Chapter 4

Water Percolation: An Indicator of Nitrogen-Leaching Potential[1]

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The amount of water that percolates through and below a crop's root zone is important in determining the amount of nitrate (NO_3) leached. Several important soil, crop, and climatic factors interact to affect the amount of percolation. The roles of some of the most important factors are outlined here. Later in the chapter, percolation amounts simulated with the Erosion-Productivity Impact Calculator (EPIC) model (Williams et al., 1984) will characterize the average percolation and the variation in percolation at several important agricultural locations around the USA. Knowledge of this variation in percolation helps to evaluate the leaching potential at these locations.

4-1 MAJOR SOIL, CROP, AND CLIMATIC FACTORS AFFECTING PERCOLATION

4-1.1 Characteristics of Soil Water

The amount of water that percolates from soil is determined in part by the balance between gains in soil water by rainfall or irrigation and losses from the soil water storage reservoir from crop water use and evaporation. For simplicity, we will characterize soil water by representing the soil as a storage barrel for water made up of different compartments (Fig. 4-1). The entire capacity of the barrel represents the total water that may be contained in the soil profile to a depth from which crops extract water.

Water stored by soil varies greatly in the amount of energy required to remove it from soil. Gravitational force causes water to percolate from the soil when the water content is between saturation (all soil pores are filled

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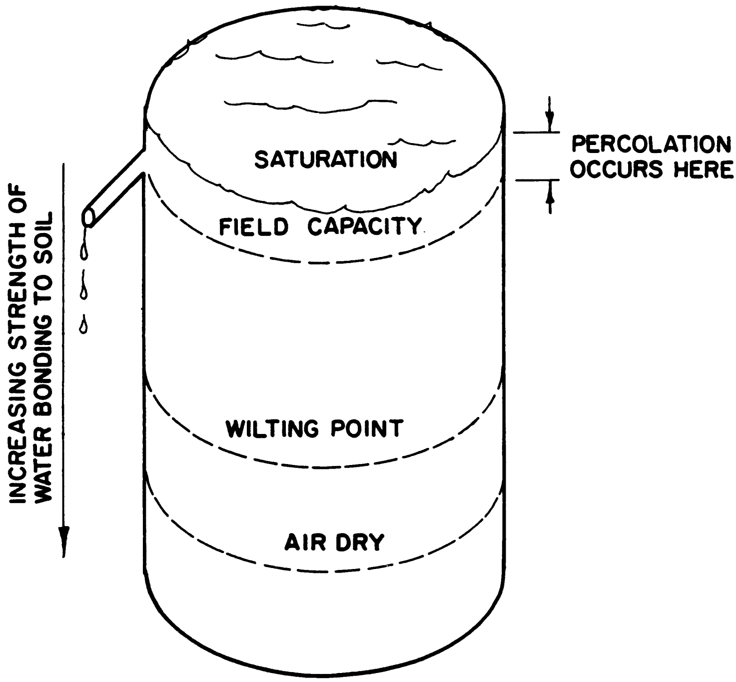

Fig. 4-1. The categories of total water in soil are represented by a water storage barrel.

with water, i.e., the barrel is full) and field capacity (no more water can drain from the soil by gravity). As the soil water content falls below field capacity because of crop use and evaporation, the remaining water is held more tightly by the soil. Water removal by crops can continue until the water level reaches the wilting point. At this level, water is attracted so strongly to soil that plant root removal of water nearly ceases. At any point in the soil drying cycle, the amount of soil water that has been removed below field capacity represents the amount of soil water storage that must be refilled before any percolation can occur.

The total size of the barrel (total water-holding capacity) and the proportion of the water in the various compartments vary with soil type. The proportion between saturation and field capacity (that portion subject to percolation) varies from a maximum with very sandy soils to a minimum on clay soils. In addition, water generally drains much faster from sands than from clays. For a given soil, the amount of infiltrating rain or irrigation water that can be absorbed by soil before and percolation depends on the soil's unfilled water storage below field capacity. The following discussion will illustrate some of the key interactions of climate, crop, and soil type that affects percolation.

4-1.2 Effect of Soil Type and Crop Presence on Single Event Percolation

If has often been noted that percolation and leaching losses of NO_3 are usually more severe when a crop is not present in the field. However, on very sandy soils, substantial percolation early in the cropping season can still occur, depending on the timing of rainfall events. To illustrate this effect of soil type and a crop on percolation, comparisons of percolation from a single rainstorm (from model simulations with EPIC) are presented for two soils, each with and without a crop (Fig. 4-2). The soils chosen were a Houston Black clay (fine, montmorillonitic, thermic Udic Pellusterts) and a Silawa sandy loam (fine-loamy, siliceous, thermic Ultic Haplustalfs) to represent extremes with regard to soil properties affecting percolation. The soils in each respective case had a water content just slightly less than field capacity the day before a 3-in. (75 mm) rain on 1 April. Wheat was the crop for the simulations at the Bell County, Texas, location.

The greatest percolation was from the sandy loam soil without a crop, in which case most of the 1.14 in. (29 mm) of percolation occurred in the first two days following the rain. The presence of a crop on the sandy loam reduced percolation to 0.89 in. (23 mm). Percolation from the clay soil was considerably different. Without a crop, the percolation continued over a longer period but still totaled only 0.76 in. (19 mm). With a crop present, a total of 0.25 in. (6 mm) of percolation occurred, mostly within the first two days following the rain. These differences in percolation between the extreme soil textures are primarily due to the larger volume of water that can be stored temporarily above field capacity for the clay soil and the faster drainage rate of the sandy loam. In the case of the clay soil with a crop, water stored above field capacity is removed largely by crop use, even for the first day following the rain.

4-1.3 Effect of Soil Type on Annual Percolation

Variation in percolation over longer time intervals depends on the differences in percolation from single drainage events, as described above, plus differences in water storage capacity and the potential for storm runoff, which also varies between soil types. The extremes in these latter two properties are again represented by sand and clay soils. Water storage and storm runoff are both usually less for sandy soils than for clay soils, with other soils typically being intermediate.

To illustrate the combined influence of these soil properties on percolation from soil, a simulation of percolation from a Sarpy loamy fine sand (mixed, mesic Typic Udipsamments) and an Adair clay loam (fine, montmorillonitic, mesic Aquic Argiudolls) was carried out for Boone County, Missouri, using the EPIC model. The cropping sequence was a soybean-wheat [*Glycine max* (L.) Merr.-*Triticum aestivum* L.] rotation in which the simulation began on 1 January, with soybean planted on 15 May and harvested in late September, followed by wheat planted 1 October and harvested the following June. This crop sequence was carried out two more times with the next soybean crop planted the following May (Year 3). A graph of the cumulative percolation vs. cumulative rainfall is given in Fig. 4-3. Percolation began earlier on the sandy soil partly because of a smaller available water storage capacity [7 in. (178 mm) vs. 8.1 in. (206 mm) for the clay loam].

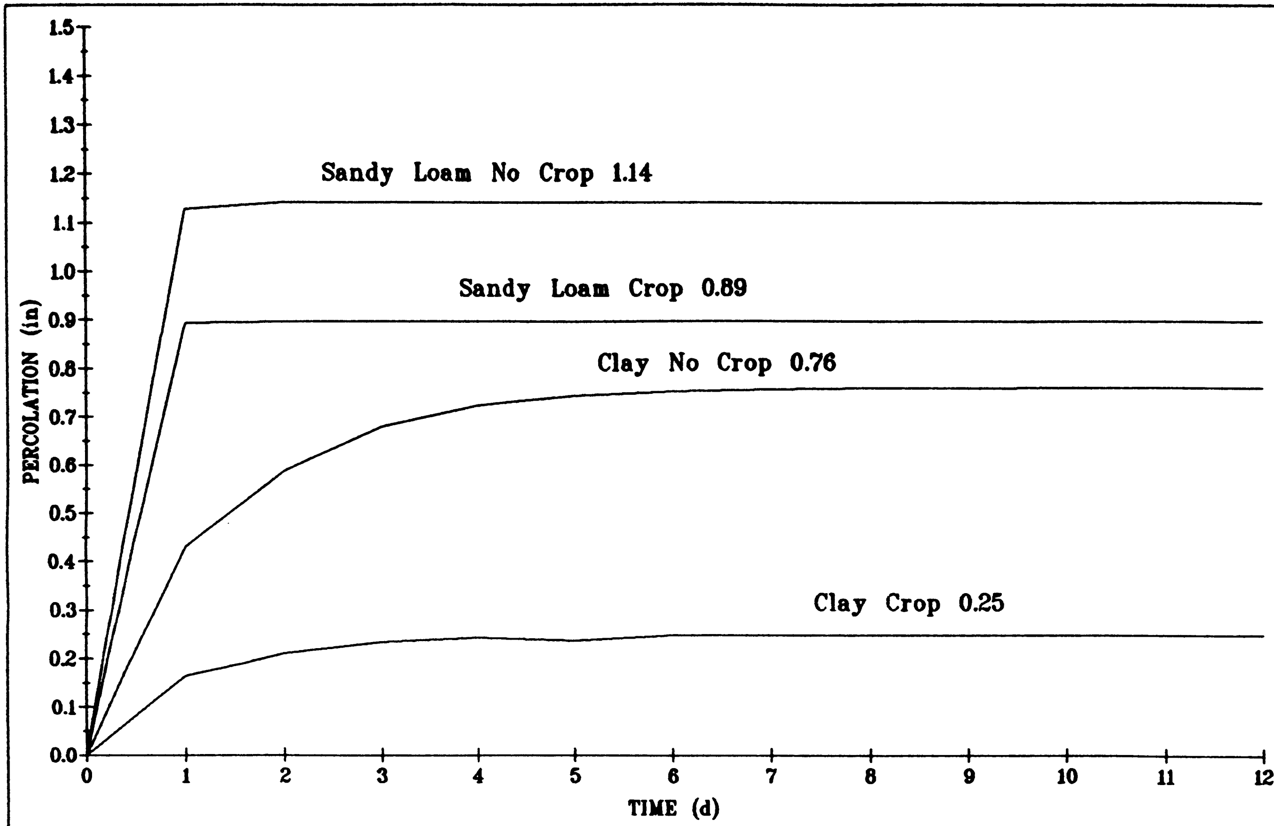

Fig. 4-2. Cumulative percolation below the root zone for wheat or no crop for a Houston Black clay or Silawa sandy loam following a single 3-in. rain at Bell County, Texas. Data are from simulations with EPIC.

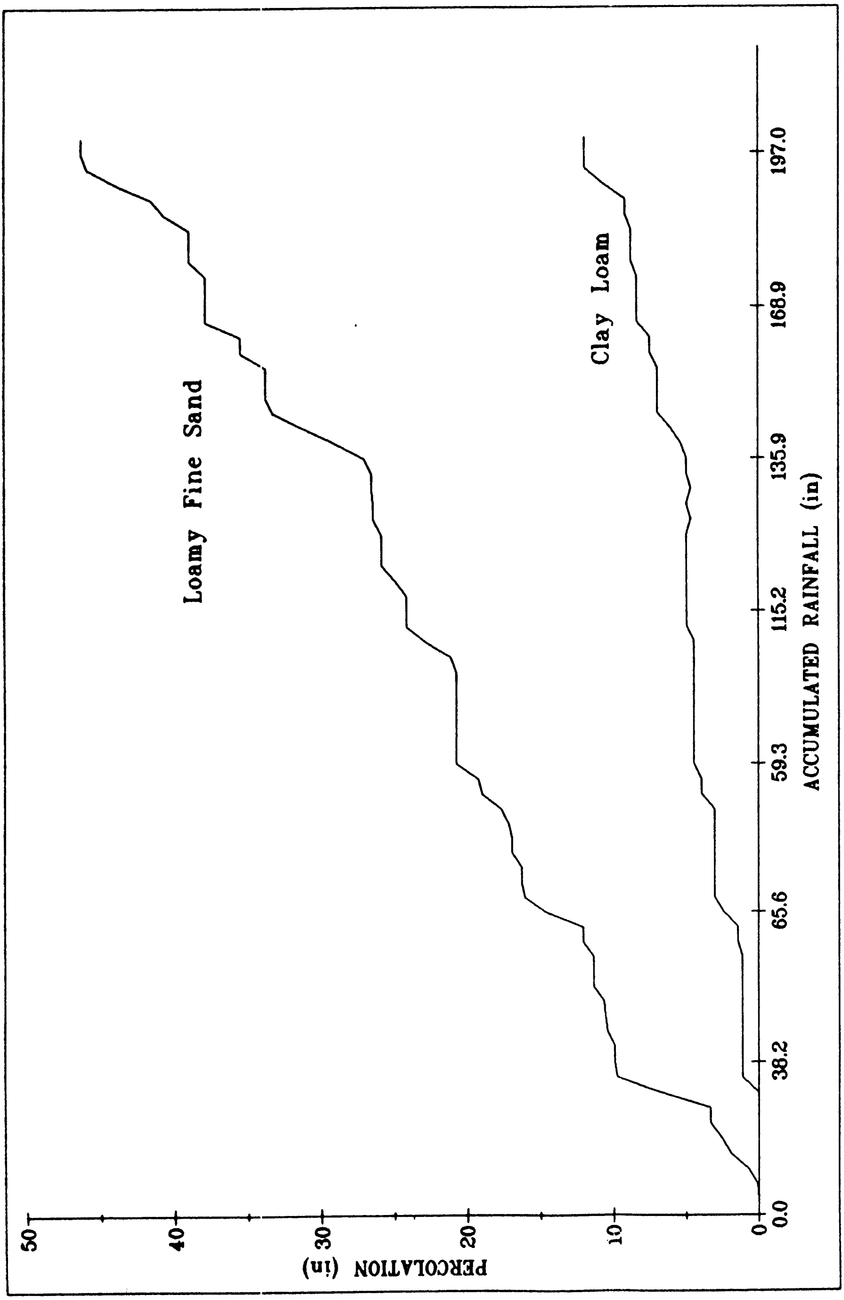

Fig. 4-3. Cumulative percolation below the root zone in a soybean-wheat rotation at Boone County, Missouri, over a 6-yr period for a Sarpy loamy fine sand and an Adair clay loam. Data are from simulations with EPIC.

In addition, the other differences in percolation rates, volumes, and differences in runoff combined to cause divergence in the curves over the 6-yr period. By the end of the simulation, nearly 200 in. (5080 mm) of precipitation had occurred. Of this total precipitation, 11.8 in. (300 mm) had percolated below the root zone of the Adair clay loam, whereas nearly five times as much [58.1 in. (1476 mm)] had percolated below the Sarpy loamy fine sand. These differences are due primarily to the extreme differences in properties of the two soils selected. In addition to these important properties of soils, the characteristics of the precipitation also affect percolation.

4-1.4 Timing of Rainfall Events and Percolation

There will generally be less percolation from single rainfall events when a crop is growing compared to the situation without a crop. Therefore, given equal rainfall, geographical locations that receive peak rainfall during the cropping season should have less percolation than locations that have peak rainfall at times when no crop is growing or the crop is immature. Likewise, peak rainfall timing relative to crop development causes year-to-year differences in percolation at a given location. This effect is illustrated with the results of a simulation with EPIC for corn (*Zea mays* L.) production at Caldwell County, Kentucky. We chose to compare the simulations from two years that had nearly identical rainfall but differed greatly in the timing of the rains (Table 4-1). Although both years had about 43 in. (1092 mm) of total annual rainfall, one year received 62% of the rain in the first 6 mo of the year, whereas the other year received only 27% of the total rainfall in the first 6 mo. The effect on percolation was pronounced. The year with early rain had 12.6 in. (315 mm) of percolation, whereas the year with later peak rainfall had 8.6 in. (218 mm) of percolation. Also, since a considerable portion of the percolation from the early rain simulation was just following N fertilizer application, but before peak crop use of N, leaching loss of N in percolate was substantial [76 lb acre^{-1} (86 kg ha^{-1})]. Loss of N from the late rain was much less at 13 lb acre^{-1} (15 kg ha^{-1}). In summary, rainfall timing with respect to crop growth and time of N application can greatly influence percolation amounts and N loss by leaching.

4-2 MODELING WATER PERCOLATION AND NITRATE LEACHING

Water percolation and NO_3 leaching can be simulated by several models at various levels of detail. Detail is expressed in temporal and spatial scales. Time steps may vary from < 1 min to 1 yr and soil layer thickness may vary from < 1 in. to several feet. The EPIC model (Williams et al., 1984) was chosen to simulate percolation and leaching for studying leaching potential mainly because of the authors' familiarity with this model. Other reasons for choosing EPIC are: (i) it is efficient—operates on a daily time step; (ii) the soil profile is described in layers of various thickness (up to 10 layers

Table 4-1. Simulation of percolation with the EPIC model for continuous corn production† at Caldwell County, Kentucky, with simulated rainfall constrained to either early or late-season rainfall.

Rainfall and percolation	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
					Early rain								
Rainfall, in.	5.8	3.2	4.3	2.8	3.7	7.0	1.2	5.2	2.4	2.4	2.1	3.4	43.4
Percolation, in.	4.7	2.0	1.9	0.9	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.1	12.6
Percolation-N, lb/acre	11.7	7.0	12.2	8.1	11.0	25.6	0.0	0.0	0.0	0.0	0.0	0.0	75.6
					Late rain								
Rainfall, in.	3.9	2.9	0.6	1.7	0.7	1.9	6.5	3.7	5.6	6.5	4.7	4.7	43.4
Percolation, in.	1.2	1.5	0.01	0.04	0.0	0.0	0.0	0.0	0.0	2.3	1.9	1.6	8.6
Percolation-N, lb/acre	2.2	4.2	0.02	0.11	0.0	0.0	0.0	0.0	0.0	0.9	2.5	3.1	13.0

† Corn planted 15 April and harvested 15 September. Nitrogen fertilizer applied at 107 lb of N/acre 15 February.

allowed); and (iii) the model is fairly comprehensive, thus important interactions with other processes were simulated using EPIC to develop relationships that are discussed in this chapter.

4-2.1 The EPIC Percolation Model

The EPIC percolation component uses a storage routing technique to simulate flow through soil layers. Flow from a soil layer occurs when soil water content exceeds field capacity. Water drains from the layer until the storage returns to field capacity. The reduction in soil water is simulated with the routing equation

$$SW_\ell = SWO_\ell \exp(-\Delta t/TT_\ell) \qquad [1]$$

where SW and SWO are the soil water contents at the end and the start of time interval Δt (24 h) and TT is the travel time through layer ℓ in h. Thus, daily percolation can be computed by taking the difference between SW and SWO.

$$O_\ell = SWO_\ell\,[1.0 - \exp(-\Delta t/TT_\ell)] \qquad [2]$$

where O is the percolation rate for layer ℓ in in. d^{-1} (mm d^{-1}).

Travel time through a layer is computed with the linear storage equation

$$TT_\ell = (PO_\ell - FC_\ell)/SC_\ell \qquad [3]$$

where PO is the porosity in inches (mm), FC is field capacity in inches (mm), and SC is saturated conductivity in in. h^{-1} (mm h^{-1}).

The routing process is applied layer by layer from the soil surface through the deepest layer. Since the saturated conductivity of some layers may be much lower than others, the routing scheme can lead to an impossible situation (porosity of low-saturated conductivity layers may be exceeded). For this reason, a back pass is executed from the bottom layer to the surface. If a layer's porosity is exceeded, the excess water is transferred to the layer above. This process continues through the top layer.

Percolation is also affected by freezing temperatures. Water can flow into a frozen layer but cannot percolate from the layer.

The basic equations of the EPIC percolation component are the same as those contained in the chemicals, runoff, and erosion from agricultural management systems (CREAMS) daily rainfall model. Test results for the CREAMS percolation model were given by Knisel (1980) and Williams and Nicks (1982).

4-2.2 The EPIC Nitrate Leaching Model

The amount of NO_3-N leached from a soil layer by percolating water is calculated as the product of percolation volume and NO_3-N concentration. After a certain volume of water has percolated through a soil layer, the amount of NO_3-N is reduced using the equation

$$WNO_{\ell}^{3} = WNOE_{o,\ell} - (O_{\ell})(c_{NO_3,\ell}) \qquad [4]$$

where WNO_3 and WNO_{3o} are the weights of NO_3-N contained in layer ℓ at the start and end of a day, and O is the percolation volume, and c_{NO_3} concentration. The NO_3-N concentration can be estimated by dividing the weight of NO_3-N by the water storage volume.

$$c'_{NO_3} = c_{NO_3} - c_{NO_3}\left(\frac{O}{PO_{\ell} - WP_{\ell}}\right) \qquad [5]$$

where c'_{NO_3} is the concentration of NO_3-N at the end of a day, PO is the soil porosity, and WP is the wilting point water content for soil layer ℓ. Equation [6] is a fine difference approximation for the exponential equation

$$c'_{NO_3} = c_{NO_3} \exp(O/PO_{\ell} - WP_{\ell}) \qquad [6]$$

Thus, the amount of NO_3-N leached (VNO_3) can be computed for any O value (volume of percolating water) by integrating Eq. [6]

$$VNO_{3\ell} = WNO_{3\ell}[1 - \exp(O_{\ell}/PO_{\ell} - WP_{\ell})] \qquad [7]$$

4-2.3 Related Processes Simulated by EPIC

The EPIC model contains nine major components: hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environment control. All of these components may affect percolation directly or indirectly. Details of the nine components are given elsewhere (Williams et al., 1984). Brief descriptions of EPIC components for simulating a few processes closely related to percolation are given here.

4-2.3.1 Surface Runoff

Surface runoff of daily rainfall is predicted using a procedure similar to the CREAMS runoff model, option one (Knisel, 1980; Williams & Nicks, 1982). Like the CREAMS model, runoff volume is estimated with a modification of the SCS curve number method (USDA-SCS, 1972). 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. EPIC also includes a provision for estimating runoff from frozen soil.

4-2.3.2 Lateral Subsurface Flow

Lateral subsurface flow is calculated simultaneously with percolation. A nonlinear function of lateral flow travel time is used to simulate the horizontal component of subsurface flow. The magnitudes of the vertical and horizontal flow components are determined by simultaneous solution of the two governing equations.

4-2.3.3 Evapotranspiration

The model offers two options for estimating potential evaporation (Priestley-Taylor, 1972; Penman, 1948). The Penman method requires solar radiation, air temperature, wind speed, and relative humidity as inputs. If wind speed and relative humidity data are not available, the Priestley-Taylor method provides an option that gives realistic results in most cases. The model computes soil and plant evaporation separately as described by Ritchie (1972). Potential soil evaporation is estimated as a function of potential evaporation and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is estimated using exponential functions of soil depth and water content. Actual plant evaporation is simulated as a linear function of potential evaporation and leaf area index.

4-2.3.4 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 32 °F (0 °C), using a linear function of temperature. Melted snow is treated the same as rainfall for estimating runoff, percolation, etc.

4-3.3.5 Crop Growth Model

A single model is used in EPIC for simulating all crops. 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 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.

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.

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).

4-2.3.6 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.

4-2.3.7 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. As implied, the user-specified option allows application dates and rates to be input. With the automatic option, the model decides when and how much water to apply. The user must input a plant water stress level to trigger automatic irrigation, the maximum volume applied per growing season, and the minimum time interval between applications. These constraints are used to automatically schedule irrigations. When automatic irrigation occurs, water is applied to bring the root zone up to field capacity plus enough to satisfy runoff losses.

4-3 SIMULATION RESULTS FOR EXAMPLE SITES

Eight sites, representing a wide variety of soils and climate, were chosen to demonstrate the percolation model and to study leaching potential. For example, sand content of the soils ranges from 9 to 95%, average annual rainfall ranges from 15 (374) to 48 in. (1214 mm), and average annual temperature ranges from 41 to 69 °F (5–21 °C).

Table 4-2 contains results of the EPIC simulations for the eight locations. Continuous corn was simulated at each site for a 20-yr period. Based on the Table 4-2 results, it appears that little leaching potential (expressed as percolation) exists when annual precipitation is less than about 16 in. (406 mm).

To study the climatic effect on percolation independently, four soils representing the four SCS hydrologic soil groups (USDA-SCS, 1972) were selected for simulations at each of the eight sites. The soils and their hydrologic groups are Ortega (A), Amarillo (B), Webster (C), and Houston (D) (very-fine, montmorillonitic, thermic Typic Chromuderts). The hydrologic soil groups were formed to aid in estimating surface runoff, but should serve equally well as percolation indicators. For example, soil group A provides for high infiltration rates, low surface runoff, and therefore, large potential percolation. The reverse is true for group D, and groups B and C represent conditions between the extremes.

Tables 4-3 to 4-6 show simulation results using the soils selected to represent the four hydrologic soils groups. The EPIC simulated percolation rates are greatest in Table 4-3 (group A) and decrease steadily through Table 4-6 (group D). Soil properties (saturated conductivity and plant-available water storage) shown in Table 4-2 explain the reasonable hydrologic soil group-percolation relationship contained in Tables 4-3 to 4-6. The A soil, Ortega, has the highest saturated conductivity and lowest storage. The B, C, and D soils follow in a logical order.

Table 4-2. Monthly precipitation.

Location	Soil†	Results from 20-yr EPIC simulations: Avg. monthly values Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
Davis, CA	Yolo	Saturated conductivity = 0.024 in./h						Plant available water storage = 10.39 in.						
Precipitation, in.		3.63	2.29	2.28	1.01	0.81	0.03	0.01	0.02	0.24	0.36	1.30	3.52	15.50
Evapotranspiration, in.		0.78	0.95	1.42	1.13	0.94	3.42	2.91	0.20	0.17	0.20	0.42	0.50	13.05
Runoff, in.		1.03	0.23	0.23	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.05	0.65	2.24
Temperature, °F		44.06	49.10	53.60	58.82	64.22	69.26	75.20	72.14	69.08	62.96	51.80	43.16	59.54
Percolation, in.		0.00	0.00	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Gainesville, FL	Ortega	Saturated conductivity = 0.496 in./h						Plant available water storage = 6.46 in.						
Precipitation, in.		2.65	2.59	2.99	2.56	3.70	5.69	7.33	7.85	4.70	2.50	1.55	3.69	47.78
Evapotranspiration, in.		0.68	0.85	1.49	3.44	4.94	5.00	2.58	1.34	1.00	0.71	0.52	0.58	23.14
Runoff, in.		0.29	0.28	0.23	0.05	0.31	0.41	1.11	1.06	0.62	0.28	0.12	0.46	5.22
Temperature, °F		57.74	59.72	64.76	69.62	75.20	78.44	79.34	79.16	77.90	71.96	62.78	56.66	69.44
Percolation, in.		1.63	1.59	1.48	0.46	0.34	0.08	0.97	4.56	3.09	1.50	0.93	2.44	19.07
Ames, IA	Webster	Saturated conductivity = 0.073 in./h						Plant available water storage = 10.79 in.						
Precipitation, in.		0.74	0.78	2.21	3.26	4.63	4.08	4.15	3.88	4.30	1.38	1.82	1.01	32.23
Evapotranspiration, in.		0.34	0.47	0.81	1.55	2.37	5.26	6.37	4.35	1.44	0.69	0.42	0.32	24.39
Runoff, in.		0.32	0.52	0.88	0.53	0.76	0.59	0.43	0.52	1.00	0.11	0.54	0.57	6.77
Temperature, °F		17.42	23.90	33.08	49.46	60.08	68.72	73.40	70.16	60.98	52.52	36.14	22.28	47.30
Percolation, in.		0.00	0.00	0.00	0.07	0.57	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.94
Hagerstown, MD	Hagerstown	Saturated conductivity = 0.009 in./h						Plant available water storage = 10.63 in.						
Precipitation, in.		2.33	2.06	3.20	2.68	3.97	3.65	3.91	3.58	2.66	2.38	3.02	3.21	36.65
Evapotranspiration, in.		0.48	0.55	0.92	1.55	2.59	5.07	6.55	4.19	1.45	0.61	0.48	0.37	24.82
Runoff, in.		1.29	1.02	1.42	0.54	0.59	0.41	0.89	0.43	0.29	0.43	0.93	1.61	9.85
Temperature, °F		32.00	34.88	40.46	54.50	62.60	69.98	74.66	71.60	63.50	55.22	42.26	30.20	52.70
Percolation, in.		0.02	0.09	0.13	0.53	0.63	0.33	0.00	0.00	0.00	0.00	0.00	0.00	1.73

Raleigh, NC	Norfolk	Saturated conductivity = 0.040 in./h						Plant available water storage = 9.37 in.						
Precipitation, in.		3.05	2.88	2.74	3.13	3.02	3.71	4.23	5.66	3.55	1.79	2.71	2.75	39.20
Evapotranspiration, in.		0.53	0.59	1.09	1.70	2.37	4.57	4.31	3.86	1.17	0.59	0.51	0.44	21.74
Runoff, in.		0.77	0.46	0.26	0.19	0.17	0.32	0.32	0.89	0.61	0.32	0.46	0.68	5.46
Temperature, °F		41.54	43.34	49.82	59.90	66.92	73.94	77.72	75.02	69.80	60.44	49.28	40.46	59.00
Percolation, in.		1.61	1.72	1.65	1.33	0.87	0.35	0.11	0.34	0.42	0.63	1.17	1.41	11.60
Bismarck, ND	Barnes	Saturated conductivity = 0.244 in./h						Plant available water storage = 11.81 in.						
Precipitation, in.		0.48	0.37	0.52	1.29	2.19	3.66	1.71	1.76	1.28	0.43	0.55	0.46	14.72
Evapotranspiration, in.		0.37	0.39	0.74	1.06	1.80	2.99	3.06	1.83	0.85	0.52	0.33	0.32	14.27
Runoff, in.		0.00	0.08	0.04	0.04	0.06	0.21	0.00	0.01	0.02	0.00	0.05	0.03	0.55
Temperature, °F		8.42	12.20	26.96	44.24	54.32	63.14	72.14	66.92	56.30	45.50	27.68	13.10	40.82
Percolation, in.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lubbock, TX	Amarillo	Saturated conductivity = 0.148 in./h						Plant available water storage = 9.84 in.						
Precipitation, in.		0.33	0.32	0.45	1.19	2.51	2.73	1.78	2.53	2.77	1.18	0.77	0.45	17.00
Evapotranspiration, in.		0.43	0.37	0.55	0.99	2.28	4.29	1.81	2.33	1.20	0.65	0.51	0.41	15.81
Runoff, in.		0.00	0.00	0.00	0.00	0.26	0.17	0.03	0.07	0.27	0.17	0.07	0.02	1.07
Temperature, °F		37.04	40.46	46.94	57.20	68.54	74.66	78.62	75.56	68.00	59.18	44.60	37.22	57.38
Percolation, in.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pullman, WA	Palouse	Saturated conductivity = 0.285 in./h						Plant available water storage = 14.17 in.						
Precipitation, in.		2.56	1.63	1.95	1.41	1.21	1.20	0.52	0.74	1.31	1.79	2.56	2.85	19.72
Evapotranspiration, in.		0.53	0.66	1.20	1.50	1.41	2.95	2.78	0.80	0.88	0.78	0.47	0.38	14.33
Runoff, in.		1.48	1.04	0.42	0.08	0.02	0.08	0.00	0.00	0.00	0.09	0.78	1.38	5.38
Temperature, °F		27.86	33.08	40.28	48.38	54.32	59.54	67.10	64.22	55.76	48.92	37.22	29.84	47.12
Percolation, in.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

† Yolo = fine-silty, mixed, nonacid, thermic Typic Xerorthents; Ortega = thermic, uncoated Typic Quartzipsamments; Webster = fine-loamy, mixed, mesic Typic Haplaquolls; Hagerstown = fine, mixed, mesic Typic Hapludalfs; Norfolk = fine-loamy, siliceous, thermic, Typic Kandiudults; Barnes = fine-loamy, mixed Udic Haploborolls; Amarillo = fine-loamy, mixed, thermic Aridic Paleustalfs; Palouse = fine-silty, mixed, mesic pachic Ultic Haploxerolls.

Table 4-3. Monthly precipitation.

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
	Results from 20-yr EPIC simulations with soil from hydrologic group A (Oretega)												
	Avg. monthly values												
	Saturated conductivity = 0.496 in./h						Plant available water storage = 6.46 in.						
Davis, CA													
Precipitation, in.	3.63	2.29	2.28	1.01	0.81	0.03	0.01	0.02	0.24	0.36	1.30	3.52	15.50
Evapotranspiration, in.	0.72	0.84	1.23	0.98	0.79	1.41	2.02	0.71	0.17	0.19	0.48	0.48	10.02
Runoff, in.	0.70	0.11	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.31	1.21
Temperature, °F	44.06	49.10	53.60	58.82	64.22	69.26	75.20	72.14	69.08	62.96	51.80	43.16	59.54
Percolation, in.	0.92	1.07	1.14	0.29	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.45	4.07
Gainesville, FL													
Precipitation, in.	2.65	2.59	2.99	2.56	3.70	5.69	7.33	7.85	4.70	2.50	1.55	3.69	47.78
Evapotranspiration, in.	0.68	0.85	1.49	3.45	4.95	5.01	2.59	1.34	1.00	0.71	0.52	0.58	23.16
Runoff, in.	0.24	0.22	0.18	0.04	0.25	0.34	0.96	0.86	0.50	0.22	0.09	0.37	4.29
Temperature, °F	57.74	59.72	64.76	69.62	75.20	78.44	79.34	79.16	77.90	71.96	62.78	56.66	69.44
Percolation, in.	1.68	1.64	1.54	0.47	0.39	0.10	1.11	4.80	3.20	1.55	0.96	2.53	19.97
Ames, IA													
Precipitation, in.	0.74	0.78	2.21	3.26	4.63	4.08	4.15	3.88	4.30	1.38	1.82	1.01	32.23
Evapotranspiration, in.	0.37	0.50	0.85	1.48	2.15	4.27	4.98	3.90	1.39	0.68	0.43	0.34	21.33
Runoff, in.	0.26	0.44	0.50	0.05	0.14	0.12	0.08	0.14	0.39	0.00	0.30	0.41	2.83
Temperature, °F	17.42	23.90	33.08	49.46	60.08	68.72	73.40	70.16	60.98	52.52	36.14	22.28	47.30
Percolation, in.	0.00	0.05	0.66	1.76	2.28	1.19	0.17	0.18	0.61	0.33	0.39	0.13	7.76
Hagerstown, MD													
Precipitation, in.	2.33	2.06	3.20	2.68	3.97	3.65	3.91	3.58	2.66	2.38	3.02	3.21	36.65
Evapotranspiration, in.	0.47	0.53	0.88	1.40	2.29	4.17	4.70	3.54	1.36	0.58	0.46	0.37	20.76
Runoff, in.	0.92	0.67	0.88	0.12	0.08	0.03	0.27	0.10	0.04	0.08	0.35	1.01	4.56
Temperature, °F	32.00	34.88	40.46	54.50	62.60	69.98	74.66	71.60	63.50	55.22	42.26	30.20	52.70
Percolation, in.	0.95	0.87	1.47	1.49	1.73	0.76	0.31	0.04	0.11	0.46	1.40	1.37	10.94

Raleigh, NC													
Precipitation, in.	3.05	2.88	2.74	3.13	3.02	3.71	4.23	5.66	3.55	1.79	2.71	2.75	39.20
Evapotranspiration, in.	0.46	0.52	1.04	1.72	2.61	5.10	4.87	4.22	1.14	0.53	0.43	0.38	23.02
Runoff, in.	0.46	0.22	0.10	0.04	0.06	0.10	0.11	0.43	0.31	0.24	0.24	0.43	2.73
Temperature, °F	41.54	43.34	49.82	59.90	66.92	73.94	77.72	75.02	69.80	60.44	49.28	40.46	59.00
Percolation, in.	1.94	2.17	1.83	1.47	0.92	0.41	0.06	0.40	0.48	0.55	1.18	1.71	13.11
Bismarck, ND													
Precipitation, in.	0.48	0.37	0.52	1.29	2.19	3.66	1.71	1.76	1.28	0.43	0.55	0.46	14.72
Evapotranspiration, in.	0.36	0.38	0.70	0.93	1.56	2.78	3.51	2.03	0.80	0.44	0.30	0.31	14.11
Runoff, in.	0.00	0.06	0.04	0.04	0.03	0.09	0.00	0.00	0.00	0.00	0.05	0.03	0.35
Temperature, °F	8.42	12.20	26.96	44.24	54.32	63.14	72.14	66.92	56.30	45.50	27.68	13.10	40.82
Percolation, in.	0.00	0.00	0.00	0.00	0.02	0.27	0.01	0.00	0.00	0.00	0.00	0.00	0.30
Lubbock, TX													
Precipitation, in.	0.33	0.32	0.45	1.19	2.51	2.73	1.78	2.53	2.77	1.18	0.77	0.45	17.00
Evapotranspiration, in.	0.41	0.36	0.54	0.98	2.01	4.61	2.29	2.39	1.14	0.60	0.48	0.38	16.19
Runoff, in.	0.00	0.00	0.00	0.00	0.09	0.05	0.00	0.01	0.13	0.06	0.04	0.00	0.39
Temperature, °F	37.04	40.46	46.94	57.20	68.54	74.66	78.62	75.56	68.00	59.18	44.60	37.22	57.38
Percolation, in.	0.00	0.00	0.00	0.00	0.12	0.03	0.00	0.00	0.00	0.09	0.00	0.00	0.24
Pullman, WA													
Precipitation, in.	2.56	1.63	1.95	1.41	1.21	1.20	0.52	0.74	1.31	1.79	2.56	2.85	19.72
Evapotranspiration, in.	0.54	0.66	1.16	1.40	1.30	2.33	3.06	1.19	0.83	0.76	0.46	0.37	14.06
Runoff, in.	1.16	0.69	0.20	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.98	3.52
Temperature, °F	27.86	33.08	40.28	48.38	54.32	59.54	67.10	64.22	55.76	48.92	37.22	29.84	47.12
Percolation, in.	0.24	0.48	0.69	0.20	0.06	0.12	0.00	0.00	0.00	0.00	0.00	0.13	1.92

Table 4-4. Monthly precipitation.

	Results from 20-yr EPIC simulations with soil from hydrologic group B (Amarillo)												
	Avg. monthly values												Annual
Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	total
	Saturated conductivity = 0.148 in./h						Plant available water storage = 9.84 in.						
Davis, CA													
Precipitation, in.	3.63	2.29	2.28	1.01	0.81	0.03	0.01	0.02	0.24	0.36	1.30	3.52	15.50
Evapotranspiration, in.	0.70	0.83	1.24	1.00	0.83	3.27	3.75	0.20	0.14	0.19	0.45	0.47	13.09
Runoff, in.	0.91	0.20	0.18	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.52	1.87
Temperature, °F	44.06	49.10	53.60	58.82	64.22	69.26	75.20	72.14	69.08	62.96	51.80	43.16	59.54
Percolation, in.	0.07	0.00	0.17	0.11	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37
Gainesville, FL													
Precipitation, in.	2.65	2.59	2.99	2.56	3.70	5.69	7.33	7.85	4.70	2.50	1.55	3.69	47.78
Evapotranspiration, in.	0.62	0.79	1.45	4.24	7.42	5.76	2.57	1.18	0.89	0.63	0.46	0.52	26.52
Runoff, in.	0.48	0.46	0.42	0.11	0.45	0.59	1.56	1.76	1.05	0.49	0.22	0.79	8.38
Temperature, °F	57.74	59.72	64.76	69.62	75.20	78.44	79.34	79.16	77.90	71.96	62.78	56.66	69.44
Percolation, in.	1.44	1.44	1.35	0.37	0.15	0.00	0.00	1.30	2.13	1.31	0.84	2.16	12.51
Ames, IA													
Precipitation, in.	0.74	0.78	2.21	3.26	4.63	4.08	4.15	3.88	4.30	1.38	1.82	1.01	32.23
Evapotranspiration, in.	0.33	0.46	0.78	1.43	2.16	5.01	6.57	4.62	1.46	0.64	0.39	0.31	24.14
Runoff, in.	0.30	0.51	0.70	0.22	0.39	0.31	0.19	0.26	0.63	0.04	0.44	0.50	4.49
Temperature, °F	17.42	23.90	33.08	49.46	60.08	68.72	73.40	70.16	60.98	52.52	36.14	22.28	47.30
Percolation, in.	0.00	0.01	0.12	0.78	0.31	0.94	0.04	0.03	0.02	0.00	0.08	0.02	3.35
Hagerstown, MD													
Precipitation, in.	2.33	2.06	3.20	2.68	3.97	3.65	3.91	3.58	2.66	2.38	3.02	3.21	36.65
Evapotranspiration, in.	0.44	0.50	0.83	1.33	2.26	4.76	6.43	4.21	1.44	0.55	0.43	0.35	23.54
Runoff, in.	1.10	0.83	1.08	0.24	0.24	0.13	0.48	0.19	0.11	0.20	0.59	1.28	6.48
Temperature, °F	32.00	34.88	40.46	54.50	62.60	69.98	74.66	71.60	63.50	55.22	42.26	30.20	52.70
Percolation, in.	0.49	0.46	1.14	1.37	1.52	0.62	0.03	0.00	0.00	0.00	0.20	0.49	6.33

Raleigh, NC													
Precipitation, in.	3.05	2.88	2.74	3.13	3.02	3.71	4.23	5.66	3.55	1.79	2.71	2.75	39.20
Evapotranspiration, in.	0.44	0.49	0.99	1.68	2.83	6.61	6.66	4.69	1.19	0.50	0.41	0.36	26.85
Runoff, in.	0.74	0.43	0.27	0.18	0.17	0.25	0.21	0.73	0.51	0.33	0.43	0.70	4.96
Temperature, °F	41.54	43.34	49.82	59.90	66.92	73.94	77.72	75.02	69.80	60.44	49.28	40.46	59.00
Percolation, in.	0.91	1.50	1.57	1.21	0.80	0.24	0.00	0.06	0.04	0.09	0.22	0.40	7.02
Bismarck, ND													
Precipitation, in.	0.48	0.37	0.52	1.29	2.19	3.66	1.71	1.76	1.28	0.43	0.55	0.46	14.72
Evapotranspiration, in.	0.35	0.37	0.70	0.94	1.57	2.89	3.66	1.89	0.79	0.45	0.30	0.30	14.20
Runoff, in.	0.00	0.07	0.06	0.06	0.05	0.20	0.00	0.01	0.02	0.00	0.06	0.04	0.59
Temperature, °F	8.42	12.20	26.96	44.24	54.32	63.14	72.14	66.92	56.30	45.50	27.68	13.10	40.82
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lubbock, TX													
Precipitation, in.	0.33	0.32	0.45	1.19	2.51	2.73	1.78	2.53	2.77	1.18	0.77	0.45	17.00
Evapotranspiration, in.	0.43	0.37	0.55	1.00	2.28	4.59	1.84	2.37	1.19	0.65	0.50	0.40	16.16
Runoff, in.	0.00	0.00	0.00	0.00	0.18	0.10	0.01	0.04	0.20	0.11	0.06	0.01	0.71
Temperature, °F	37.04	40.46	46.94	57.20	68.54	74.66	78.62	75.56	68.00	59.18	44.60	37.22	57.38
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pullman, WA													
Precipitation, in.	2.56	1.63	1.95	1.41	1.21	1.20	0.52	0.74	1.31	1.79	2.56	2.85	19.72
Evapotranspiration, in.	0.44	0.56	1.02	1.30	1.32	2.93	4.63	0.89	0.78	0.68	0.38	0.30	15.22
Runoff, in.	1.34	0.86	0.29	0.05	0.00	0.03	0.00	0.00	0.00	0.04	0.61	1.14	4.37
Temperature, °F	27.86	33.08	40.28	48.38	54.32	59.54	67.10	64.22	55.76	48.92	37.22	29.84	47.12
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4–5. Monthly precipitation.

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
	Results from 20-yr EPIC simulations with soil from hydrologic group C (Webster)												
	Avg. monthly values												
	Saturated conductivity = 0.073 in./h						Plant available water storage = 10.79 in.						
Davis, CA													
Precipitation, in.	3.63	2.29	2.28	1.01	0.81	0.03	0.01	0.02	0.24	0.36	1.30	3.52	15.50
Evapotranspiration, in.	0.69	0.83	1.26	1.03	0.87	3.51	3.16	0.21	0.18	0.19	0.38	0.44	12.74
Runoff, in.	1.14	0.30	0.28	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.06	0.76	2.60
Temperature, °F	44.06	49.10	53.60	58.82	64.22	69.26	75.20	72.14	69.08	62.96	51.80	43.16	59.54
Percolation, in.	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Gainesville, FL													
Precipitation, in.	2.65	2.59	2.99	2.56	3.70	5.69	7.33	7.85	4.70	2.50	1.55	3.69	47.78
Evapotranspiration, in.	0.67	0.85	1.57	4.50	7.75	5.97	2.59	1.29	0.96	0.69	0.50	0.56	27.89
Runoff, in.	0.72	0.69	0.58	0.17	0.66	0.88	2.04	2.50	1.50	0.72	0.33	1.17	11.97
Temperature, °F	57.74	59.72	64.76	69.62	75.20	78.44	79.34	79.16	77.90	71.96	62.78	56.66	69.44
Percolation, in.	1.12	1.15	1.10	0.28	0.05	0.00	0.00	0.23	0.83	0.72	0.57	1.56	7.61
Ames, IA													
Precipitation, in.	0.74	0.78	2.21	3.26	4.63	4.08	4.15	3.88	4.30	1.38	1.82	1.01	32.23
Evapotranspiration, in.	0.34	0.48	0.82	1.54	2.35	5.27	6.41	4.44	1.46	0.69	0.41	0.32	24.53
Runoff, in.	0.31	0.51	0.82	0.41	0.60	0.47	0.33	0.42	0.87	0. 09	0.52	0.54	5.89
Temperature, °F	17.42	23.90	33.08	49.46	60.08	68.72	73.40	70.16	60.98	52.52	36.14	22.28	47.30
Percolation, in.	0.00	0.00	0.01	0.32	0.78	0.52	0.00	0.00	0.00	0.00	0.00	0.00	1.63
Hagerstown, MD													
Precipitation, in.	2.33	2.06	3.20	2.68	3.97	3.65	3.91	3.58	2.66	2.38	3.02	3.21	36.65
Evapotranspiration, in.	0.47	0.53	0.88	1.44	2.44	5.06	6.48	4.22	1.44	0.58	0.46	0.37	24.37
Runoff, in.	1.21	0.95	1.26	0.38	0.39	0.25	0.70	0.33	0.22	0.34	0.80	1.48	8.30
Temperature, °F	32.00	34.88	40.46	54.50	62.60	69.98	74.66	71.60	63.50	55.22	42.26	30.20	52.70
Percolation, in.	0.28	0.15	0.69	1.00	1.11	0.41	0.00	0.00	0.00	0.00	0.00	0.10	3.74

Raleigh, NC													
Precipitation, in.	3.05	2.88	2.74	3.13	3.02	3.71	4.23	5.66	3.55	1.79	2.71	2.75	39.20
Evapotranspiration, in.	0.46	0.51	1.06	1.82	3.02	6.87	6.75	4.63	1.20	0.52	0.43	0.37	27.62
Runoff, in.	1.07	0.74	0.48	0.33	0.26	0.40	0.37	1.09	0.77	0.40	0.65	0.89	7.47
Temperature, °F	41.54	43.34	49.82	59.90	66.92	73.94	77.72	75.02	69.80	60.44	49.28	40.46	59.00
Percolation, in.	0.35	0.73	0.93	0.95	0.56	0.10	0.00	0.00	0.00	0.00	0.02	0.24	3.88
Bismark, ND													
Precipitation, in.	0.48	0.37	0.52	1.29	2.19	3.66	1.71	1.76	1.28	0.43	0.55	0.46	14.72
Evapotranspiration, in.	0.37	0.38	0.72	1.00	1.66	2.95	3.21	1.80	0.84	0.49	0.32	0.32	14.07
Runoff, in.	0.00	0.09	0.07	0.07	0.07	0.28	0.02	0.02	0.02	0.00	0.06	0.03	0.73
Temperature, °F	8.42	12.20	26.96	44.24	54.32	63.14	72.14	66.92	56.30	45.50	27.68	13.10	40.82
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lubbock, TX													
Precipitation, in.	0.33	0.32	0.45	1.19	2.51	2.73	1.78	2.53	2.77	1.18	0.77	0.45	17.00
Evapotranspiration, in.	0.43	0.39	0.57	1.02	2.31	4.04	1.78	2.27	1.31	0.72	0.53	0.43	15.82
Runoff, in.	0.00	0.00	0.00	0.00	0.24	0.19	0.04	0.08	0.27	0.15	0.10	0.01	1.09
Temperature, °F	37.04	40.46	46.94	57.20	68.54	74.66	78.62	75.56	68.00	59.18	44.60	37.22	57.38
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pullman, WA													
Precipitation, in.	2.56	1.63	1.95	1.41	1.21	1.20	0.52	0.74	1.31	1.79	2.56	2.85	19.72
Evapotranspiration, in.	0.54	0.68	1.21	1.45	1.33	3.00	3.32	0.78	0.84	0.78	0.49	0.39	14.79
Runoff, in.	1.44	0.95	0.38	0.07	0.00	0.04	0.00	0.00	0.00	0.05	0.65	1.23	4.83
Temperature, °F	27.86	33.08	40.28	48.38	54.32	59.54	67.10	64.22	55.76	48.92	37.22	29.84	47.12
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4-6. Monthly precipitation.

Results from 20-yr EPIC simulations with soil from hydrologic group D (Houston)													
	Avg. monthly values												Annual
Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	total
	Saturated conductivity = 0.040 in./h						Plant available water storage = 10.00 in.						
Davis, CA													
Precipitation, in.	3.63	2.29	2.28	1.01	0.81	0.03	0.01	0.02	0.24	0.36	1.30	3.52	15.50
Evapotranspiration, in.	0.83	0.98	1.48	1.21	1.06	3.43	1.61	0.13	0.19	0.21	0.48	0.54	12.15
Runoff, in.	1.32	0.39	0.41	0.07	0.04	0.00	0.00	0.00	0.00	0.02	0.08	0.94	3.29
Temperature, °F	44.06	49.10	53.60	58.82	64.22	69.26	75.20	72.14	69.08	62.96	51.80	43.16	59.54
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gainesville, FL													
Precipitation, in.	2.65	2.59	2.99	2.56	3.70	5.69	7.33	7.85	4.70	2.50	1.55	3.69	47.78
Evapotranspiration, in.	0.67	0.88	1.68	4.60	7.40	4.89	2.39	1.28	0.96	0.69	0.50	0.56	26.50
Runoff, in.	0.96	0.93	0.80	0.31	0.94	1.27	2.50	3.23	1.96	0.96	0.46	1.55	15.89
Temperature, °F	57.74	59.72	64.76	69.62	75.20	78.44	79.34	79.16	77.90	71.96	62.78	56.66	69.44
Percolation, in.	0.80	0.94	0.78	0.23	0.00	0.00	0.00	0.06	0.47	0.39	0.39	1.11	5.17
Ames, IA													
Precipitation, in.	0.74	0.78	2.21	3.26	4.63	4.08	4.15	3.88	4.30	1.38	1.82	1.01	32.23
Evapotranspiration, in.	0.34	0.48	0.83	1.60	2.48	5.34	6.22	3.88	1.42	0.70	0.43	0.32	24.04
Runoff, in.	0.32	0.52	0.93	0.64	0.94	0.75	0.59	0.63	1.12	0.13	0.61	0.57	7.75
Temperature, °F	17.42	23.90	33.08	49.46	60.08	68.72	73.40	70.16	60.98	52.52	36.14	22.28	47.30
Percolation, in.	0.00	0.00	0.00	0.00	0.18	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.40
Hagerstown, MD													
Precipitation, in.	2.33	2.06	3.20	2.68	3.97	3.65	3.91	3.58	2.66	2.38	3.02	3.21	36.65
Evapotranspiration, in.	0.48	0.54	0.90	1.50	2.57	5.17	6.42	3.95	1.40	0.60	0.48	0.37	24.38
Runoff, in.	1.32	1.05	1.46	0.57	0.63	0.46	0.99	0.51	0.35	0.48	0.98	1.65	10.44
Temperature, °F	32.00	34.88	40.46	54.50	62.60	69.98	74.66	71.60	63.50	55.22	42.26	30.20	52.70
Percolation, in.	0.03	0.02	0.14	0.63	0.64	0.20	0.00	0.00	0.00	0.00	0.00	0.00	1.67

Raleigh, NC													
Precipitation, in.	3.05	2.88	2.74	3.13	3.02	3.71	4.23	5.66	3.55	1.79	2.71	2.75	39.20
Evapotranspiration, in.	0.46	0.52	1.09	1.93	3.14	6.97	6.14	3.93	1.17	0.53	0.43	0.37	26.68
Runoff, in.	1.33	1.04	0.72	0.57	0.43	0.68	0.61	1.47	0.98	0.48	0.82	1.13	10.26
Temperature, °F	41.54	43.34	49.82	59.90	66.92	73.94	77.72	75.02	69.80	60.44	49.28	40.46	59.00
Percolation, in.	0.22	0.33	0.57	0.62	0.33	0.04	0.00	0.00	0.00	0.00	0.00	0.00	2.12
Bismarck, ND													
Precipitation, in.	0.48	0.37	0.52	1.29	2.19	3.66	1.71	1.76	1.28	0.43	0.55	0.46	14.72
Evapotranspiration, in.	0.38	0.39	0.72	1.01	1.70	2.91	2.86	1.82	0.87	0.50	0.32	0.33	13.82
Runoff, in.	0.00	0.10	0.06	0.07	0.10	0.41	0.04	0.07	0.04	0.00	0.06	0.05	1.00
Temperature, °F	8.42	12.20	26.96	44.24	54.32	63.14	72.14	66.92	56.30	45.50	27.68	13.10	40.82
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lubbock, TX													
Precipitation, in.	0.33	0.32	0.45	1.19	2.51	2.73	1.78	2.53	2.77	1.18	0.77	0.45	17.00
Evapotranspiration, in.	0.47	0.43	0.63	1.07	2.31	3.29	1.72	2.21	1.39	0.80	0.61	0.47	15.41
Runoff, in.	0.00	0.00	0.00	0.01	0.32	0.28	0.07	0.16	0.37	0.22	0.10	0.02	1.56
Temperature, °F	37.04	40.46	46.94	57.20	68.54	74.66	78.62	75.56	68.00	59.18	44.60	37.22	57.38
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pullman, WA													
Precipitation, in.	2.56	1.63	1.95	1.41	1.21	1.20	0.52	0.74	1.31	1.79	2.56	2.85	19.72
Evapotranspiration, in.	0.58	0.72	1.30	1.56	1.44	3.00	2.35	0.78	0.91	0.83	0.53	0.43	14.42
Runoff, in.	1.48	1.02	0.43	0.08	0.00	0.06	0.00	0.00	0.00	0.08	0.74	1.35	5.26
Temperature, °F	27.86	33.08	40.28	48.38	54.32	59.54	67.10	64.22	55.76	48.92	37.22	29.84	47.12
Percolation, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

4-4 THE NITROGEN-LEACHING INDEX

Managing N fertilization to minimize leaching maximizes fertilizer efficiency and helps protect the environment from pollution. Fertilizer management may be a complex problem involving amounts, timing, type of N applied, and depth and method of application. A comprehensive simulation model like EPIC is useful in making these complex decisions. However, for some areas of the country with low annual rainfall or at least low rainfall during the winter, little or no percolation occurs. The same is true for medium rainfall areas that have soils with high storage capacity and low saturated conductivity values.

A simple N-leaching index (LI) based on percolation potential would be useful in identifying problem areas. Once a problem area is identified, more detailed simulation models can be used to address complex fertilizer management problems.

To be useful, the LI must be based on readily available inputs and computations should be practical for calculators. The inputs selected were average monthly precipitation and the hydrologic soil group.

The N LI developed here is simply an estimate of average annual percolation for a particular site. The methodology was developed considering results of EPIC simulations contained in Tables 4-3 to 4-6. Obviously, the percolation-precipitation ratio increases nonlinearly as precipitation increases. Also, annual precipitation below a threshold value produces no percolation. The threshold precipitation value is a function of hydrologic soil groups. For example, soils in hydrologic soil group A (high saturated conductivity and low storage capacity) have relatively low thresholds. Conversely, when estimating surface runoff, the precipitation threshold is highest for the A group. Thus, an equation of the form used to estimate surface runoff for individual storms may be useful in estimating a leaching index. The SCS (USDA-SCS, 1972) runoff curve number equation is

$$Q = (P - 0.2\ s)^2/P + 0.8\ s \qquad [8]$$

where Q is surface runoff volume, P is precipitation amount, and s is a retention parameter. The retention parameter is related to curve number using the equation

$$s = (1000/CN) - 10. \qquad [9]$$

An equation of the same form can be written to estimate the percolation index (PI).

$$PI = (P - 0.4\ s)^2/P + 0.6\ s \qquad [10]$$

where the PI is an estimate of average annual percolation in inches, P is the average annual rainfall in inches, and the coefficients 0.4 and 0.6 were adjusted to give higher precipitation threshold values than the 0.2 and 0.8 of

Eq. [8]. Of course, a new curve number table is required to estimate the s parameter of Eq. [10].

The PI curve numbers were developed for each of the four hydrologic soils groups by fitting Eq. [10] to the EPIC simulated percolation rates contained in Tables 4–3 to 4–6. The Golden Section method (Wagner, 1969) was used to minimize the sum of squared deviations between Eq. [10] estimates and EPIC simulations. The resulting curve numbers are 28, 21, 17, and 15 for soil groups A, B, C, and D, respectively.

Another factor of considerable importance in estimating percolation is the seasonal rainfall distribution. Rainfall that occurs in the absence of crops is much more likely to percolate than growing season rainfall because evapotranspiration is low during the winter. This was demonstrated with the simulated evapotranspiration results contained in Tables 4–2 to 4–6.

Several schemes for expressing seasonal precipitation effects were developed and evaluated. Although methods based on potential evaporation estimates and temperature-weighted precipitation seem to offer great promise, they were not significantly better than a simple method involving only average monthly precipitation. The seasonal index (SI) is estimated with the Eq. [11]:

$$SI = (2\ PW/P)^{1/3} \qquad [11]$$

where PW is the fall and winter precipitation amount and P is the annual precipitation. Fall and winter precipitation are computed by summing the values for October, November, December, January, February, and March.

The LI is estimated by combining Eq. [10] and [11]

$$LI = (PI)\ (SI) \qquad [12]$$

Percolation simulated with EPIC and estimated with the LI for the eight demonstration sites is shown in Table 4–7. Table 4–8 contains test results from four other locations not used in model development. The agreement between LI and EPIC simulated percolation amounts seems satisfactory. This is especially true considering that field-measured percolation data are not available at any of the sites. Thus, the LI should provide useful information for use in estimating leaching potential.

4–5 SUMMARY AND CONCLUSION

Major soil, crop, and climatic factors and their interactions with percolation are discussed. Percolation is affected directly by the soil water balance (precipitation, runoff, evapotranspiration, and soil water storage capacity). Soils with low-storage capacity and high-saturated conductivity have large percolation potentials if rainfall is high. Also, the seasonal rainfall distribution is an important factor. Winter rainfall is much more likely to percolate

Table 4-7. Percolation simulated with EPIC and estimated with leaching index (LI) for eight demonstration sites.

Location	Hydrologic soil group†	Avg annual percolation, in. Simulated Table 2	Estimated LI	Table 3	Estimated LI	Table 4	Estimated LI	Table 5	Estimated LI	Table 6	Estimated LI
Davis, CA	B	0.07	0.01	4.09	1.06	0.35	0.01	0.02	0.00	0.00	0.00
Gainesville, FL	A	19.07	19.44	19.96	19.44	12.52	13.31	7.60	9.05	5.16	6.74
Ames, IA	C	0.94	2.07	7.76	7.98	3.35	4.26	1.61	2.07	0.40	1.09
Hagerstown, MD	C	1.73	4.26	10.94	12.81	6.34	7.56	3.74	4.26	1.67	2.65
Raleigh, NC	B	11.60	8.80	13.11	14.27	7.01	8.81	3.88	5.27	2.12	3.48
Bismarck, ND	B	0.00	0.00	0.32	0.47	0.00	0.00	0.00	0.00	0.00	0.00
Lubbock, TX	B	0.00	0.07	0.24	1.03	0.00	0.07	0.00	0.00	0.00	0.00
Pullman, WA	B	0.00	1.57	1.93	2.80	0.00	0.57	0.00	0.00	0.00	0.00

† Hydrologic soil groups (HSG) used estimated LI for Table 4-2 comparisons. Hydrologic soil group A is used for all locations in Table 4-3 comparisons. HSG = B, Table 4-4; HSG = C, Table 4-5; and HSG = D, Table 4-6.

Table 4-8. Leaching index (LI) test results for four sites not used in developing LI.

Location	Annual precipitation	Fall and winter precipitation	Soil type†	Hydrologic soil group	SI‡	PI	LI	EPIC-simulated percolation
	in.	in.				in.	in.	in.
Oconee, GA	44.57	21.61	Cecil	B	0.99	12.98	12.85	15.20
Jackson, IL	40.16	17.24	Hosmer	C	0.95	6.12	5.82	3.58
Bell, TX	32.60	14.61	Houston	D	0.96	1.48	1.43	0.63
Escambia, AL	58.82	25.39	Benndale	B	0.95	23.54	22.41	20.63

† Cecil = clayey, kaolinitic, thermic Typic Kanhapludults; Hosmer = fine-silty, mixed, mesic Typic Fragiudalfs; Houston = very-fine, montmorillonitic, thermic Typic Chromuderts; Benndale = coarse-loamy, siliceous, thermic Typic Paleudults.
‡ SI = seasonal index; PI = percolation index; EPIC = Erosion-Productivity Impact Calculator.

than growing season rainfall because evapotranspiration is low during the winter.

Two methods were presented for analyzing leaching potential—EPIC simulation and the LI. The EPIC simulations are recommended for solving detailed N-leaching management problems (amount, timing, type of N applied, depth, and application method). However, a simple N-LI based on percolation potential is useful in identifying problem areas.

The LI developed here is a function of annual precipitation, hydrologic soil group, and seasonal rainfall distribution. Tests at 12 locations with wide ranges in soils and climate show that LI agrees closely with EPIC annual percolation estimates.

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