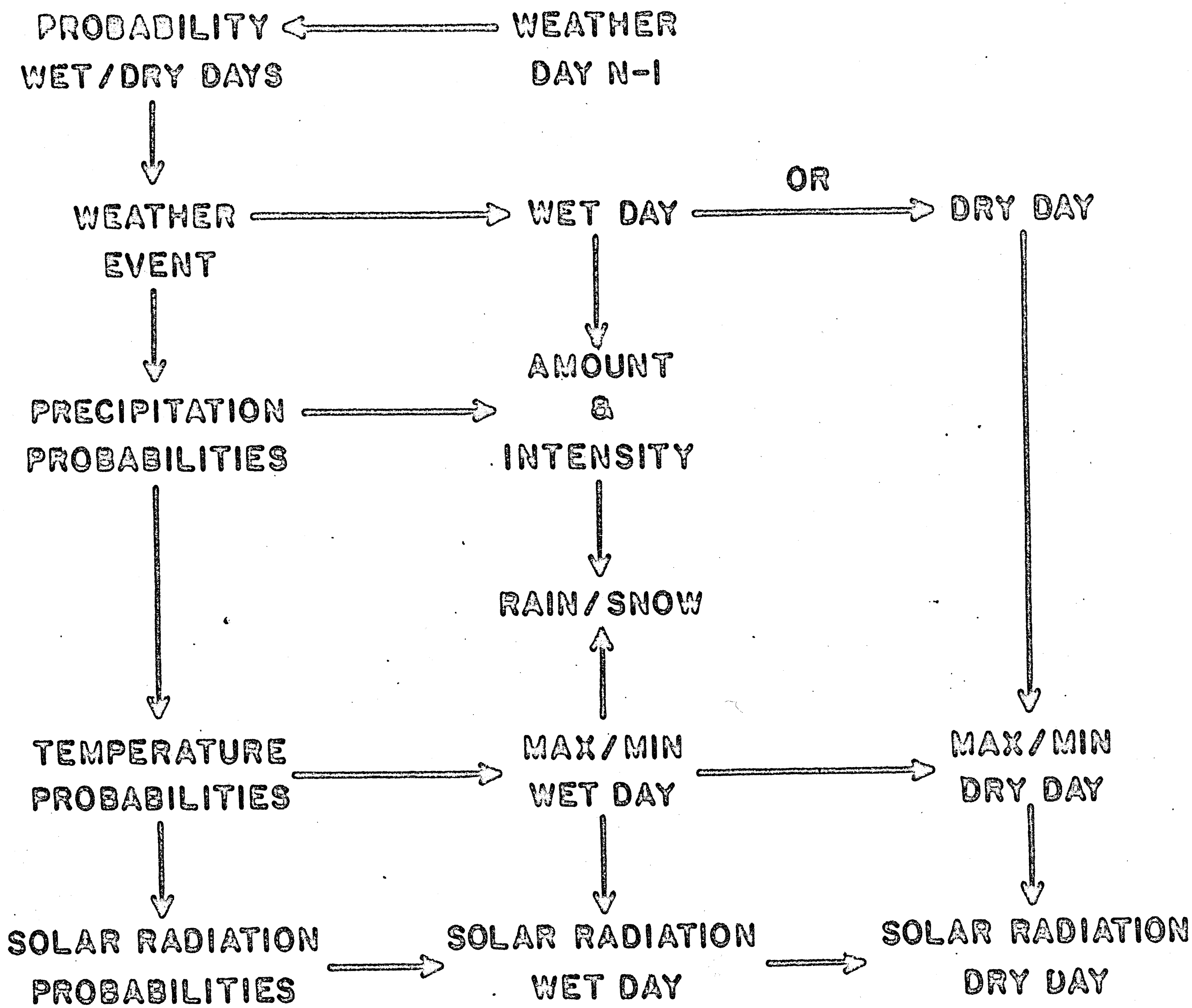


Figure 2--Weather submodel

called WGEN (Weather Generator) (17). WGEN incorporates precipitation parameters for 139 U.S. locations with temperatures and solar radiation from 31 locations into a data base which can generate input estimates interpolated to any specified U.S. latitude and longitude (28, 29, 30). The weather model has a user option to inspect the values generated and correct them to prespecified monthly average values for precipitation and temperature.

Hydrology Submodel

The hydrology submodel simulates volume and peak discharge rate of surface runoff--given a daily rainfall event, snow melt, and/or irrigation (21) (fig. 3). The procedures used are similar to the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) runoff model except that EPIC accommodates variable soil layers and estimates runoff from frozen soils (7, 35). Estimates of infiltration, percolation, lateral subsurface flow, drainage, evapotranspiration, irrigation, and snow melt are used to compute a revised soil moisture level to begin the next daily cycle. Irrigation is simulated by adjusting the soil moisture level to field capacity when a user-specified moisture stress level is triggered by the plant growth submodel.

Wind and Water Erosion Submodel

The soil erosion submodel uses two forms of erosion equations as estimators of water erosion (fig. 4). The two equations are identified as: 1) the universal soil loss equation (USLE), and 2) the Onstad-Foster Equation (AOF). The two equations differ only in the way the rainfall factor is computed. This difference may be described in terms of the general USLE equation. The USLE soil loss equation is:

$$A = RK(LS)CP$$

where:

A = computed soil loss
R = the rainfall erosion index (EI)
K = the soil erodibility factor
LS = the slope length-steepness factor
C = the crop management (cover) factor
P = the erosion control practice factor

The USLE erosion model estimates longtime average erosion from particle detachment caused by raindrop impact. The USLE R factor combines rainfall energy/volume (E) with storm peak intensity (I) (42). The AOF equation incorporates both rainfall and runoff in the R factor to estimate sediment yields (10).

EPIC's application of both equations differs from traditional use by calculating erosion each day, given the precipitation derived from the other submodels (including irrigation and snow melt) using a C factor value specific to the day's biomass and residue conditions. Annual erosion estimates and long-term annual averages are derived by summing daily events and averaging them over the years simulated. Although both equations are computed in EPIC, AOF is used to estimate changes in the soil profile caused by erosion events for the 1985 RCA.

Figure 3--Hydrology submodel

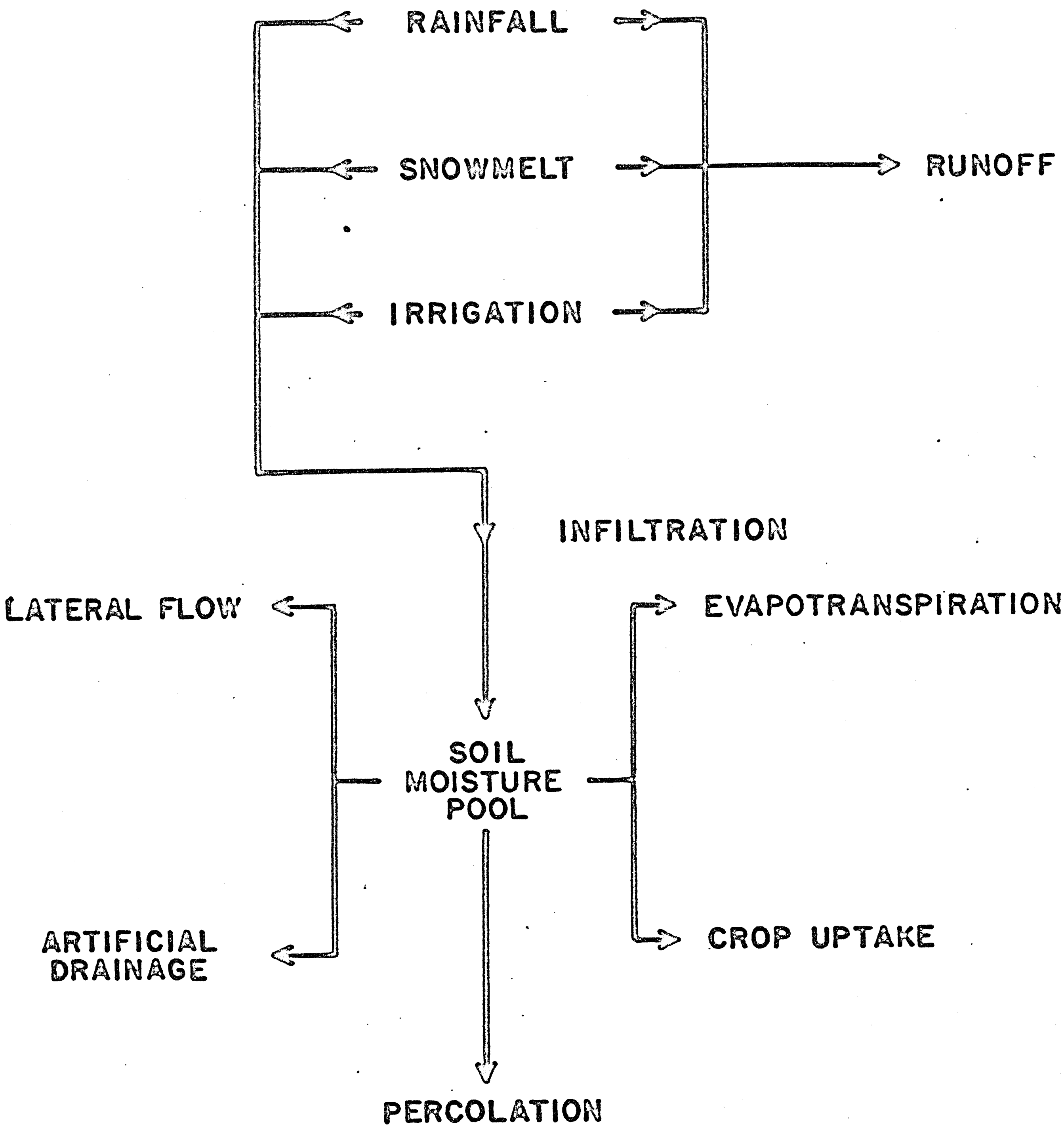
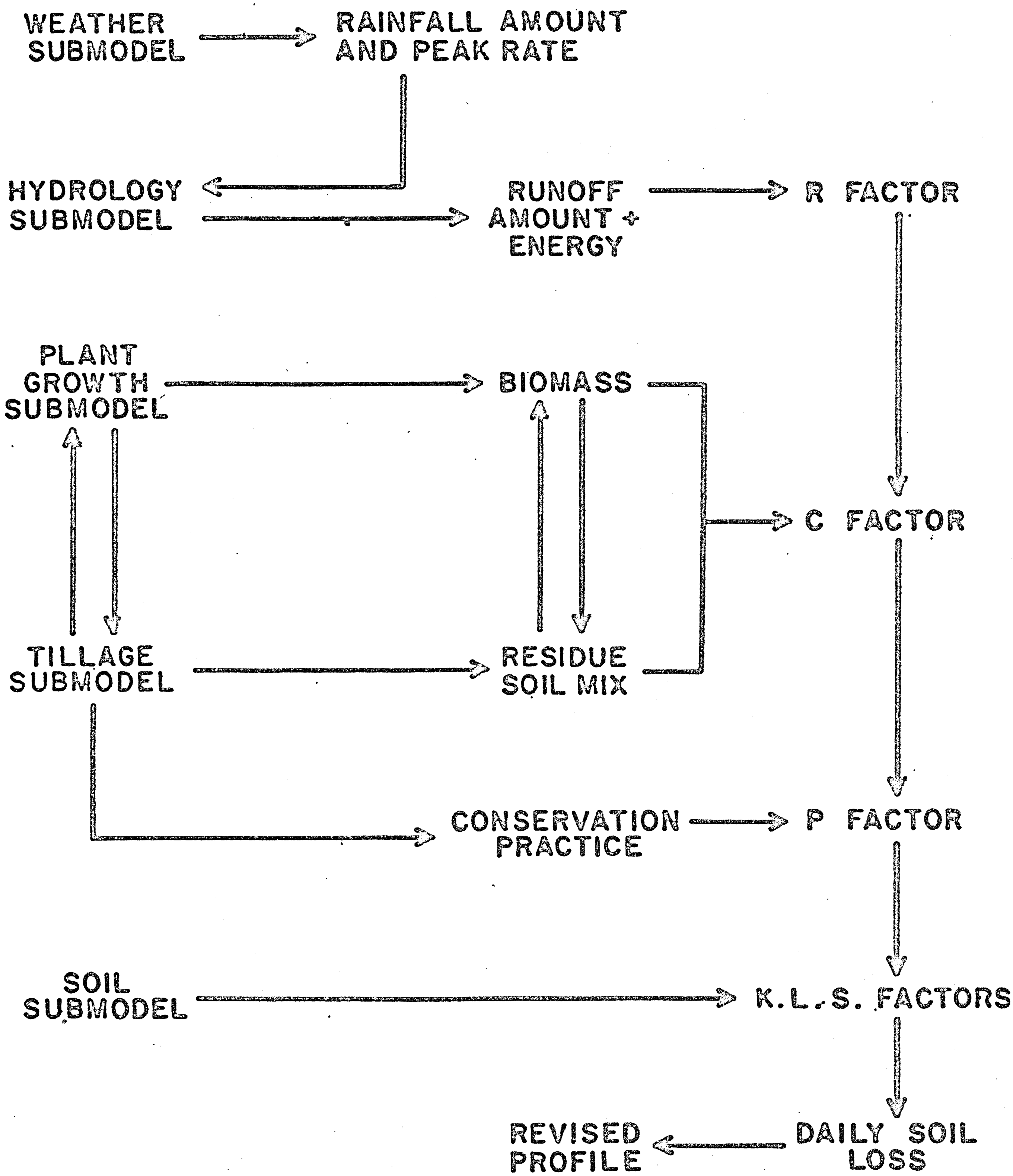


Figure 4--Soil erosion submodel



The wind erosion equation is:

$$WE = CIKLV$$

where:

- WE = computed wind erosion in t/ha
- C = climatic factor, wind
- I = the soil erodibility factor, wind
- K = the soil ridge roughness factor
- L = the field length along the prevailing wind direction
- V = the quantity of vegetation cover

Plant Nutrient Submodel

EPIC models and monitors three plant nutrients--nitrogen (N), phosphorus (P), and lime. Nitrogen processes simulated include fertilization, nitrogen fixation, rainfall nitrogen, mineralization, denitrification, immobilization, leaching of NO_3, upward NO_3 movement by soil water evaporation, crop uptake, organic N transported by sediment, and NO_3 in runoff (fig. 5). The N mineralization and immobilization model is a modification of the PARRAN mineralization model (18). Organic N loss from individual runoff events is estimated with a loading function developed by McElroy and others and modified by Williams and Haun (8, 33). Enrichment ratios are determined as described by Knisel (7). The other processes are described by Williams (40).

Phosphorus processes include mineralization, immobilization, sorption-desorption, crop uptake, fertilization, runoff of soluble P, and sediment transport of mineral and organic phosphorus (fig. 6). The P mineralization and immobilization model is similar to the N mineralization and immobilization model (4).

EPIC simulates the use of lime to neutralize the toxic level of aluminum in highly weathered soils and to maintain desired soil pH in moderately weathered soils. For highly weathered soils, the percentage of aluminum saturation is estimated from soil base saturation, pH, cation exchange capacity, and organic content. Topsoil pH and base saturations are affected by application of ammonia-based fertilizers and lime and by mixing topsoil with deeper soil layers. Lime requirements are computed annually. If they exceed users' specified levels, lime is applied, and soil pH, base saturation, and aluminum saturation are updated.

Plant Growth Submodel

EPIC uses a general plant growth submodel with crop specific parameters to simulate the growth of corn, wheat, grain sorghum, soybeans, cotton, peanuts, alfalfa, grasses, oats, and barley (fig. 7).

The plant growth model simulates energy interception; energy conversion to roots; above-ground biomass; root, grain, and fiber production; and moisture and nutrient uptake. Annual crops are grown from a user-specified planting date to harvest date, frost, or until accumulated heat units equal potential heat units (maturity) for the crop. Perennial crops maintain root systems through frost-induced dormancy and start regrowth when average daily air temperature exceeds the base temperature specified for the plant. Plant growth

Figure 5--Nitrogen submodel

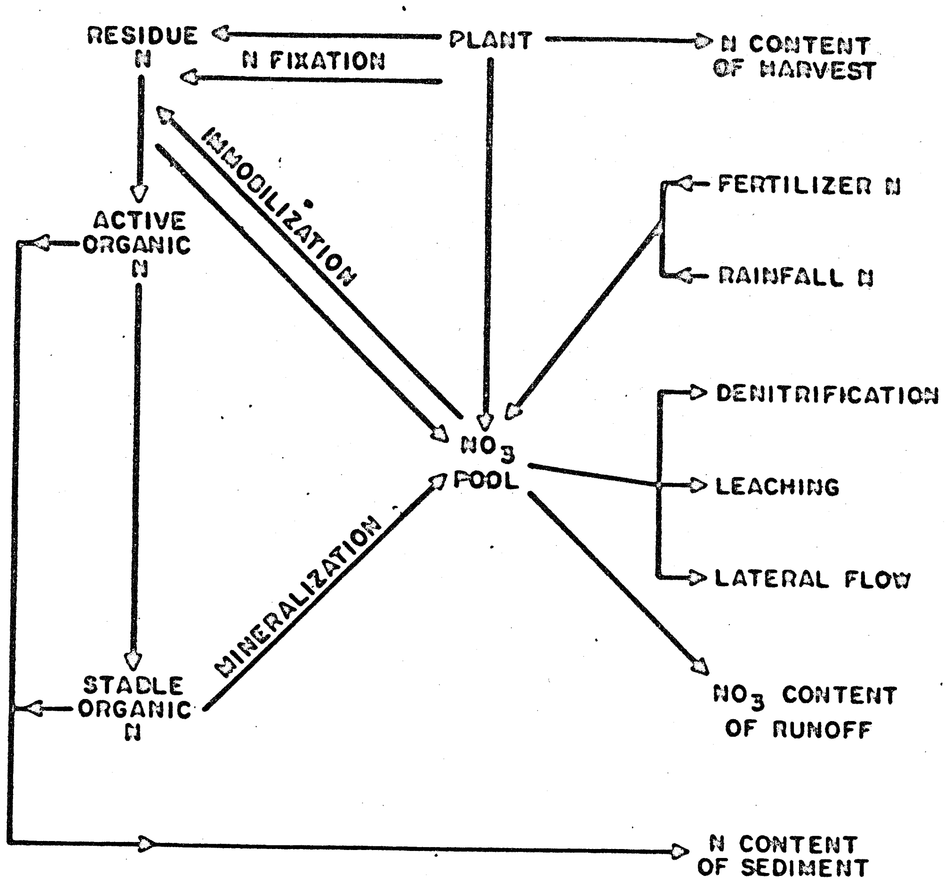


Figure 6--Phosphorus submodel

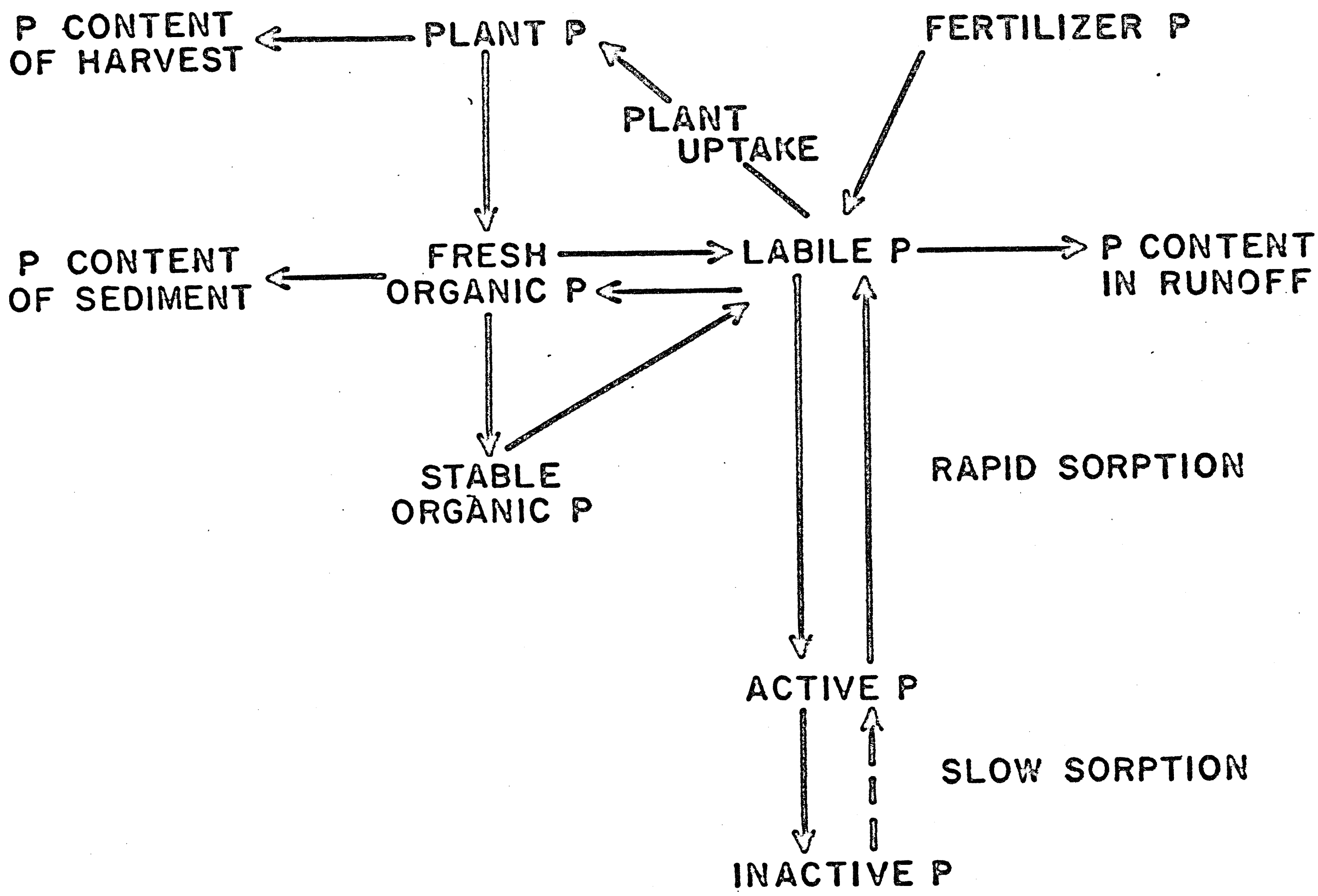
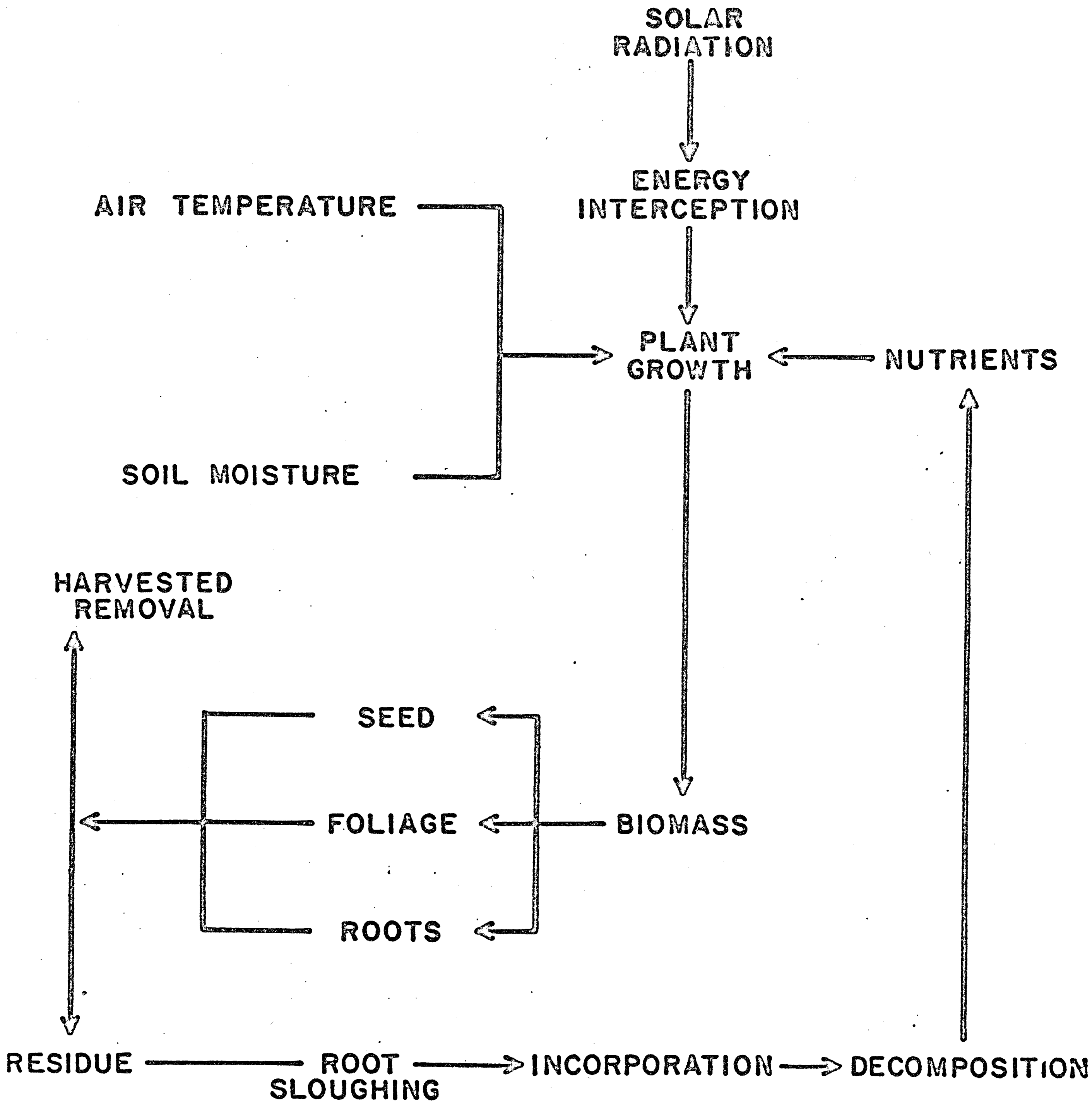


Figure 7--Plant growth submodel



is constrained by water, nutrient, and temperature stresses. Soil temperature is simulated to serve the nutrient cycling and root growth components of EPIC.

Soil Submodel

The soil submodel monitors change in soil properties. Initial soil properties are specified for a fixed 10-millimeter (mm) top layer and up to 9 additional layers of user-specified thickness to a maximum root zone depth of 1,500-2,000 mm unless interrupted at a shallower depth by impervious layers.

Soil characteristics used by EPIC (and specified by layer) are thickness of layer; bulk density; water-holding capacity; minimum field capacity; wilting point; organic N; NO_3; labile P; crop residue; sum of the bases; organic C; $CACO_3$; coefficient of linear extension; pH; KCl extractable aluminum content; coefficient of linear extensibility; percentage of sand, silt, and clay; and coarse fragment inclusions.

The soil model simulates soil removal by runoff by reducing the thickness of the second layer to maintain a constant 10-mm thick top layer. Soil properties of the top layer are adjusted by interpolation to simulate mixing with second or lower layers, depending on how much soil is removed. The model also computes daily soil temperature as a function of the previous day's soil temperature, the current day's air temperature, bulk density, soil water content, and cover (growing biomass, residue, and snow). The soil moisture pool (hydrology submodel) is varied within limits of soil water availability (13)(fig. 8).

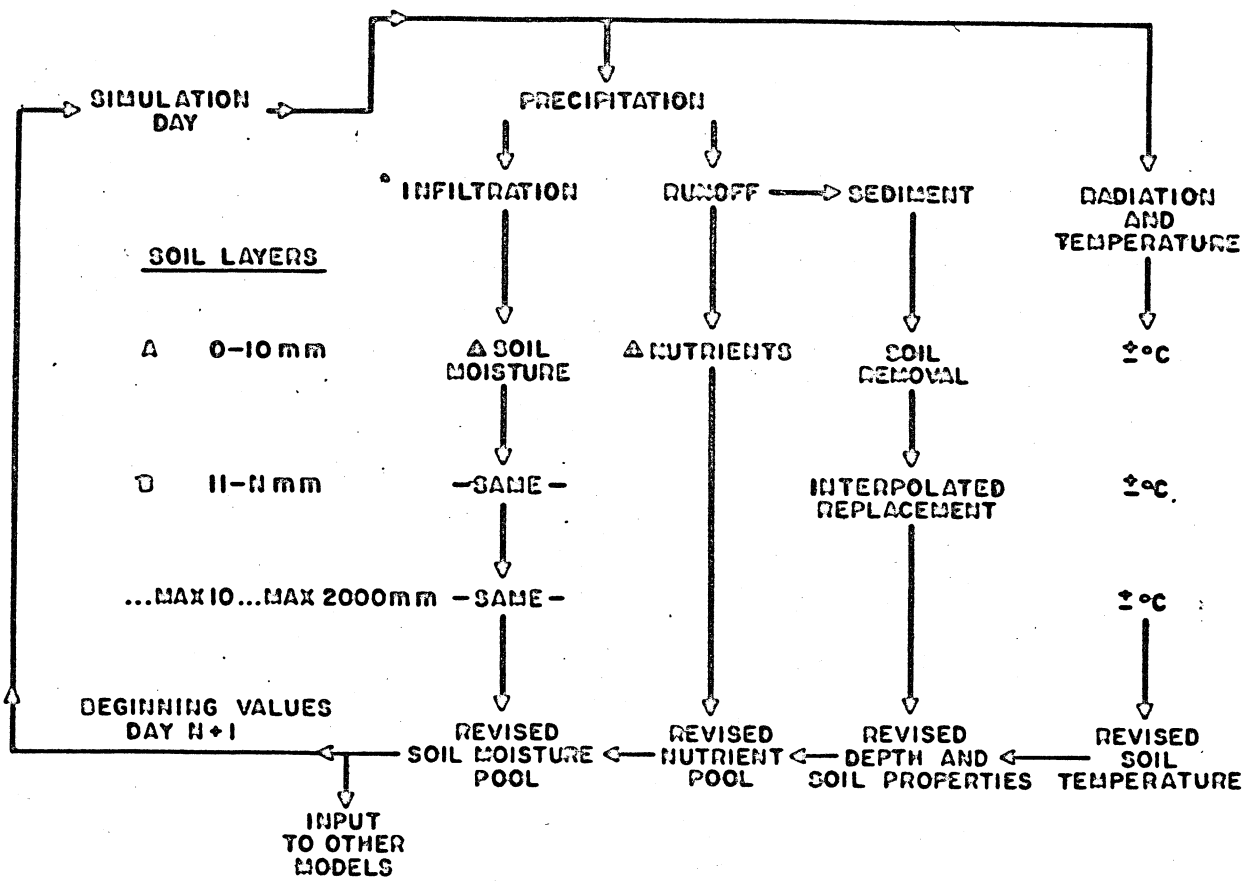
Tillage and Management Submodel

The tillage and management submodel is controlled by user-specified crop rotations and crop budgets. Crop rotations may vary from a single, continuous crop to a 6-year rotation with six crops. In every case, the rotation repeats in an identical form for the length of the simulation. Crop budgets include only machinery operations, the sequential date such operations are performed, and the engineering coefficients required by the other submodels. The number and sequence of the various tillage operations are usually based upon Firm Enterprise Data System (FEDS) budgets (5). FEDS information is supplemented by adding depth of soil penetration (or height of cut), mixing efficiency (average percentage of surface residue mixed into the soil over the specified depth), row height (ridging), row interval, and surface roughness for each tillage machine.

The submodel maintains a daily account of standing and flat residue and the gradual change between the two. Soil settling and smoothing is computed after each rainfall event. After a tillage operation, the percentages of crop residue incorporation, nutrient mixing, and change in bulk density are computed for the depth of soil penetration, and surface ridging, height interval, and roughness are adjusted.

One of four alternative harvest options may be specified. These are: 1) traditional harvest which removes seed or biomass or both and kills the plant; 2) hay harvest which allows multiple harvests with plant regrowth; 3) no harvest for crops like green manure or summer fallow; and 4) multiple harvest operations of crops like cotton. Traditional harvest kills the plant and

Figure 8--Soil submodel



partitions the biomass into the portion removed (seed), flat residue, and standing residue according to the specified height of the cutting. Hay harvest assumes a perennial plant with regrowth during the growing season and dormancy (with maintenance of roots) during the winter.

Plant Environmental Control Submodel

The plant environmental control submodel is an assortment of functions and control parameters not included in other parts of the model. This submodel includes irrigation, fertilization, lime, and pesticide functions.

Irrigation is controlled by specifying the plant water-stress level, the runoff ratio, and whether the application method is sprinkler or furrow. When the user-specified stress level is reached, the model adjusts the root zone soil moisture level to field capacity and records water applications for soil moisture, plus runoff losses.

EPIC provides two options for fertilizer application. The user may specify absolute amounts, dates, and depths of application of nitrogen and phosphate, which are systematically repeated for each crop year in the rotation throughout the simulation. In the 1985 RCA, the second option specified a plant-stress factor that initiates fertilization during the growing season. With this option, the model automatically adjusts the NO_3-N and labile P levels to the concentration in the soil at the beginning of the simulation. The pre-planting adjustment and plant stress additions are converted to fertilizer units and recorded as fertilizer applications.

EPIC also simulates the use of lime applications to neutralize toxic levels of acidity in the plow layer. When the sum of acidity due to extractable aluminum and fertilizer nitrogen exceeds 4 tons per hectare, the required amount of lime is incorporated into the plow layer.

The effects of insects, weeds, and diseases are simulated in EPIC by specifying a loss factor that reduces output from the plant growth model by a constant factor for all crops in all years.

RCA DATA STRUCTURE

The basis of the 1985 RCA data structure is a network of land resource groups within physiographic regions to identify and cross-link the many physical, agronomic, and economic data sets required for EPIC input and subsequent RCA analysis. Each of the resource/site combinations is characterized by the dimensions and physical features of the region and the characteristics of each of the eight land groups. For the more precise data requirements of EPIC, regions and land groups are represented by environments (climate) specific to a midcounty and individual benchmark soil mapping units, respectively.

Resource Framework

Major land resource areas (MLRA's) are used to partition the United States into 168 physiographic areas (fig. 9). MLRA's are homogeneous with respect to the regular and repeating nature of the natural landscape, patterns of soil bodies, climate, water resources, land use, and type of farming. They are large enough to be redefined to county boundaries for data generation, national modeling, and policy analysis. MLRA names, descriptions, and codes are delineated in Land Resource Regions and Major Land Resource Areas of the United States (23). Four MLRA's (128, 133A, 136, and 153A) were subdivided into north (N) and south (S) portions for RCA modeling purposes. MLRA's are divided tabularly into eight land groups (table 1). The land groups are formed by clustering class-subclasses from the 1982 National Resource Inventory (NRI) (24).

Class-subclasses are based upon the land capability classification system which classifies soils (and soil map units) into four subclasses with similar kinds of limitations and hazards to their capability of producing common cultivated crops without deterioration over a long period of time (6). The four subclasses are: erosion, designated by the symbol (e); wetness, drainage, or overflow (w); rooting-zone limitations, stoniness, low moisture-holding capacity, salinity, and so on (s); and temperature or lack of moisture (c). When two kinds of limitations are essentially equal, the subclasses have the priority e, w, s, and c. For example, soils with both an erosion hazard and a water problem are classified as an (e) subclass. Thus, soils classified as a (w) tend to have no erosion problem.

Land capability classes further divide subclasses into eight groups on the basis of the ordinal degree of hazard or limitation. The degree of limitation becomes progressively greater from class I to class VIII.

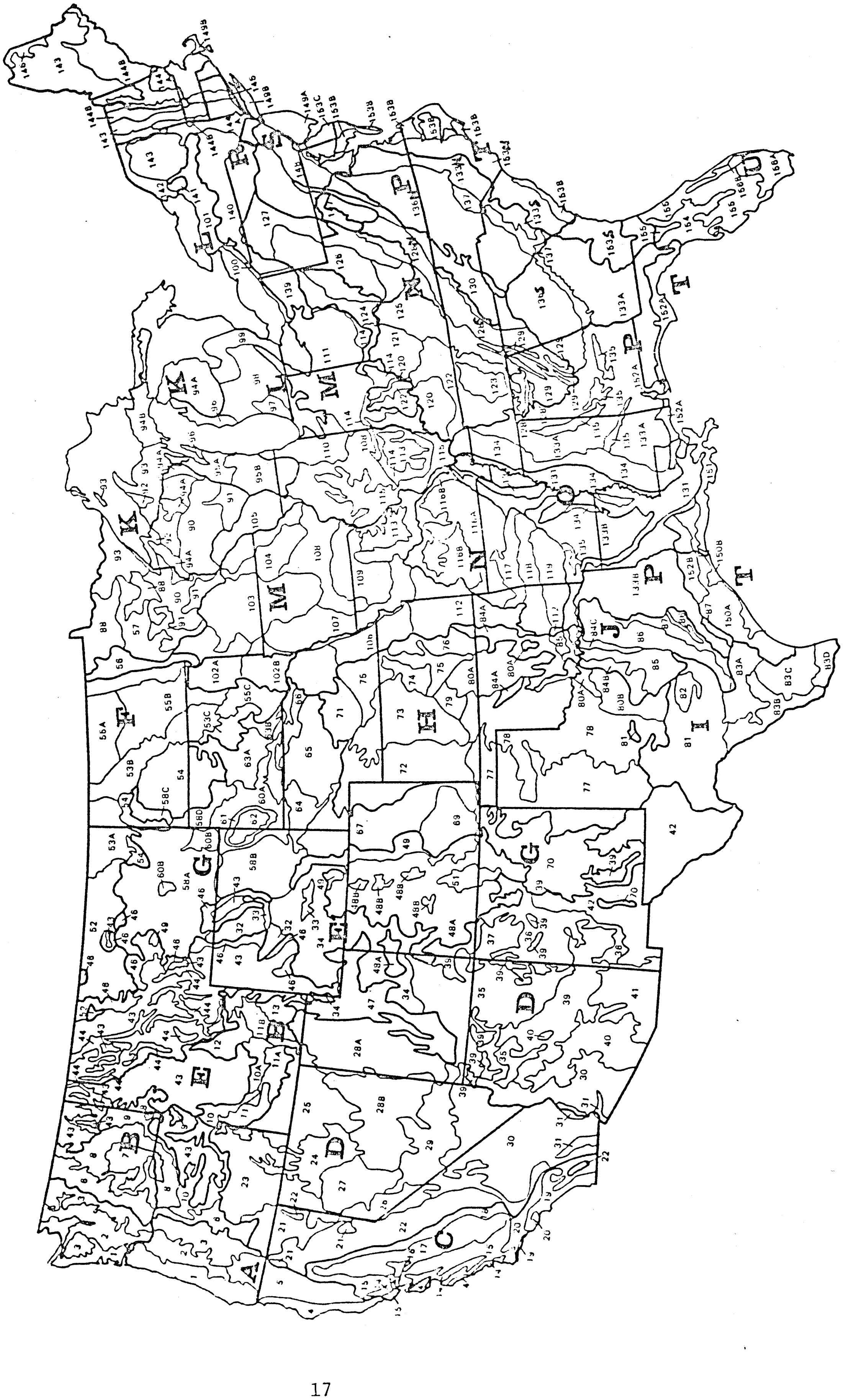
Soils in the first four classes under appropriate levels of management are usually considered capable of sustained production of cultivated crops. Soils in classes V, VI, VII, and VIII are not generally suited to cultivated crops. For RCA purposes, the 29 class-subclasses are grouped into the 8 RCA land groups to provide 3 groups with erosion susceptibility (slight, moderate, and severe); 3 groups with climate, soil, and water problems; 1 group with no problems; and 1 group considered unsuitable for cultivation. For more precise delineation, each land group in each of the MLRA's is characterized by a soil series that is felt to be the most representative of all soils in the land group.

Table 1--RCA land groups by class-subclass and conservation practices considered in the 1985 EPIC/RCA data system

RCA soil group	Land capability class/subclass	Conservation alternatives: Straight row	Contour	Strip cropping	Terrace	Wind strip 2/
1.	I, IIwa, IIIwa 1/	X				
2.	IIe	X	X	X	X	X
3.	IIIe	X	X	X	X	X
4.	IVe	X	X	X	X	X
5.	IIc, IIIc, IVc	X				
6.	IIs, IIIs, IVs	X				
7.	IIw, IIIw, IVw	X				
8.	V, VI, VII, VIII	X	X	X	X	X

1/ The "wa" subclass designates a soil with a wetness limitation that has been alleviated by drainage.
2/ In the Great Plains only.

Figure 9--Major land resource areas for 1985 RCA



Crops

The RCA system includes 18 crops: winter barley, spring barley, corn for grain, corn silage, cotton, legume hay, nonlegume hay, winter oats, spring oats, pasture and range, peanuts, sorghum for grain, sorghum silage, soybeans, summer fallow, sunflowers, winter wheat, and spring wheat (table 2). Hay crops are subcoded for EPIC purposes by establishment and harvest. Barley, wheat, and oats are subcoded winter and spring. Fall-planted small grains are divided into planting and harvesting segments so that they can be sequenced in the proper rotation order.

Rotations

The major influence of rotations on productivity and erosion rates in any given year may be attributed to the preceding year in the rotation.

Thus, all rotations may be reduced to 2-year segments for data estimation purposes without significant loss of accuracy. The EPIC data framework is based upon the minimum number of rotations needed to estimate crop sequence data sets for all RCA crops and important crop sequences. The rotations used are agronomically feasible, reasonable, and practical. They are constructed, however, to generate data sets for RCA relevant crops and crop sequences with a minimum number of rotations and simulations and do not necessarily represent the most commonly used rotations in the area. Rotations in the EPIC system are all 4-year rotations to standardize data sets and generate a minimum of 25-crop years of data for each crop sequence.

Table 2--RCA/EPIC crops, crop codes, and units

Crop	Code	Unit: Metric per ha	Unit: English per acre
Spring barley	SBR	Kg	Bu (48 lbs)
Winter barley	WBR	Kg	Bu (48 lbs)
Corn for grain	CGR	Kg	Bu (56 lbs)
Corn silage	CSL	Kg	Ton
Cotton	COT	Kg (seed)	Lbs (lint)
Legume hay harvest	LHA	Kg	Ton
Nonlegume hay harvest	NLH	Kg	Ton
Spring oats	SOT	Kg	Bu (32 lbs)
Winter oats	WOT	Kg	Bu (32 lbs)
Pasture and range	PAS	Kg	Ton
Peanuts	PNT	Kg	Cwt
Sorghum for grain	SGR	Kg	Bu (56 lbs)
Sorghum silage	SSL	Kg	Ton
Soybeans	SOY	Kg	Bu (60 lbs)
Summer fallow	FAL		
Sunflowers	SUF	Kg	Lbs
Spring wheat	SWT	Kg	Bu (60 lbs)
Winter wheat	WWT	Kg	Bu (60 lbs)
Establish legume hay	ELH	none	none
Establish nonlegume hay	ENL	none	none

Tillage Practices

For each MLRA rotation, four types of tillage options are specified:

1) Fall plow--any form of clean tillage that does not maintain winter cover.
2) Spring plow--any form of clean spring tillage that maintains residue from the previous crop undisturbed during the winter.
3) Conservation tillage--a form of tillage that retains 30- to 85-percent residue cover on the soil surface after planting.
4) No till--a form of tillage that maintains more than 85-percent cover at planting. Planting is completed by only disturbing a narrow seedbed approximately 1 to 3 inches wide. Weeds are primarily controlled using herbicides.

Strict application of the above definitions in EPIC simulations requires some modification. The terms fall and spring conventional tillage have little relevance to winter small grains and hays. As a result, the EPIC system uses a single, conventional-cultivated wheat and hay establishment budget for use with both "spring" and "fall" tilled row crops in rotations. In areas where growing seasons are longer and less precise, "fall" and "spring" become the first and second part of the growing season and/or before and after January 1.

Conservation Measures

Conservation measures (besides conservation and zero tillage) considered in the RCA include contouring, contour strip cropping, and terracing. Strip cropping for wind erosion in the Great Plains is also included (see table 1). The impact of conservation practices on erosion rates affects the AOF equation in the EPIC model in several ways. Conservation tillage and rotation practices are simulated by reducing the C factor to reflect increased surface residue and/or decreased years of erosive crops in the rotation. With the exception of terraces, where the LS factor is changed to reflect the shortening of natural slope length to terrace intervals, all other conservation impacts are estimated by changing the practice factor (P) value (table 3). In EPIC, specific criteria for estimating P factor values are taken directly from tables 13, 14, and 15 in (42). Practice factor values are the same for all three conservation practices (contour, contour strip cropping, and terraces) within the respective slope groups. Contour strip cropping merely permits contouring to be practiced on longer slopes. Terracing removes all slope restrictions.

RCA DATA ASSEMBLY

The six data files that make up the RCA data system and provide input for the EPIC/RCA model are not directly comparable to the RCA data structure described in the previous section. As a result, this section is structured by input file with the description cutting across RCA structure, definitions, and data requirements as necessary.

Tillage Array File

Three data sources are combined to assemble the tillage array data files that control the tillage submodel (fig. 10). These are the crop budget sequence,

Table 3--Criteria for the selection of P factors

Land slope	P value	Maximum allowable slope length: Contour	Maximum allowable slope length: Contour strip	Contour strip width	Terrace interval
Percent		Feet			
1 to 2	60	400	800	130	180
3 to 5	50	300	600	100	180
6 to 8	50	200	400	100	160
9 to 12	60	120	240	80	160
13 to 16	70	80	160	80	120
17 to 20	80	60	120	60	90
21 to 25	90	50	100	50	90

Source: (42)

rotation, and plant and harvest date files. Planting and harvest dates are based on estimates from "Usual Planting and Harvesting Dates" and are adjusted to reflect review comments and special rotation needs (27).

The crop budget sequence file was initially prepared by the Soil Conservation Service (SCS), USDA, field staff in the 48 conterminous States (25). The SCS staff used composite FEDS budgets or budgets from the SCS crop budget system to construct a schedule of typical machinery operations required to achieve clean tillage with or without winter cover, conservation, and zero tillage practice objectives for each RCA crop (3). Engineering data required by the tillage submodel were added to the SCS machinery operations from Agricultural Research Service (ARS) files. Machinery operations were then sequenced by days before or after planting and harvest dates.

Rotations for the RCA/CARD model were prepared by CARD and SCS (3). As previously described, this set of rotations was reduced to a minimum number necessary for EPIC requirements. The resulting file of EPIC rotations provides the control mechanism to cross-reference the planting and harvest date file and crop budget sequence file and produce the final tillage array to input an EPIC simulation.

Crop Parameters

The crop parameter file provides the data used by the plant growth submodel to simulate growth of specific kinds of plants (fig. 11). These data are required to differentiate important growth characteristics, physical parameters, and chemical properties among the RCA crops. The sensitivity of individual crops to temperature and radiation is also calibrated to reflect modern plant breeding tailored to climatic zones.

Like all simulation models, EPIC output reflects "laboratory" results. Loss of stands by erosion, insect damage, flooding, weed competition, and many other aberrations common to nature are not part of the model. As a result, a standard, arbitrary factor is used in all RCA runs to reduce harvest amounts by a 10-percent mechanical loss and a 15-percent natural disaster loss. It must be recognized that a standard natural disaster loss factor for all MLRA's is not correct but is a necessary generalization given budget and time constraints.

MLRA: 77 ROT: 8 TILL: SPLW RCA: 3 CLASS: 3E SERIES: AMARILLO LAT: 34.50 LONG: 102.50 DATE: 01/16/85 TIME: 11:20:26

ORIGINAL CROP ROTATION FORMAT 8

	--- YEAR 1 ---			--- YEAR 2 ---			--- YEAR 3 ---			--- YEAR 4 ---			--- YEAR 5 ---			--- YEAR 6 ---		
	CR 1	CR 2	CR 3	CR 1	CR 2	CR 3	CR 1	CR 2	CR 3	CR 1	CR 2	CR 3	CR 1	CR 2	CR 3	CR 1	CR 2	CR 3
CROP	PNT			SGR			NLH	NLH		NLH								
BUD	1520			1522			1537	1576		1580								

THE FOLLOWING 5 CROPS ARE GROWN: PNT, SGR, NLH, NLH, NLH

OF THESE 5 CROPS 3 ARE UNIQUE: PNT, SGR, NLH

THE SIMULATION WOULD BEGIN ON JULIAN DAY 1

E P I C T I L L A G E A R R A Y

YEAR 1 1 CROP(S): PNT

MONTH	DAY	JULIAN DAY	MACHINERY CODE	OPERATION NAME	TILLAGE CODE	MIXING EFFICIENCY	RANDOM ROUGHNESS	ROW HEIGHT	ROW INTERVAL	TILLAGE DEPTH
3	1	60	34	MOLDBOARD PLOW	0	0.900	60.000	0.0	0.0	180.000
5	2	122	32	OFFSET DISK	0	0.600	50.000	0.0	0.0	100.000
5	21	141	32	OFFSET DISK	0	0.600	50.000	0.0	0.0	100.000
5	21	141	71	SPRAYER	0	0.0	0.0	0.0	0.0	0.0
5	28	148	42	HARROW-SPRINGTOOTH	0	0.200	13.000	50.000	150.000	40.000
5	30	150	60	ROW PLANTER	10	0.050	5.000	10.000	860.000	60.000
5	30	150	71	SPRAYER	0	0.0	0.0	0.0	0.0	0.0
6	12	163	41	ROW CROP CULTIVATOR	0	0.500	15.000	50.000	860.000	60.000
6	23	174	41	ROW CROP CULTIVATOR	0	0.500	15.000	50.000	860.000	60.000
7	16	197	71	SPRAYER	0	0.0	0.0	0.0	0.0	0.0
9	16	259	71	SPRAYER	0	0.0	0.0	0.0	0.0	0.0
10	27	300	86	PEANUT DIGGER	1	0.500	20.000	0.0	0.0	180.000

YEAR 2 1 CROP(S): SGR

MONTH	DAY	JULIAN DAY	MACHINERY CODE	OPERATION NAME	TILLAGE CODE	MIXING EFFICIENCY	RANDOM ROUGHNESS	ROW HEIGHT	ROW INTERVAL	TILLAGE DEPTH
2	15	45	34	MOLDBOARD PLOW	0	0.900	60.000	0.0	0.0	180.000
4	17	107	31	TANDEM DISK	0	0.500	18.000	0.0	0.0	75.000
5	1	121	70	SPREADER	0	0.0	0.0	0.0	0.0	0.0
5	6	126	42	HARROW-SPRINGTOOTH	0	0.200	13.000	50.000	150.000	40.000
5	13	133	42	HARROW-SPRINGTOOTH	0	0.200	13.000	50.000	150.000	40.000
5	15	135	52	DRILL	10	0.250	10.000	0.0	0.0	40.000
5	15	135	71	SPRAYER	0	0.0	0.0	0.0	0.0	0.0
5	31	151	41	ROW CROP CULTIVATOR	0	0.500	15.000	50.000	860.000	60.000
9	27	270	80	COMBINE	1	0.0	0.0	0.0	0.0	-150.000

Figure 10--Sample tillage array

Figure 11--Sample printout showing crop parameters

```
 PNT

DRY MATTER/ENERGY =    25.0 KG/HA/MJ
DRY MATTER/CROP YIELD = 3.00
MIN VALUE OF C FACTOR = 0.200
N PORTION OF YIELD = 0.0550 KG/KG
P PORTION OF YIELD = 0.0091 KG/KG
MIN TEMP FOR CROP GROWTH = 10.00 C
MAX TEMP FOR OPTIMAL PLANT GROWTH = 25.00 C
PLANTS/M**2 =    20.00
MAX LEAF AREA INDEX =     5.0
FRACTION OF GROWING SEASON WHEN LAI STARTS DECLINING = 0.000
POTENTIAL HEAT UNITS =   1000. C
SEED WEIGHT =      50. KG/HA
MAX CROP HEIGHT =   1500. MM
HARVEST EFFICIENCY = 0.050
PEST FACTOR = 0.050
ALUMINUM TOLERANCE INDEX =    4.0
FRACTION WATER IN YIELD = 0.060
N UPTAKE COEFS
          0.0324    0.0265    0.0250
P UPTAKE COEFS
          0.0074    0.0037    0.0035
```

EPIC production estimates are used in the RCA only as relative production indices among soil groups, crop sequences, tillages, and irrigation-nonirrigation alternatives within MLRA's. Average yields of each MLRA, developed by CARD for the RCA/CARD, provide the absolute yield base for MLRA's and relative production relationships among MLRA's.

Weather

The weather submodel is driven by a random number generator which determines a starting point in a random number table. When a starting point is fixed, the random number table may be used to generate identical weather patterns for any number of repetitive runs. This ensures that differences among simulations of alternative crop, management, tillage, and conservation assumptions are independent of random weather variation.

For the 1985 RCA, weather patterns are generated for the centroid county in each MLRA and tested for randomness (no trend in annual average temperature and precipitation). The mean values are checked against National Oceanic and Atmospheric Administration (NOAA) weather records and calibrated to NOAA mean values (fig. 12).

The weather data sets are maintained and used in all EPIC simulations for the RCA. This ensures that multiple simulations (alternative soils, rotations, tillages, and so on) within an MLRA are all based on identical weather data.

Soil Property File

The soil properties file assembled for the RCA contains soil property data sets for 822 soil series. These data, when combined with slope phases from the resource data file, provide data for the approximately 1,185 soil groups used in the RCA analysis.

The soil data base, which supports the soil property file, is assembled from a variety of sources. Computer tapes from the SCS, National Soil Survey Laboratory (NSSL), and Riverside Laboratory (RIVR) were processed into a basic file, which was supplemented with soil survey investigation reports (SSIR) and State university laboratories (26). In all, about 12,000 pedon samples were processed.

The initial data set was screened by series name to provide a list of pedon samples available to use as input data for the series that represent the RCA soil groups. Few were complete enough to meet the rigorous data needs of EPIC for soil properties. Most had data gaps and many were deficient or inconsistent with respect to two of the most important parameters--plant extractable water and plant wilting point. The soil water-holding capacity for the drained upper limit and the wilting point were estimated using texture, organic matter, cation exchange capacity, pH, and calcium carbonate (13). The difference in these two values is the plant extractable water capacity of the soil.

The completed pedon data set was merged with an appropriate SOILS-5 soil interpretation record, the soil taxonomy name (22) and code file, and the resource file to produce a complete soil table (fig. 13).

MLRA: 77 ROT: 0 TILL: SPLW RCA: 3 CLASS: 3E SERIES: AMARILLO LAT: 34.50 LONG: 102.50 DATE: 01/16/85 TIME: 11:28:26

CLIMATE DATA FOR WEATHER NUMBER 77 GENERATOR SEED 2

MO MAX .5 H RAIN

6.60 2.50 0.70 8.90 39.90 52.80 40.60 37.60 25.40 13.20 2.30 38.10

-MO RAIN PROB-- W/D	W/W	-MO STATS FOR DAILY RAIN-- MEAN	ST DV	SKW CF
0.087	0.312	0.162	0.230	2.718
0.120	0.354	0.143	0.187	2.315
0.112	0.347	0.178	0.234	2.289
0.114	0.375	0.259	0.328	2.282
0.177	0.433	0.325	0.483	3.400
0.189	0.465	0.537	0.790	2.835
0.186	0.416	0.355	0.491	2.594
0.181	0.384	0.316	0.461	2.666
0.141	0.379	0.317	0.495	2.743
0.099	0.448	0.317	0.505	3.108
0.074	0.395	0.191	0.248	2.231
0.088	0.374	0.153	0.227	2.711

**********RAINFALL,TEMP, AND RAD ARE GENERATED**********

FOURIER COEFS (MEAN, AMPLITUDE)

MAX TEMP CLEAR	=	22.74	12.23
MAX TEMP RAIN	=	18.60	12.23
COEF OF VAR MAX TEMP	=	0.13	-0.08
MIN TEMP	=	8.21	12.15
COEF OF VAR MIN TEMP	=	0.17	-0.12
SOL RAD CLEAR	=	496.	208.
SOL RAD RAIN	=	351.	208.

AVE MO VALUES (METRIC)

4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR	
TMX	12.50	14.50	18.83	23.61	27.50	32.28	33.17	32.89	29.33	24.17	17.94	12.83	23.30	TMX
TMN	-3.44	-2.22	1.22	6.33	11.78	16.67	18.61	18.00	14.17	8.06	1.28	-2.67	7.32	TMN
RAD	292.26	353.93	454.69	561.34	630.62	665.02	649.73	581.66	484.72	385.40	308.64	271.49	469.96	RAD
RAIN	14.22	14.73	19.30	31.50	71.88	70.10	69.09	55.63	49.53	46.48	14.22	15.75	472.43	RAIN
DAYP	3.48	4.54	4.54	4.63	7.37	7.83	7.49	7.04	5.55	4.71	3.27	3.82	64.28	DAYP
ALPH	0.62	0.36	0.32	0.49	0.52	0.64	0.63	0.60	0.47	0.27	0.65	0.60		ALPH
WVL	5.81	6.26	6.70	6.70	6.70	6.26	5.36	5.36	5.81	5.81	5.81	5.81		WVL
WENG	192.50	231.21	307.26	297.35	307.26	239.18	145.02	145.02	186.29	192.50	186.29	192.50	2622.37	WENG

Figure 12--Sample printout of weather data

MLRA: 77 ROT: 0 TILL: SPLW RCA: 3 CLASS: 3E SERIES: AMARILLO LAT: 34.50 LONG: 102.50 DATE: 01/16/85 TIME: 11:28:26

SOIL DATA

SOIL NUMBER: 20

SOIL SERIES NAME: AMARILLO PEDON: 387 SOILS 5: 480 SOURCE: NSSL

	YEAR	STATE	COUNTY	SAMPLE
SURVEY NUMBER:	81	TX	227	3

	ORDER	SUBGRP	PART SIZE	MINEROL	REACT	SOIL TEMP	OTHER
TAXONOMIC CODE:	AUSPA	AR34	96	34	2	18	2

TAXONOMIC DESCRIPTION: FINE-LOAMY, MIXED, THERMIC ARIDIC PALEUSTALF

	FROM		TO	
SAMPLE NUMBERS:	1878	-	1882	YEAR: 81

SOIL ERODIBILITY: 0.11 CURVE # - ROW: 78.00 SOIL ALBEDO: 0.15 WEATHERING FACTOR: 0
WIND SOIL ERODIBILITY: 193.00 CURVE # - GRAIN: 75.00 MAXIMUM SOIL DEPTH: 2000.00

SOIL LAYER NO

	1	2	3	4	5	6	7	8	9	TOT
DEPTH (MM)	10.	150.	230.	580.	840.	1120.	1400.	1730.	2000.	
POROSITY (M/M)	0.396	0.396	0.396	0.404	0.434	0.366	0.370	0.374	0.374	
WP SW (M/M)	0.060*	0.060*	0.060*	0.156	0.181	0.178	0.157*	0.132	0.130	
FC SW (M/M)	0.180*	0.180*	0.180*	0.281*	0.295	0.309	0.291*	0.278	0.274	
PLT AVL SW (MM)	1.2	16.8	9.6	47.2	29.6	36.7	37.5	48.2	38.9	265.7
SW (MM)	0.2	2.2	1.3	6.3	3.9	4.9	5.0	6.4	5.2	35.3
SAT COND (MM/H)	12.05	12.05	12.05	10.28	8.18	9.15	10.06	8.71	8.04	
SSF TIME (D)	11.4	11.4	11.4	18.5	44.6	30.1	21.1	24.1	22.1	
BD 33 KPA (T/M3)	1.60	1.60	1.60	1.58	1.50	1.68	1.67	1.66	1.66	
SAND (%)	83.1	83.1	83.1	66.2	58.2	61.4	66.1	54.9	57.0	
SILT (%)	8.0	8.0	8.0	16.6	17.9	17.6	15.9	25.9	24.6	
CLAY (%)	8.9	8.9	8.9	17.2	23.9	21.0	18.0	19.2	18.4	
PH H2O (1:1)	8.3	8.3	8.3	8.1	8.1	8.2	8.3	8.3	8.3	
SM BS (CMOL/KG)	5.5*	5.5*	5.5*	11.0*	14.7*	12.9*	11.4*	7.4*	7.6*	
CEC (CMOL/KG)	5.5	5.5	5.5	11.0	14.7	12.9	11.4	7.4	7.6	
AL SAT (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
CACO3 (%)	0.4	0.4	0.4	0.2	0.4	1.1	1.0	25.6	20.6	
LAB P (G/T)	30.*	30.*	10.*	10.*	10.*	10.*	10.*	10.*	10.*	372.
P SORP RTO	0.58	0.58	0.58	0.58	0.58	0.57	0.57	0.42	0.45	
MN P AC (G/T)	22.	22.	7.	7.	7.	7.	7.	14.	12.	329.
MN P ST (G/T)	88.	88.	29.	29.	29.	30.	30.	54.	48.	1315.
ORG P (G/T)	78.	79.	78.	77.	74.	67.	62.	62.	60.	2214.
NO3 (G/T)	5.*	5.*	5.*	5.*	5.*	5.*	5.*	5.*	5.*	162.
ORG N AC (G/T)	38.	38.	15.	14.	13.	10.	8.	8.	7.	397.
ORG N ST (G/T)	265.	265.	208.	271.	247.*	193.*	146.*	145.*	132.*	6446.
ORG C (%)	0.20	0.20	0.20	0.30	0.26	0.20	0.15	0.15	0.14	
CROP RSD (KG/HA)	34.*	434.*	445.*	500.*	161.*	25.*	1.*	1.*	1.*	1602.

ROOT ZONE FIELD CAPACITY = 193. MM

MINERALIZATION CONSTANT = 0.000300
0

Figure 13--Sample soil property file

Miscellaneous Parameters

The miscellaneous parameter file used in EPIC simulations is a variety of "bits and pieces" of information (fig. 14). Some items are of little importance (except for computer processing), and once prescribed, are left unchanged throughout the RCA. Plant stress levels for fertilizer and irrigation water application are examples of factors that can affect productive capacity significantly but were held constant throughout all RCA runs. As previously described, the precise physical and chemical data required by EPIC are developed by soil series from soil pedon samples. These data are frequently independent of some phasing criteria which divide the series into specific soil map units and in turn into RCA soil groups. As a result, the soil pedon file (described in the previous section) must be supplemented with additional soils information.

The resource data file is designed to control the assembly of soil resource information for an EPIC simulation. The resource data file is coded by MLRA, RCA soil group, series name, and soil pedon numbers to locate and input the appropriate soil data. The file also contains the slope length and steepness provided by the SCS State staffs from the 1982 NRI. Conservation practice factors required by the AOF and USLE equations are taken directly from (42). Terrace intervals by slope groups were furnished by the SCS field staff.

Computation of wind erosion requires data on the unbroken length and width of the field and the angle of the field with respect to the wind. Wind direction, velocity, and direction by compass point are contained in the climate data file.

Precise estimates of field size and angle are not available. Research has shown, however, that the maximum distance benefited from a field boundary is approximately 1,000 feet. Hence, field dimensions are arbitrarily assumed to be 1,320 feet by 2,640 feet with an axis of 45 degrees for the basic, no-wind conservation practice. This field size of 80 acres is large enough to negate any field size influence on the wind erosion estimates and small enough to be a reasonable field size assumption for U.S. agriculture.

OUTPUT

The EPIC model uses the several hundred data inputs described in the previous section to simulate natural processes and interactions among climate, land, and agriculture. The model accumulates daily estimates of approximately 90 variables for relevant inputs (specific weather parameters, for example), monitors resource status (remaining soil depth, surface residues), and measures outputs (plant growth, erosion, and so on).

EPIC measures change in output values among simulations resulting from different inputs, assumption, and management alternatives. The model can be used to estimate the response from two different soils in the same climate or the same soil in two different climates. Alternatively, the model may be used to estimate two different management options, holding both soil and climate constant. Systematic manipulation of management factors is relatively easy to specify and relate to measurement variables in the aggregate. Gradual changes in resource variables are much more difficult, and climatic parameters (in a sequential replicative sense) are statistically random.

Figure 14--Sample of miscellaneous parameter file

```
NO YRS =     4
BEGINNING DAY =    1
BASIN AREA =    1.00 HA
RUNOFF CN2 =  77.0
SLOPE ADJ CN2 = 70.3
TP-40 RAINFALL AMOUNTS (10 YR FREQ) FOR DUR
     0.5 =  48.30 MM
     6 H =  82.60 MM
NO YRS RECORD MAX .5 H RAIN =    8.0
CHANNEL LENGTH =   0.10 KM
CHANNEL SLOPE = 0.0100 M/M
LATITUDE =  34.50 DEG
SOIL ALBEDO = 0.15
AVE N CONC IN RAINFALL =  0.80 PPM
CHANNEL N =  0.050
SURFACE N =  0.050
MX ROOT ZONE DEPTH =  1500. MM
WATER CONTENT OF SNOW INITIALLY =     6.4 MM
PEAK RATE-EI ADJUSTMENT FACTOR =  1.000
PLANT STRESS FOR FERT APP =  0.950
CU = 0.50
YRS OF CULTIVATION BEFORE IYR = 100.0
WATER STRESS FACTOR =  1.5
PERCENT OF GROWING SEASON WHEN FERTILIZATION QUITS =   0.50 %
NUMBER OF DAYS BETWEEN FERTILIZATION =   15
PERCENT OF ANNUAL FERTILIZATION RATE APPLIED AT TOP DRESSING =   3.00 %
SLOPE LENGTH =    86. M
SLOPE STEEPNESS = 0.0100 M/M
SOIL CLASS RECORD NUMBER =  689
CF =  85.
FIELD LENGTH  805. M
FIELD WIDTH =   402. M
FIELD ANGLE 45. DEG
AV WIND VEL =  5.77 M/S
ST DV WIND VEL =  2.90 M/S
WATER EROSION FACTORS
     P =    1.000      LS =     0.158
TIME OF FLOW CONCENTRATION =    0.596 H
DRYLAND AGRICULTURE
STRAIGHT ROWS
```

The statistical properties of EPIC output are further complicated by the lack of well specified time-series data to generate adequate population statistics. Conventional data sources and past research address many, if not all, EPIC output parameters in one-on-one, one-on-several, or one-on-the-aggregate relationships. Few specify the interactions of many individual parameters, and essentially none have the longevity to provide a data base for statistical validation.

The relationship of agriculture to the environment is frequently generalized by two variables--plant yields and soil erosion. EPIC estimates of these parameters are closely associated with the general weather patterns generated by the model. The magnitude and frequency of each weather parameter can be computed and calibrated to historical weather records. However, the relationship among these individual parameters and the aggregate impact of all climatic factors on plant growth is much more difficult to measure and explain statistically.

Each weather variable and (given an assumed weighting system) weather in the aggregate have a frequency distribution which can be quantified statistically. Thus, an EPIC estimate (yield or erosion, for example) for a specific day, week, month, or year is specific to a single point on a frequency distribution curve of all possible weather events for the respective period of time. However, EPIC simulates the day-by-day interaction of climate, soil, nutrients, and tillage on sequential changes in plant growth, residue recycling, soil moisture, nutrient balances, soil losses, and so on. Any value for a single day is unique to the weather sequence and a determinant of the subsequent day. Data from an EPIC simulation for n years (number of years simulated) estimate a single point on n frequency distribution curves. Each of these points is sequentially dependent upon all preceding points. Simulation of other random weather sequences would estimate different sequentially dependent points on the same n frequency distribution curves. Hence, in the aggregate, EPIC output may be better described as the product of n points on a frequency distribution of weather possibilities for next year in random order.

Report Writer

The EPIC model has the internal capacity to measure and maintain estimates of approximately 90 variables by daily time steps. The standard report writer accumulates monthly and annual averages and prints a table for each simulation year (fig. 15). These data are further summed to report averages of all years in the simulation (fig. 16). Soil data can be printed for each year or the last year in the simulation only (fig. 17). The tables are identical except for the items on the bottom of the soil input table so that beginning and ending soil conditions can be directly compared. EPIC output for the 1985 RCA is presented in Erosion-Productivity Index Simulator (EPIS) Model (12).

MLRA: 77 ROT: 8 TILL: SPLW RCA: 3 CLASS: 3E SERIES: AMARILLO LAT: 34.50 LONG: 102.50 DATE: 01/16/85 TIME: 11:28:26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR	
TMX	10.50	12.50	18.50	25.77	27.48	28.70	34.47	31.37	28.52	20.03	15.87	12.54	22.38	TMX
TMN	-3.94	-2.38	0.88	8.70	12.11	15.37	18.63	16.94	13.55	5.01	-0.71	-2.81	6.86	TMN
RAD	270.85	329.77	445.36	565.23	644.01	650.84	646.06	581.84	502.22	381.91	287.82	280.29	467.11	RAD
RAIN	0.0	37.26	5.31	31.75	132.81	83.40	35.68	23.51	115.52	114.24	2.87	21.51	604.04	RAIN
SNOW	0.0	7.52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.52	SNOW
Q	0.0	0.0	0.0	0.0	0.0	0.06	0.0	0.0	0.36	3.76	0.0	0.0	4.18	Q
SSF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	SSF
PRK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	PRK
ET	0.0	18.77	13.84	28.55	86.12	89.60	67.37	22.75	42.80	47.13	21.88	15.68	465.49	ET
EP	0.0	0.0	0.38	3.14	25.08	38.89	37.07	11.54	0.0	0.0	0.0	0.0	116.11	EP
SW	45.60	63.09	54.56	57.75	94.54	88.37	56.68	57.43	129.78	183.15	174.14	179.97		SW
USLE	0.0	0.0	0.0	0.00	0.00	0.01	0.00	0.00	0.04	0.02	0.0	0.0	0.07	USLE
AOF	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.02	0.01	0.0	0.0	0.03	AOF
EI	0.0	3.23	0.06	12.08	88.93	103.24	18.26	8.30	83.65	34.17	0.07	2.91	364.90	EI
Y	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.00	0.00	0.0	0.0	0.00	Y
C	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.01	0.02	0.0	0.0	0.01	C
PET	50.82	64.38	113.00	184.18	232.20	264.02	328.82	260.57	180.24	102.48	67.50	60.21	1818.72	PET
YW	8.63	8.80	15.03	12.85	8.37	10.78	7.94	7.70	13.28	18.35	18.43	18.65	152.93	YW
RN	0.0	0.28	0.04	0.25	1.06	0.67	0.29	0.19	0.92	0.81	0.02	0.17	4.82	RN
YON	2.95	3.03	4.70	4.12	2.76	4.77	2.77	2.78	5.56	6.83	6.86	6.87	54.28	YON
YNO3	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.05	0.21	0.0	0.0	0.26	YNO3
SSFN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	SSFN
PRKN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	PRKN
MNN	3.43	3.70	4.82	6.82	10.18	11.18	13.09	10.37	8.70	4.55	3.32	2.98	83.35	MNN
IMN	0.78	0.83	1.13	1.54	2.13	2.54	2.82	2.95	3.28	1.41	0.85	0.77	21.23	IMN
DN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	DN
NFIX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NFIX
UNO3	0.0	0.0	8.11	6.80	15.38	6.06	8.08	0.62	0.0	0.0	0.0	0.0	45.15	UNO3
HMN	0.82	0.78	0.80	1.04	1.36	1.56	2.06	1.76	1.78	1.15	0.89	0.87	14.98	HMN
YP	1.27	1.31	2.05	1.82	1.24	2.18	1.29	1.33	2.67	3.34	3.33	3.33	25.16	YP
YAP	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.00	0.01	0.0	0.0	0.01	YAP
UPP	0.0	0.0	0.50	0.88	2.22	1.64	1.41	0.59	0.0	0.0	0.0	0.0	7.33	UPP
MNP	0.72	0.77	1.00	1.40	2.07	2.31	2.78	2.29	2.03	1.07	0.78	0.70	17.92	MNP
IMP	0.23	0.25	0.34	0.46	0.64	0.76	0.87	0.73	0.67	0.29	0.20	0.16	5.58	IMP
PLAB	362.68	363.00	362.87	362.70	362.03	361.83	362.09	362.54	362.87	362.53	362.11	361.66		PLAB
PMIN	322.00	322.05	321.91	321.68	321.44	320.91	321.12	321.42	321.53	321.41	321.18	320.97		PMIN
TNO3	37.85	41.00	36.73	35.46	29.18	32.44	34.82	41.82	48.12	51.95	54.34	56.72		TNO3
HU	2775.50	2775.50	2812.38	3006.18	3385.77	3873.56	4426.98	0.0	0.0	0.0	0.0	0.0		HU
LAI	0.05	0.05	0.00	0.05	0.83	0.13	0.35	0.0	0.0	0.0	0.0	0.0		LAI
RD	1500.00	1500.00	1500.00	1500.00	1500.00	1500.00	1500.00	0.0	0.0	0.0	0.0	0.0		RD
RTWT	1012.03	1012.03	931.14	318.00	320.72	363.00	280.56	0.0	0.0	0.0	0.0	0.0		RTWT
DM	1012.03	1012.03	939.68	318.00	1221.33	569.82	1312.95	0.0	0.0	0.0	0.0	0.0		DM
RSD	458.32	523.73	574.14	651.61	696.31	653.88	513.56	431.01	360.06	319.46	285.80	253.93		RSD
STD	1676.05	1508.57	1365.65	1737.85	1354.82	1000.23	666.33	603.38	459.72	381.60	340.10	294.60		STD
TMP	1381.62	1628.08	1668.73	1714.20	2124.47	2224.62	2095.22	1444.17	2261.31	3082.71	3263.65	3246.85	2179.72	TMP

TAOF = 0.33 ALS = 1.60 EK = 0.18 WK = 300.00 TUSLE = 8.18 TWE = 582.06 TERO = 582.38 ERTH = 36.44

NLM YLD = 2113. KG/HA DM = 3387. KG/HA IRGA = 0. MM CAW = 371. MM MX RD = 1500. MM NFIX = 0. KG/HA LIME = 0.0 T/HA
FN = 58.00 FP = 0.0 FNSD = 37.17 FNPL = 20.83 PRSD = 61.86 PSTD = 0.02
STRESS FACTORS (DAYS & VALUE) -- WATER = 20 0.85 N = 123 0.11 P = 0 0.0 TEMP = 88 0.02

Figure 15--Sample printout of monthly and annual averages of an individual simulation year

MLRA: 77 ROT: 8 TILL: SPLW RCA: 3 CLASS: 35 SERIES: AMARILLO LAT: 34.50 LONG: 102.50 DATE: 01/16/85 TIME: 11:28:26

PEAK FLOW RATE STATS (MM/H)

MAX = 4.05 MEAN = 0.88 ST DV = 1.469 GEN EFF = 0.237

AVE MO VALUES (METRIC)

4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR	
C	0.0	0.0	0.0	0.0	0.0	0.00	0.16	0.0	0.01	0.02	0.0	0.0	0.05	C
AOF	0.0	0.0	0.0	0.0	0.0	0.00	0.07	0.0	0.00	0.00	0.0	0.0	0.08	AOF
YW	6.73	13.61	20.37	21.78	26.52	16.02	6.47	4.78	8.44	8.73	5.91	6.15	145.51	YW
RAIN	6.74	12.89	20.00	55.20	79.49	76.31	65.05	28.70	57.56	69.25	6.44	14.27	491.91	RAIN
SNOW	4.55	4.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.78	SNOW
Q	0.0	0.0	0.0	0.0	0.0	0.02	0.84	0.0	0.09	0.94	0.0	0.0	1.89	Q
DAYQ	0.00	0.00	0.00	0.00	0.00	0.25	0.50	0.00	0.50	0.50	0.00	0.00	1.75	DAYQ
TAV	2.99	6.49	9.60	14.79	18.97	24.59	26.09	24.76	21.00	14.72	10.77	4.61	14.95	TAV
RAD	305.91	358.31	442.58	555.30	628.50	624.89	641.28	584.12	517.88	395.98	324.51	277.84	471.43	RAD
HRLT	10.41	11.20	12.25	13.35	14.32	14.78	14.51	13.64	12.55	11.43	10.56	10.15		HRLT

AVE ANNUAL VALUES (METRIC)

4	TMX	22.86	TMN	7.04	RAD	471.43	RAIN	491.01	SNOW	8.78	Q	1.89	SSF	0.0	PRK	0.0	ET	455.44
	EP	164.87	IRGA	0.0	AOF	0.08	EI	281.36	Y	0.00	C	0.05	RN	3.94	YON	46.44	YNO3	0.08
	SSFN	0.0	PRKN	0.0	MNN	62.46	IMN	23.16	DN	0.0	NFIX	-0.01	UNO3	113.45	HMN	15.50	YLN	78.55
	PET	1852.42	PEP	409.00	ER	3.73	YP	19.93	YAP	0.00	UPP	17.93	FN	43.93	FP	10.60	CN	55.49
	YLP	12.43	TMP	1363.40	USLE	2.05	MNP	13.81	IMP	6.18	WVL	6.02	WDIR	3.11	YW	145.51	LIME	0.0
	CAW	317.99	TAOF	0.33	EK	0.19	WK	300.00	TUSL	8.19	TWE	582.06	TERO	582.38				

AVE ANNUAL CROP YLD DATA

CROP	YLD (KG/HA)	DRY MTR (KG/HA)	TOT RAD (LY)	HT UNTS (C)	RD (MM)	--------AVE STRESS FACTORS--------- WATER	N	P	TEMP
PNT	2372.5	6805.6	86856.2	1860.7	1434.2	0.471	1.000	1.000	0.854
SGR	1786.4	4417.5	76912.5	1854.6	1320.1	0.474	1.000	1.000	0.998
MLH	2722.0	3622.2	77884.1	3258.0	1465.1	0.800	0.714	1.000	0.705

Figure 16- Sample printout of monthly and annual averages of all simulation years

MLRA: 77 ROT: 0 TILL: SPLW RCA: 3 CLASS: 3E SERIES: AMARILLO LAT: 34.50 LONG: 102.50 DATE: 01/16/05 TIME: 11:20:26

SOIL DATA

SOIL LAYER NO

	1	2	3	4	5	6	7	8	9	TOT
DEPTH (MM)	10.	114.	104.	543.	003.	1003.	1363.	1693.	1863.	
POROSITY (M/M)	0.400	0.396	0.396	0.404	0.434	0.366	0.370	0.374	0.374	
WP SW (M/M)	0.060	0.060	0.060	0.156	0.181	0.178	0.157	0.132	0.130	
FC SW (M/M)	0.180	0.180	0.180	0.291	0.295	0.309	0.291	0.278	0.274	
PLT AVL SW (MM)	1.2	12.4	0.6	47.2	20.6	36.7	37.5	48.2	38.0	261.3
SW (MM)	0.0	6.5	0.0	40.4	20.6	36.6	36.0	26.7	5.2	180.0
SAT COND (MM/H)	12.04	12.05	12.05	10.28	8.18	8.15	10.06	9.71	8.04	
SSF TIME (D)	11.4	11.4	11.4	18.5	44.6	30.1	21.1	24.1	22.1	
BD 33 KPA (T/M3)	1.60	1.60	1.60	1.58	1.50	1.68	1.67	1.66	1.66	
SAND (%)	83.1	83.1	83.1	66.2	58.2	61.4	66.1	54.9	57.0	
SILT (%)	8.0	8.0	8.0	16.6	17.9	17.6	15.9	25.9	24.6	
CLAY (%)	8.9	8.9	8.9	17.2	23.9	21.0	18.0	19.2	18.4	
PH H2O (1:1)	8.2	8.2	8.2	8.1	8.1	8.2	8.3	8.3	8.3	
SM BS (CMOL/KG)	5.3	5.3	5.3	11.0	14.7	12.9	11.4	7.4	7.6	
CEC (CMOL/KG)	5.5	5.5	5.5	11.0	14.7	12.9	11.4	7.4	7.6	
AL SAT (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
CACO3 (%)	0.4	0.4	0.4	0.2	0.4	1.1	1.0	25.6	20.6	
LAB P (G/T)	41.	27.	22.	8.	10.	10.	10.	10.	10.	362.
P SORP RTO	0.58	0.58	0.58	0.58	0.58	0.57	0.57	0.42	0.48	
MN P AC (G/T)	20.	20.	16.	6.	7.	8.	8.	14.	12.	321.
MN P ST (G/T)	156.	79.	68.	27.	29.	30.	30.	54.	48.	1302.
ORG P (G/T)	85.	78.	78.	76.	73.	67.	61.	61.	60.	2156.
NO3 (G/T)	8.	2.	1.	1.	1.	1.	1.	1.	5.	.57.
ORG N AC (G/T)	71.	32.	28.	13.	11.	9.	7.	7.	7.	355.
ORG N ST (G/T)	269.	272.	274.	271.	247.	193.	146.	145.	132.	6285.
ORG C (%)	0.24	0.20	0.20	0.30	0.26	0.20	0.15	0.15	0.14	
CROP RSD (KG/HA)	183.	53.	26.	14.	4.	2.	1.	1.	1.	280.

SOIL WATER BALANCE = 0.772085E-02

ERODED SOIL THICKNESS = 36.4 MM

ROOT ZONE FIELD CAPACITY = 184. MM

FINAL WATER CONTENT OF SNOW = 0.0 MM

N BALANCE = 0.6402

7021.6404 15.7801 185.7703 0.3201 0.0 0.0 0.0 314.2024 175.7207 -0.0383
6712.1406

P BALANCE = 2.6863

4232.2617 78.7102 0.0174 48.7343 42.3058 4142.5234

Figure 17- Sample printout of soil properties at the end of n years of simulation

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GLOSSARY OF TERMS

Input Terms

AAP = Average annual precipitation (MM)
ALPHA = Alpha
ANG = Clockwise angle of field length from north (DEG)
AP = Initial labile P CONC (G/T)
APM = Peak rate - EI adjustment factor
AWV = Average annual wind velocity (M/S)
BD = Bulk density (T/M**3)
BETA = Beta
BFT = N stress level for automatic fertilizer
BIR = Value of water stress factor when irrigation begins
CAC = Calcium carbonate (%)
CBN = Organic carbon conc (%)
CEC = NH4OAC cation exchange capacity (MEQ/100G)
CF = Wind climatic factor (%)
CHN = Mannings n for channel
CLASS = Land capability class/subclass
CN2G = II condition curve number for grain crops
CN2R = II condition curve number for row crops
CODE = Horizon codes
COLE = Coefficient of linear extensibility (%)
CRF = Coarse fragments (%)
CRM(1) = Sol rad - clear (mean)
CRM(2) = Sol rad - clear (amplitude)
CRMP(1) = Sol rad - rain (mean)
CRMP(2) = Sol rad - rain (amplitude)
CTM(1) = Max temp - clear (mean)
CTM(2) = Max temp - clear (amplitude)
CTMN(1) = Min temp (mean)
CTMN(2) = Min temp (amplitude)
CTMP(1) = Max temp - rain (mean)
CTMP(2) = Max temp - rain (amplitude)
CTS(1) = Coef of var max temp (mean)
CTS(2) = Coef of var max temp (amplitude)
CTSN(1) = Coef of var min temp (mean)
CTSN(2) = Coef of var min temp (amplitude)
DA = Basin area (HA)
DIR = Monthly block wind data (% wind direction)
EFI = Irrigation efficiency
EK = Soil erodibility factor
FC = Water content at 0.3 bars (MM/MM)
FE = Iron (%)
FFC = Fraction of field capacity for initial water storage, (0 allows program to estimate FFC)
FL = Field length (M)
FW = Field width (M)
HA = Hectares
IBD = Julian day simulation begins
ICLAS = Record number of values read from direct access class file
IDAYB = Number of days between fertilization
IDR = Layer number of drainage

IDS	= Soil weathering information
	= 0 for calcareous soils and noncalcareous soils without weathering information
	= 1 for noncalcareous slightly weathered soils
	= 2 for noncalcareous moderately weathered soils
	= 3 for noncalcareous highly weathered soils
	= 4 input PSP
II	= Harvest or planting tillage code
	= 1 for harvest seed, lint, etc. only
	= 2 for no harvest, crop plowed under
	= 3 for harvest hay (hay has several harvests per year, last harvest must be code 1)
	= 4 for multiple harvests of seed, lint, etc. during a growing season
	= 10 for planting
IMLRA	= Sequential MLRA number used to access weather, budget index, and planting and harvest files
IPCD	= Conservation practice factor code
	= 1 for contouring
	= 2 for contour stripcropping
	= 3 for contour irrigated furrows
	= 4 for terracing
	= 5 for straight rows
IPD	= Printout format
	= 0 for annual
	= 1 for monthly
	= 2 for daily
IRCA	= RCA soil group
IROT	= Record number of crop rotation in direct crop rotation file
IRR	= Irrigation code
	= 1 for dryland areas
	= 2 for sprinkler irrigation
	= 3 for furrow irrigation
ISOIL	= Record number of soil in direct access soil file
ITL	= Julian day of tillage operation
IWIND	= Consideration of wind erosion
	= 0 for no wind erosion
	= 1 for wind erosion
IWRT	= Printing of monthly or annual values
	= 0 for no printing
	= 1 for printing
K1	= Generator seeds
LC	= Number of different crops grown during simulation
LOC	= Representative location - county, State (not read)
LT	= Tillage operation identification number
LY	= Crop ID numbers in sequence
MLRA	= Major land resource area (not read)
NBYR	= Number of years of runoff simulation
NDC	= Array of different crops grown during simulation
NN	= Number of crops grown during the year
NRO	= Number of years of crop rotation
OBMN	= Monthly mean minimum temperature (C)
OBMX	= Monthly mean maximum temperature (C)

PGROW	= Percentage of growing season when fertilization quits
PH	= Soil pH (1:1)
PPLANT	= Percentage of annual fertilizer rate applied at planting
PRW(1)	= Probability of wet day after dry day
PRW(2)	= Probability of wet day after wet day
PTOP	= Percentage of annual fertilizer rate applied at top dressing
RCN	= Average concentration of N in rainfalL (PPM)
RSD	= Crop residue (KG/HA)
RST(1)	= Mean of daily rainfall
RST(2)	= Standard deviation of daily rainfall
RST(3)	= Skew coefficient of daily rainfall
RTN	= Number of years the soil has been cultivated at the start of the simulation
RZ	= MX root zone depth
S	= Slope steepness (M/M)
SALB	= Soil albedo
SAN	= Sand (%)
SIL	= Silt (%)
SL	= Slope length (M)
SMB	= Base saturation (%), calculated from sum of NH4OAC bases (MEQ/100G) and cation exchange capacity
SMY	= Monthly mean precipitation (MM)
SN	= Surface N value
SNO	= Water content of snow on ground (MM)
SOIL	= Array of 21 soil variables
SOILN	= Soil series name and source information
SOILTX	= Soil texture
STAR	= Array of 19 soil variable estimate flags
SWV	= Standard deviation of wind velocity (M/S)
TLD	= Tillage depth (MM)
TP24	= No years record max 0.5 H rain (MM)
TP5	= TP-40 10 Years frequency .5 H rainfall (MM)
TP6	= TP-40 10 years freuency 6 H rainfall (MM)
U	= Soil water content at 15 bars (MM/MM)
WI	= Monthly maximum 0.5 H rain (MM)
WK	= Wind soil erodibility factor (T/HA)
WN	= Initial organic N concentrate (G/T)
WNO3	= Initial NO_3 concentrate (G/T)
WVL	= Monthly wind data (VEL M/S)
YIELD	= Reported yield
YLNG	= Longitude (degrees)
YLT	= Latitude (degrees)
Z	= Depth to bottom of layers (MM)

Output Terms

AOF = Soil loss, Onstad-Foster estimate (T/HA)
ALS = Aluminum saturation (%)
C = Average USLE C factor
CAN = Crop available N (KG/HA)
CAW = Crop available water (MM)
CN = Average SCS runoff curve number
CROP = Crop name
DAYQ = Number of days with runoff
DM = Total plant biomass (KG/HA)
DN = Denitrification (KG/HA)
DNS = Days of nitrogen stress
DPS = Days of phosphorus stress
DTS = Days of temperature stress
DWS = Days of water stress
EI = Rainfall energy factor (T/HA*H)
EK = Soil erodibility factor
EP = Actual plant evaporation (MM)
ER = Enrichment ratio (nitrogen and phosphorus)
ERTH = Eroded thickness (MMJ)
ET = Actual evapotranspiration (MM)
EVN = NO_3 upward movement from soil evaporation (KG/HA)
FN = Average annual N fertilizer rate (KG/HA)
FNPL = Average annual N applied at planting (KG/HA)
FNSD = Average annual N side dressed (KG/HA)
FON = Fresh organic N (KG/HA)
FP = Average annual P fertilizer rate (KG/HA)
HMN = Humus mineralization (KG/HA)
HRLT = Average daily light duration (H)
HU = Accumulated heat units (C)
HUM = Humus (T/HA)
IM = Immobilization
IMN = N immobilized (KG/HA)
IMP = P immobilized (KG/HA)
IRGA = Irrigation water applied (MM)
LAI = Leaf area index
LIME = Average annual lime fertilizer rate (T/HA)
MN = Mineralization
MNN = N mineralized (KG/HA)
MNP = P mineralized (KG/HA)
MXRD = Maximum root depth (MM)
NFIX = Nitrogen fixation (KG/HA)
PEP = Potential plant evaporation
PET = Potential evapotranspiration
PLAB = Labile P present in soil profile (KG/HA)
PMIN = Mineral P pool (KG/HA)
PNS = Percentage of nitrogen stress
PPS = Percentage of phosphorus stress
PRK = Percolation (MM)
PRKN = NO_3 loss in percolate (KG/HA)
PRSD = Residue at planting (KG/HA)
PSTD = Standing dead residue at planting (KG/HA)
PTS = Percentage of temperature stress
PWS = Percentage of water stress
Q = Surface runoff (MM)

RAD	=	Average solar radiation (C)
RAIN	=	Rainfall (MM)
RD	=	Root depth
RN	=	Nitrogen in rainfall (KG/HA)
RSD	=	Crop residue (KG/HA)
RTWT	=	Root weight (MG)
SNOW	=	Water content of snow (MM)
SS03	=	Leached NO_3
LSSF	=	Subsurface flow (MM)
SSFN	=	NO_3 loss in subsurface flow (KG/HA)
STD	=	Standing dead residue (KG/HA)
SW	=	Total soil water in profile (MM)
TAOF	=	Accumulated soil loss Onstad-Foster estimate (T/HA)
TAV	=	Average temperature (C)
TERO	=	Accumulated erosion AOF+YW (T/HA)
TMN	=	Average minimum temperature (C)
TMP	=	Average temperature in third soil layer (C)
TMX	=	Average maximum temperature (C)
TNO3	=	NO_3 present in soil profile (KG/HA)
TUSLE	=	Accumulated soil loss USLE estimate (T/HA)
TWE	=	Accumulated wind erosion (T/HA)
UNO3	=	N uptake by crop (KG/HA)
UPP	=	P uptake by crop (KG/HA)
USLE	=	Soil loss - USLE estimate (T/HA)
WDIR	=	Average wind direction (clockwise rad from N)
WK	=	Soil erodibility factor for wind (T/HA)
WVL	=	Average wind velocity (M/S)
Y	=	Soil loss MUSLE estimate (T/HA)
YAP	=	Labile P in runoff (KG/HA)
YAP	=	Soluble P loss (KG/HA)
YEAR	=	Year of simulation
YLD	=	Crop yield (KG/HA)
YLP	=	Amount of P removed by crop harvest (KG/HA)
YLN	=	Amount of N removed by crop harvest (KG/HA)
YN	=	Yield organic nitrogen
YNO3	=	NO_3 loss in surface runoff (KG/HA)
YON	=	Organic N loss with sediment (KG/HA)
YP	=	P loss with sediment (KG/HA)
YPA	=	Available phosphorus
YW	=	Soil loss from wind erosion (T/HA)

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