Control of WATER POLLUTION from cropland

Volume I
A manual for guideline development

Agricultural Research Service
Department of Agriculture

Office of Research and Development
Environmental Protection Agency

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Control of WATER POLLUTION from cropland

Volume I
A manual for guideline development

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Agricultural Research Service
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FOREWORD

In the years ahead, U.S. farmers will have to increase food and fiber production to meet domestic and world needs. Increased production will require greater use of chemicals and more intensive management of available but limited cropland. Existing and new production technology must be integrated into cropping systems that will assure sustained crop production and simultaneously protect or enhance the quality of our environment. These cropping systems must include management elements that control soil erosion and prevent the discharge of pollutants from cropland into the Nation's waters. To assist U.S. farmers in increasing food and fiber production while protecting the environment, the Agricultural Research Service (USDA) and the Office of Research and Development (EPA) are issuing this informational report. This report is Volume I. Volume II is a literature review and provides supplementary information in greater detail to support Volume I.

This technical report was designed for use in the development of management guidelines and should be used in conjunction with local expertise. The scope of the report is limited to problems of non-irrigated agricultural lands and is based on current understanding. The scope will be expanded and the contents updated as additional information becomes available from ongoing research.

This joint USDA/EPA report is published as partial fulfillment of provisions of the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, which reaffirms the objective of restoring and maintaining the quality of the Nation's waters.

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SECTION 1

INTRODUCTION

In today's agriculture, the use of chemicals is clearly necessary to maintain high yields and high quality of our agricultural products and to provide economic benefits to the farmer and the consumer. In today's concern for clean water, there are demands for preventing pollutants from entering ground and surface waters. Consequently, agricultural practices are being examined as to their contribution to water pollution.

Sources of pollutants are usually classed as "point" and "nonpoint". "Point" sources have received most of the attention and are covered by a permit system. The permit defines the requirements and the compliance schedule that must be followed. "Nonpoint" sources are diffuse in nature and discharge pollutants into waters by dispersed pathways. Examples are construction activities, mining areas, stormwater runoff from urban areas, and agricultural runoff. The nonpoint agricultural pollutants of primary concern are sediment, nitrogen and phosphorus compounds, and pesticides. Oxygen-consuming organic compounds, dissolved salts, and other pollutants are of less general concern and are beyond the scope of this manual.

The purpose of the manual is to provide information to individuals or agencies charged with developing plans for the control or reduction of pollution from nonpoint agricultural sources. Information on the sources, causes, and potentials of sediment, nutrient, and pesticide losses from cropland is dealt with in depth, as is information on selecting cropping systems, tillage practices, and other measures that may be necessary to control pollutants. *It is important to recognize that the manual does not specify that nonpoint pollution from agricultural sources is necessarily a problem. Also, the manual does not establish pollution control goals or specific criteria that should be met by a control plan, since this is the responsibility of the States or other governing bodies.* Pollution from irrigation return flow, forestry activities, and transport of pollutants by wind are excluded. Rangelands are not discussed specifically, but the principles presented for cropland will apply.

The information presented should be useful in selecting the control measures that are appropriate for the special conditions imposed by the climate, soils, topography, and farming practices of a particular land area. The manual also presents procedures for estimating the cost of various control practices at the farm level. The regional and national economic impacts of certain nonpoint pollution control methods are also discussed.

Although it is difficult to conceive of a system that would completely eliminate all possible risks to the environment from the use of agricultural chemicals, practices and systems can be developed that will greatly reduce such risks. Agricultural chemicals may be transported to streams and lakes in solution in runoff water, suspended in runoff water, or adsorbed on the entrained soil particles. Phosphates, organic nitrogen compounds, and the persistent organochlorine insecticides are examples of materials that may be carried primarily on the sediment; nitrate exemplifies a potential pollutant that is dissolved in water. The reduction of runoff and erosion will clearly reduce chemical transport; consequently, measures directed specifically to runoff and erosion reduction are included in the manual. However, complete elimination of surface runoff is not generally

realizable or desirable and some portion of the chemicals may leave treated areas in the runoff that does occur. Methods of managing the chemicals themselves to minimize pollution are, therefore, also included.

General information is included for identifying the regions of the country where the transport of chemicals into streams in runoff water or by eroded soil could be most severe and the principal classes of chemicals that may be carried within a given region. Methods of controlling or reducing losses of chemicals from individual fields are presented along with guidelines and methodology for choosing the most appropriate methods. Guidelines for selecting appropriate control methods for regions are developed by selecting practices suitable for the predominant agricultural conditions within a region.

Quantitative information was used in the development of these guidelines wherever it was available in sufficiently general form that it could be utilized in a nationwide manual. *Because of the variation of climate, soils, and agricultural practices throughout the United States, no single group of control measures can be used for every region nor will the regional information presented herein be accurate for all areas within the region.* More detailed procedures that are consistent with the basic principles and concepts described in this manual should be used where the necessary information is available.

This manual, which is designated as Volume I of a two-volume set, provides a systematic procedure to aid the user in identifying specific potential problems and appropriate corrective measures. Volume II reviews the appropriate basic principles on which the instructions are founded and provides documentation of the information presented.

Material in this manual is based on the contributions of many persons in the Agricultural Research Service, Economic Research Service, Extension Service, Forest Service, State Agricultural Experiment Stations, Soil Conservation Service, and others, and all contributions are gratefully acknowledged.

SECTION 2

USE OF THE MANUAL

Agencies charged with the development of a program to control pollution in waters discharging from a given land area will, with use of the systematic procedures shown in this manual, be able to identify potential nonpoint pollution problems within the area and to recommend one or more practical measures for controlling any likely or existing problems. *The most effective use of this manual will be achieved when it is used as a guide by a group of specialists for developing specific guidelines for a localized area.* For example, a State Government, a Soil Conservation District, or other agency could bring together farmers, scientists, engineers, and other specialists who are familiar with the area. These representatives, working as a group and using the manual as a guide, could develop a list of specific practices for the area that would control or reduce pollution from nonpoint agricultural sources. This type of local input is essential to arrive at the best possible choice of practices.

The general procedure to be followed is shown in Figure 1. The scheme depends primarily on the answers resulting from a sequential series of questions embodied in four flow charts (Figures 36, 37, 38, and 39 for control of erosion in large areas, erosion in field-sized areas, plant nutrients, and pesticides, respectively) shown in Section 6. If all pollutants from nonpoint sources are to be considered, the appropriate flow chart for erosion control should be consulted first, as shown in Figure 1, followed by the flow charts for nutrient and pesticide control. Erosion should be addressed first because eroded sediment is not only the most serious water pollutant in itself, but also poses a double threat in that it often carries along adsorbed nutrients or pesticides. If, on the other hand, a specific pollutant is of concern, any one of the four flow charts may be entered and followed individually to obtain the appropriate control practices. Sections 3, 4, and 5 give some information required to respond to the questions posed in the flow charts with respect to problem identification (Section 3), specific control measures (Section 4), and economic considerations (Section 5). More detailed information about the specific area should be developed by the user group. To aid the user of the manual, examples showing how the scheme is applied to specific land areas are included in Section 6 following the flow charts. The final operation in the master flow chart, Figure 1, constitutes an overall evaluation process. This evaluation should be done by persons having knowledge of the specific land areas and conditions.

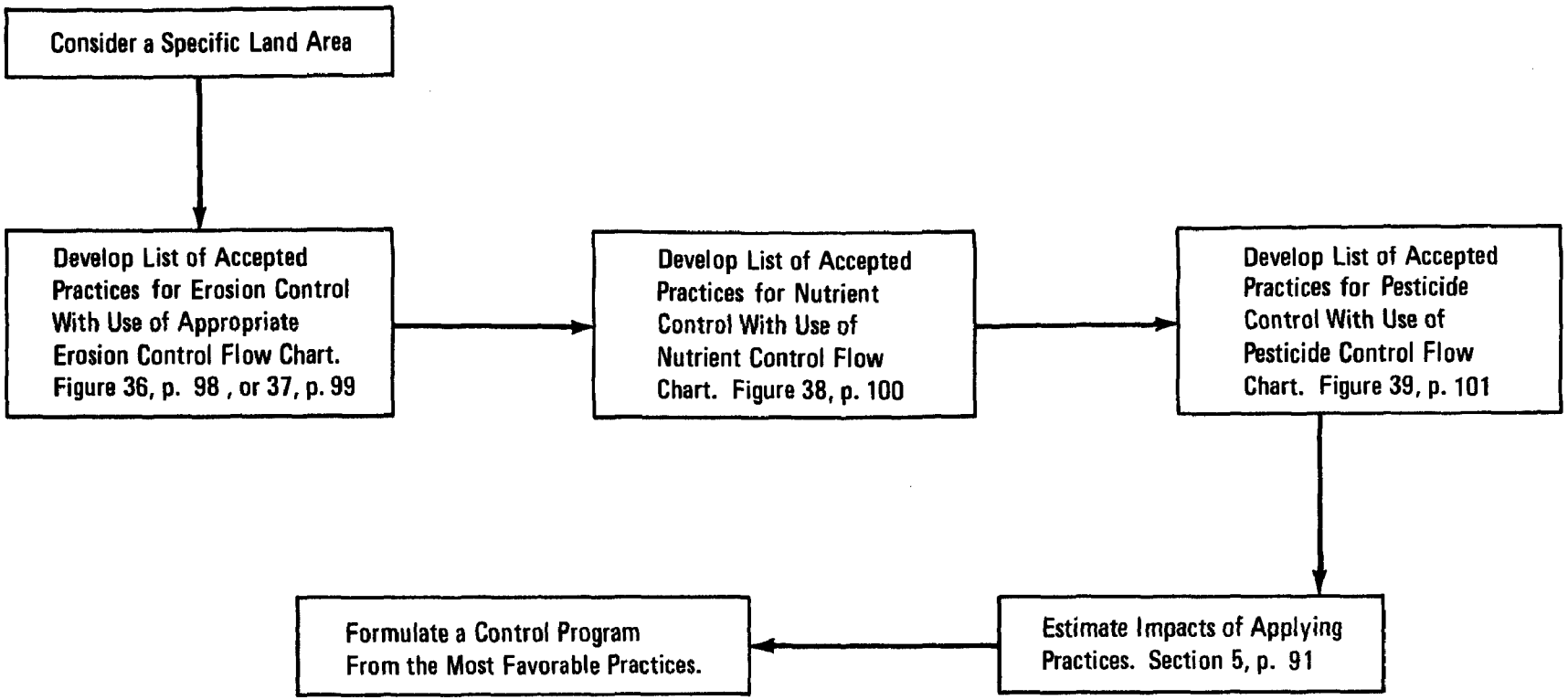


Figure 1.–Master flow chart.

SECTION 3

IDENTIFICATION OF POTENTIAL NONPOINT POLLUTION PROBLEMS

There must be transport of agricultural pollutants from fields to water bodies before they can cause a pollution problem. It is important to recognize, however, that even when there is transport, concentrations may not be at damaging levels. The transport processes—direct runoff, sediment movement, and percolation—are largely controlled by natural conditions such as the characteristics of the land and the climate of the area. An understanding of the relationships involved as well as of the behavior of the chemicals after application is necessary before measures to control pollution can be intelligently applied. This section provides information to help the user obtain such an understanding by (1) showing geographical distributions of factors relating to potential pollutant losses from cropland, and (2) presenting the principal considerations necessary for interpretation of the data. This information is basic to the use of the decision-making flow charts, shown later, that will serve as a guide to the appropriate corrective measures.

3.1 LAND RESOURCE AREAS

Geographic potentials for direct runoff, erosion, and percolation are presented below for Land Resource Areas. These Areas were delineated in a classification system devised by the Soil Conservation Service of the U. S. Department of Agriculture and described in detail in Agriculture Handbook No. 296, "Land Resource Regions and Major Land Resource Areas of the United States", which is available from the U. S. Government Printing Office.[1] In brief, a *Land Resource Area* is defined as a geographic area characterized by a particular pattern of soil type, topography, climate, water resources, land use, and type of farming. The 156 Land Resource Areas of the contiguous 48 states are shown in Figure 2, along with their combinations into major Land Resource Regions.

[1] Agriculture Handbook No. 296 is currently being revised. The anticipated revisions include the subdivision of some of the larger Land Resource Areas (such as 133 in the Southeast) and should have only a minor effect on the material presented in this manual.

Although it is recognized that considerable differences occur within a Land Resource Area, this unit is used as an aggregate for presenting information relative to water erosion and pollution. These units provide a means of considering rather large areas, and the same principles can be applied to smaller units where more detailed information is available.

3.2 ESTIMATING POTENTIAL DIRECT RUNOFF

Runoff (or streamflow) is that portion of the precipitation that appears in surface streams. Precipitation that falls on an arbitrary land area and eventually becomes runoff may be classified as either surface runoff, subsurface runoff, or groundwater runoff, depending on the path of flow to the stream. *Surface runoff* (or overland flow) is water that travels over the ground surface to reach a stream. *Subsurface runoff* (also called subsurface flow, interflow, subsurface stormflow, or storm seepage) is water that has infiltrated the surface soil and moved laterally through the upper soil horizons toward the stream as shallow saturated flow above the main groundwater level. *Groundwater runoff* (or groundwater flow) is water that has infiltrated the surface soil, percolated to the general groundwater table, and then moved laterally to reappear in the stream. Surface runoff moves rather rapidly and is present during and shortly after a storm. Subsurface runoff moves somewhat more slowly than surface runoff, but appears in the stream during or shortly after a storm. Groundwater runoff may be in transit for days or years before it reaches a stream. These three types of runoff are not mutually exclusive in that an individual parcel of water may use any one or combinations of more than one of these modes of travel to a stream.

The amount of water that moves by each of these three routes must be known before the transport of agricultural chemicals from a field can be described in detail. Surface runoff may carry chemicals in solution, in suspension, or adsorbed to suspended soil particles. Subsurface runoff and groundwater runoff can only carry soluble chemicals that are not strongly adsorbed to

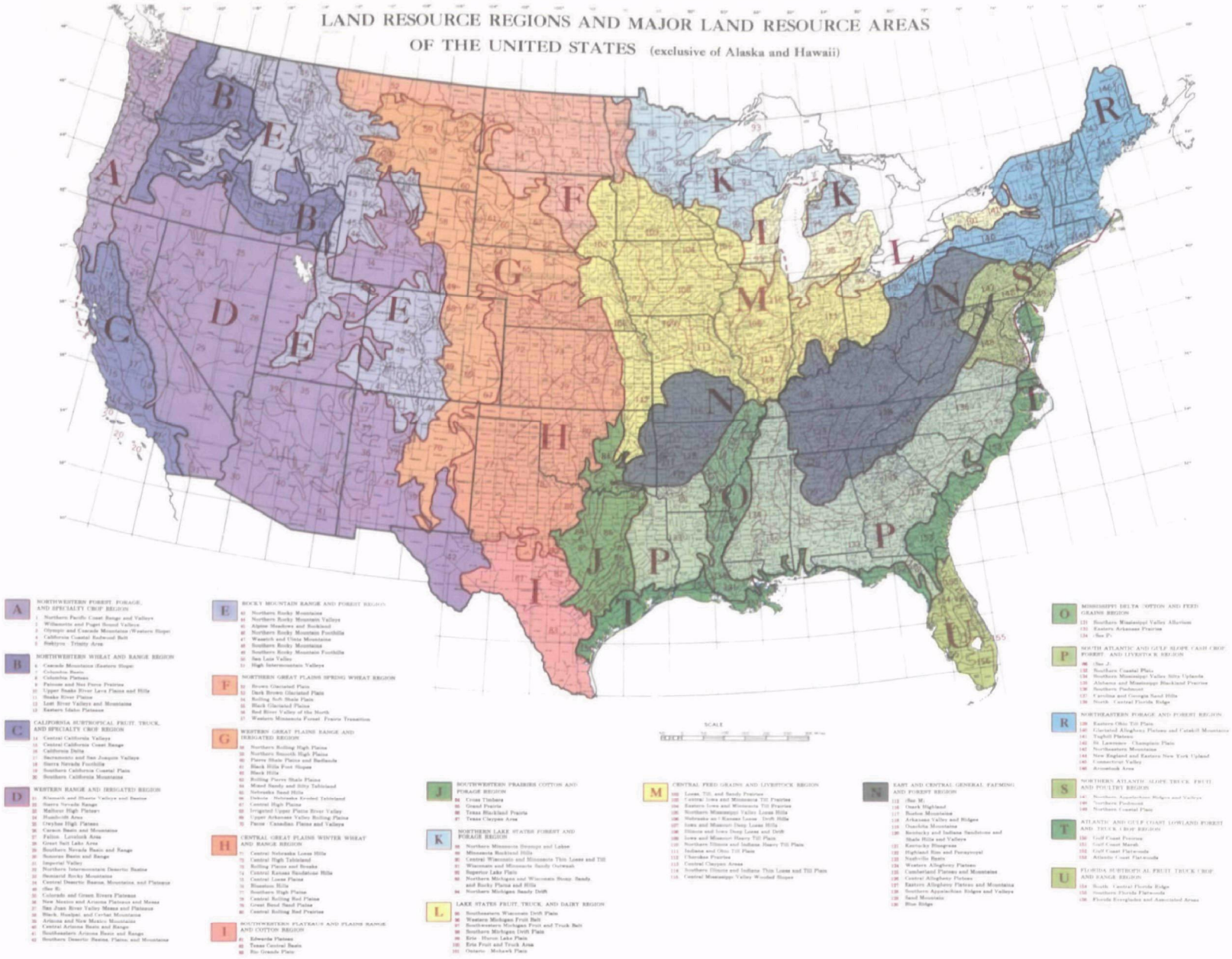


Figure 2.–Land resource regions and major land resource areas of the United States.

soil particles. Because of the large travel time involved, a *nonpersistent* chemical transported by groundwater runoff may not be a hazard when it reaches a surface stream. For example, nitrates that have leached below the root zone could be denitrified if the groundwater runoff is discharged to a surface stream through wet soils where anaerobic conditions exist and an energy source is present.

Maps of average annual "surface-water" runoff such as those published by the U. S. Geological Survey are based on measurements of streamflow and include various amounts of surface runoff, subsurface runoff, and groundwater runoff from watersheds with substantial variations in land use. Because the pathway that water takes from a field to a stream largely determines what types and how much of a chemical may be transported to a stream, the three types of runoff need to be estimated separately to assess potential problems.

Rainfall and runoff data from plots and small watersheds with various land uses and treatments have been obtained at many locations in the United States during the past 40 years. Unfortunately, with the type of instrumentation used, it is not possible to separate surface runoff from subsurface runoff, so these two components are lumped together with precipitation falling on the channels and called *direct runoff.* These direct runoff data provide good estimates of surface runoff because it is the primary component of direct runoff from plots and small watersheds and, *for most agricultural plots, it is the only component.*

Utilizing extensive plot and small watershed data, the Soil Conservation Service, USDA, developed an empirical equation for predicting direct runoff from any given rainfall. Although the Soil Conservation Service procedure is highly simplified, it produces reasonable estimates of direct runoff and is the only method that has parameters defined nationally and that can be used with readily available data. The different infiltration characteristics of soils are accounted for by classifying soils into four hydrologic soil groups based on the minimum rate of infiltration obtained for bare soil after prolonged wetting. "Curve numbers" have been developed for several crops and management practices which, when used in the equation, can show the effect of changes of crops or land management practices on direct runoff. For more detailed information on the Soil Conservation Service procedure for estimating direct runoff, see Appendix A, Volume II.

Potential direct runoff is defined here as the direct runoff predicted by the Soil Conservation Service runoff estimation procedure for an index row crop. Corn, planted in straight rows, was chosen as the index crop because it is grown widely in the United States and has direct runoff characteristics similar to those of several other row crops (cotton or soybeans, for example). Straight rows were chosen because they have the highest direct runoff potential of any cropland management practice.

Potential direct runoff for each of the four hydrologic soil groups was simulated for a 20- to 25-year period by using the Soil Conservation Service procedure and daily precipitation data for 52 meteorological stations in the 48 contiguous states. Most of the Western United States was omitted because: (1) Rainfall gradients are usually steep and interpolation between widely separated weather stations would be subject to large errors; and (2) much of the cropland is irrigated, so the SCS method of estimating direct runoff could not be used without extensive modification. Mountainous, forested, and swamp areas were also omitted because they contained insignificant cropland. A degree-day method was used to estimate snowmelt. A detailed description of the simulation procedure used, maps of potential mean-annual direct runoff and mean-growing-season direct runoff for each hydrologic soil group, and a brief analysis of relative errors are included in Appendix A, Volume II.

Average annual and average growing season (planting-to-harvest) potential direct runoff estimates for the *predominant agricultural soils* in each Land Resource Area are shown in Figures 3 and 4. The annual potential direct runoff is the runoff estimated for a specified condition and is *not* the *actual direct runoff* for a field. It is *only an index* of the relative hazard of transport of persistent chemicals in solution or suspension in surface runoff. The growing-season potential direct runoff is probably a better index of loss of nonpersistent pesticides than is the annual potential direct runoff.

The time distribution of direct runoff within a year may be an important consideration in the selection of a chemical or its time of application. The percentage of annual potential direct runoff occurring in each 28-day period beginning January 1 is shown in Figure 5.

More detailed maps of potential direct runoff could be prepared on a state or watershed basis by using published or unpublished soil survey maps available from the Soil Conservation Service.

3.3 ESTIMATING POTENTIAL EROSION

Sediment, which is an end product of soil erosion, is by volume the greatest single pollutant of surface waters, and it is also the principal carrier of some of the chemical pollutants. In some watersheds, sediment from

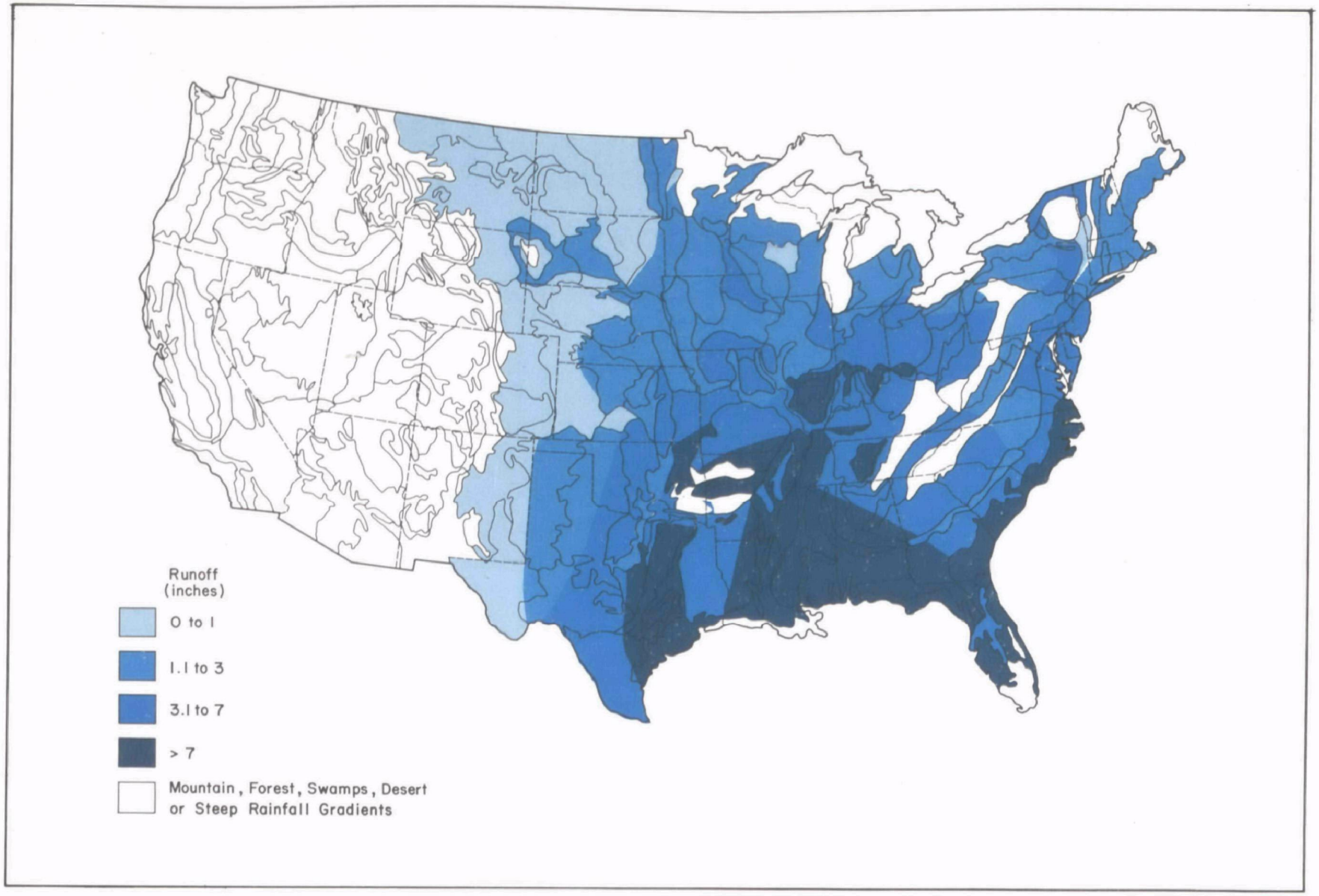


Figure 3.–Average annual potential direct runoff.

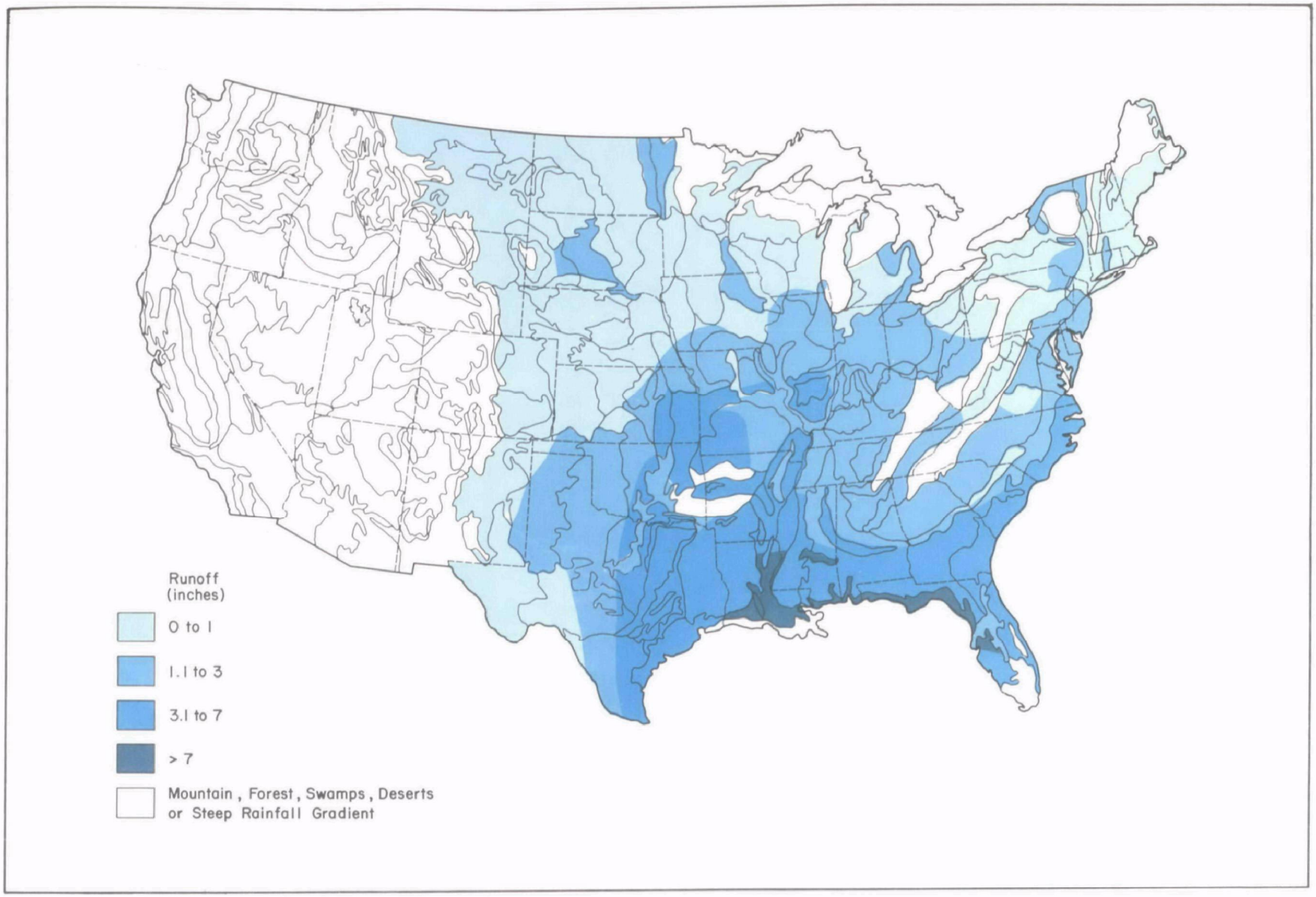


Figure 4.–Average growing season potential direct runoff.

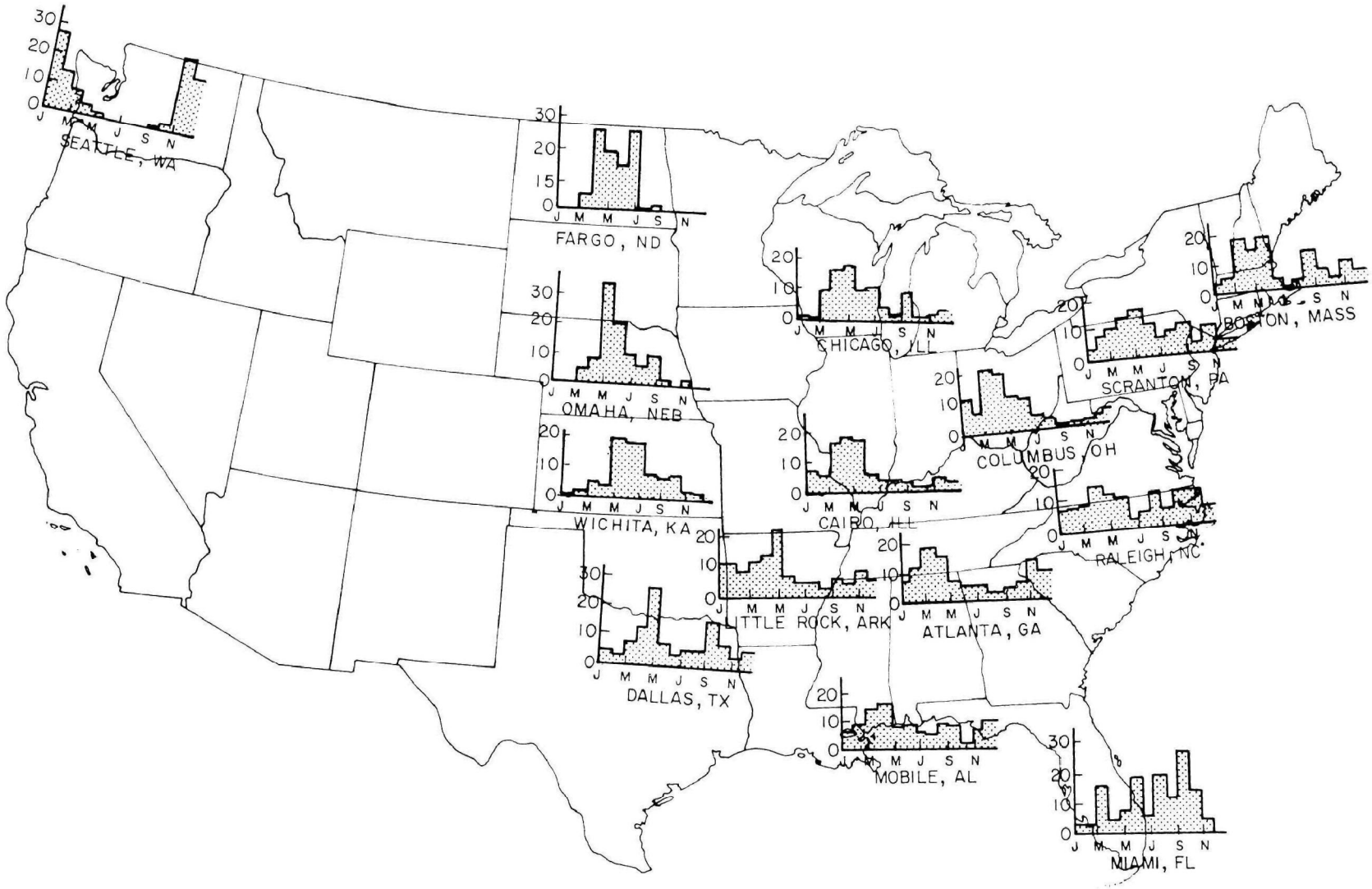


Figure 5.–Percentage distribution of annual potential direct runoff in 28-day intervals. Summer row crop (corn-straight rows).

nonagricultural sources exceeds that from cropland, and in regions of relatively low rainfall or sandy soils, wind erosion may exceed water erosion. However, for the purposes of this manual, the interest is in sediment from cropland erosion by rainfall and runoff.

Although classified as nonpoint, most of a watershed's sediment may come from a few relatively small areas that need special attention. Table 1 lists likely sources that can usually be identified by observation. Both agricultural and nonagricultural sources should be identified, so that the sediment from the latter will not be inadvertently ascribed to the cropland. A recent estimate attributes about half of our country's total sediment to cropland sources, but this ratio cannot be applied to all watersheds.

For several decades, selections of cropland erosion-control practices have been guided by estimates of the average annual rates of soil movement from the field slopes. On this basis, potential water erosion losses range from negligible to more than 100 tons per acre. A 1967 conservation needs inventory showed that about 20 percent of our country's 438 million acres of cropland were averaging more than 8 tons of soil loss per acre per year, 30 percent were averaging less than 3 tons, and the other 50 percent between 3 and 8 tons. A ton of dry soil is approximately 1 cubic yard in volume. Spread uniformly over an acre of surface, it would have a depth of less than one-hundredth of an inch.

Table 1. Conditions indicative of high sediment-yield potential that can usually be identified by observation.

Cropland
1. Long slopes farmed without terraces or runoff diversions
2. Rows up and down moderate or steep slopes
3. No crop residues on surface after new crop seeding
4. No cover between harvest and establishment of new crop canopy
5. Intensively farmed land adjacent to stream without intervening strip of vegetation
6. Runoff from upslope pasture or rangeland flowing across cropland
7. Poor stands or poor quality of vegetation
Other Sources
1. Gullies
2. Residential or commercial construction
3. Highway construction
4. Poorly managed range, idle, or wooded areas
5. Unstablized streambanks
6. Surface mining areas
7. Unstablized roadbanks
8. Bare areas of noncropland

Field soil loss data provide excellent guides for plans to preserve the long-range productivity of our land resource, but they are *not* quantitative estimates of cropland contributions to watershed sediment. Most eroded soil particles come to rest many times, and must be moved again many times, before they reach a continuous stream system. Fractions of the soil eroded from upslope areas that actually reach a continuous stream are discussed under Sediment Delivery Ratios, Section 3.3c.

Erosion hazards are so extremely local in nature that soil loss estimates and control guides can be accurate only on a field basis. Procedures for use of this approach will be presented, but first we will consider guides for general appraisals of potential cropland-sediment hazards on a broader scale.

3.3a Estimating Potential Cropland Sediment

The potential cropland contribution to sediment in streamflow depends on the erosion rate, the sediment delivery ratio, and the cropland density. Figures 6, 7, and 8 were developed from the 1967 USDA Research Needs Inventory data. Figure 6 shows cropland acreages as percentages of total land area for the 156 major Land Resource Areas that were defined in Figure 1. Figure 7 shows the distribution of cropland on which soil erosion is the dominant limitation for agricultural use. Figure 8 shows percentages of rangeland and will help to account for the sometimes quite substantial sediment content of streamflows in resource areas having relatively little cropland. The sparse natural cover on much of the rangeland cannot protect the soil surface against the occasional erosive rainstorms.

Neither actual nor potential erosion rates have been quantitatively mapped nationally because they are extremely localized. Soil properties, slope steepness, and slope lengths usually vary widely even within a single resource area. The important soil, topographic, and cultural practice details are generally available only on a locality basis. However, the geographic trends in the levels of these parameters and in rainfall pattern were estimated in relative terms and used to develop Figure 9.

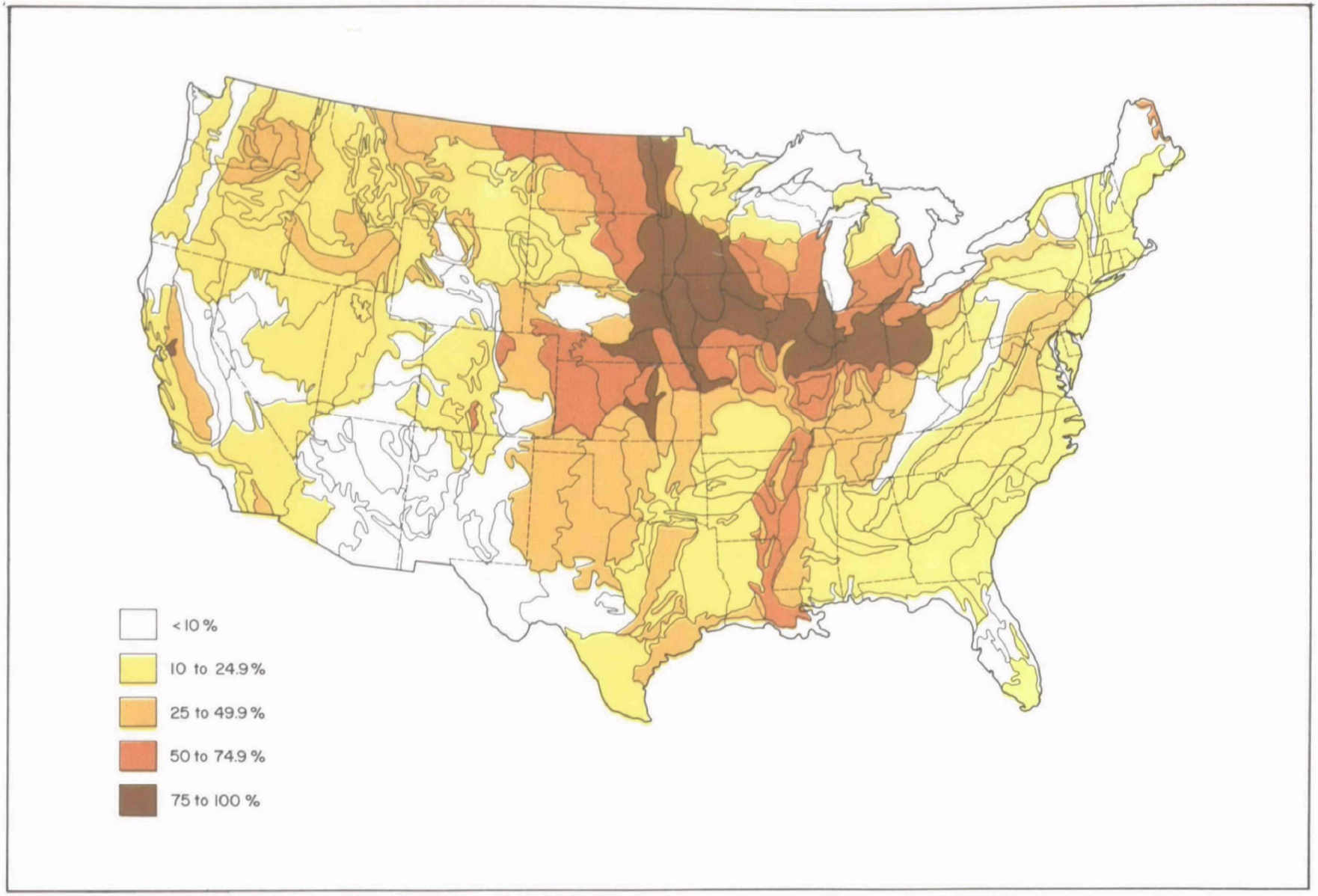


Figure 6.–Croplands as percentages of total land resource areas.

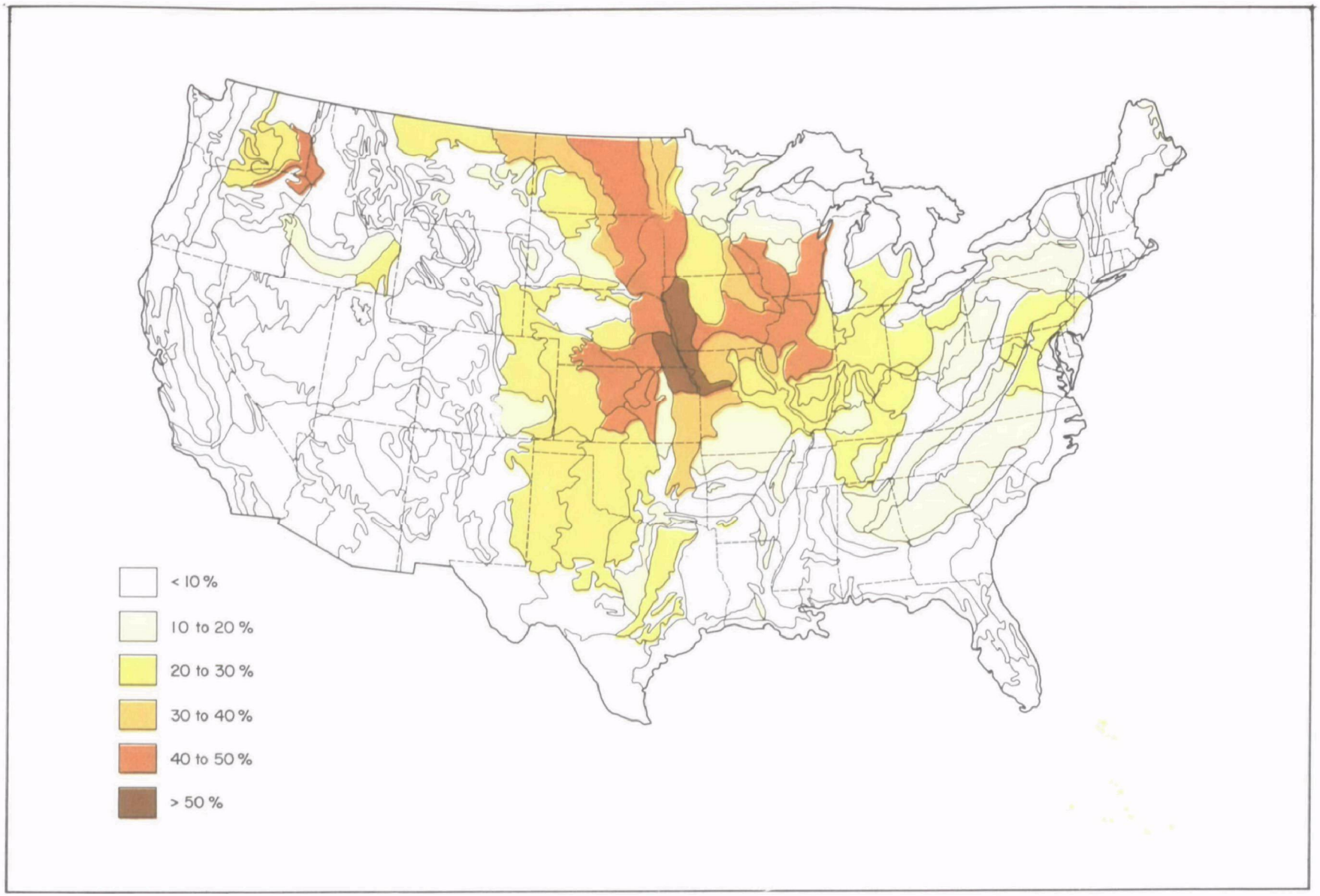


Figure 7.–Croplands on which erosion is the dominant limitation for their agricultural use as percentages of total land resource areas.

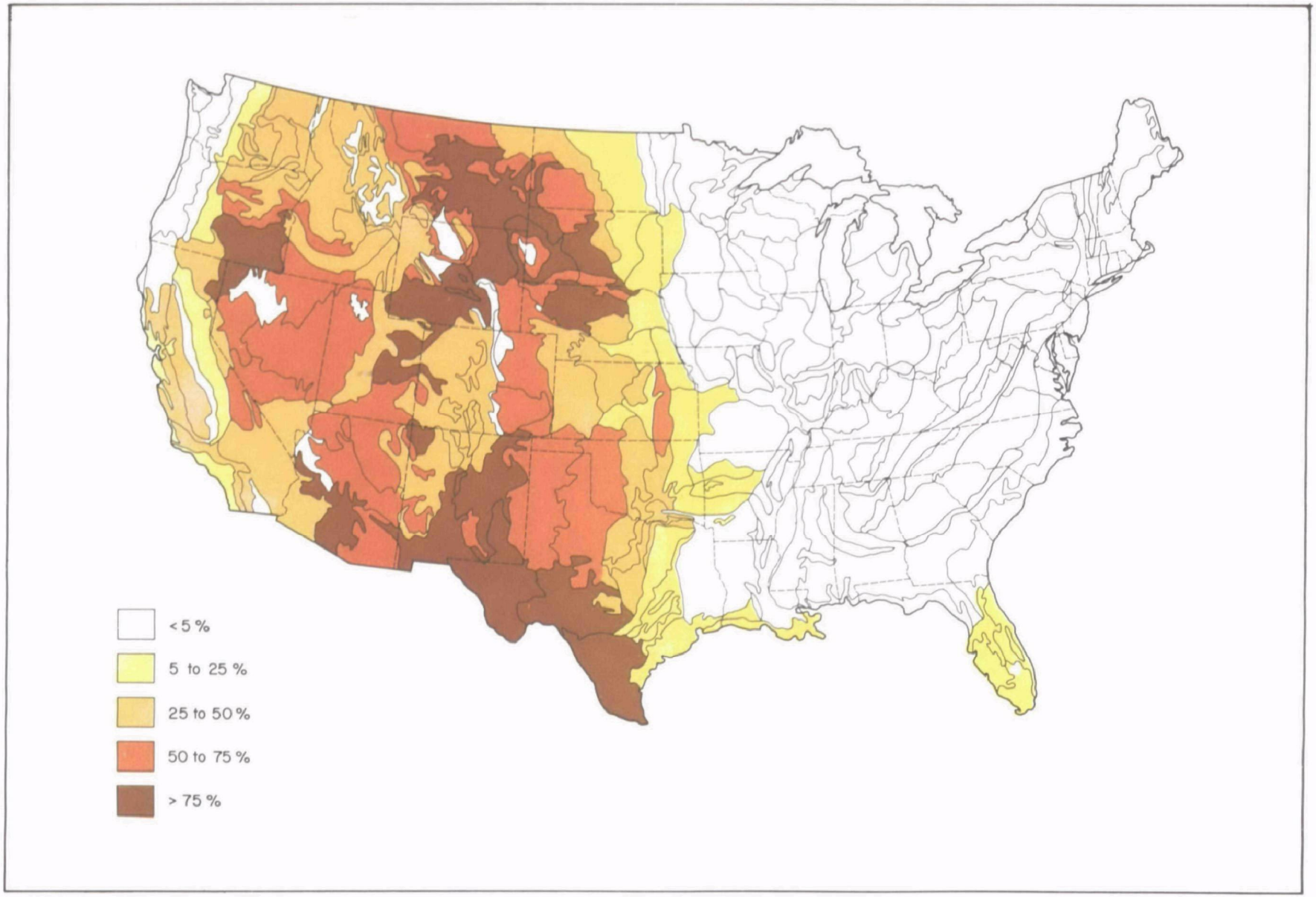


Figure 8.–Rangelands as percentages of total land resource areas.

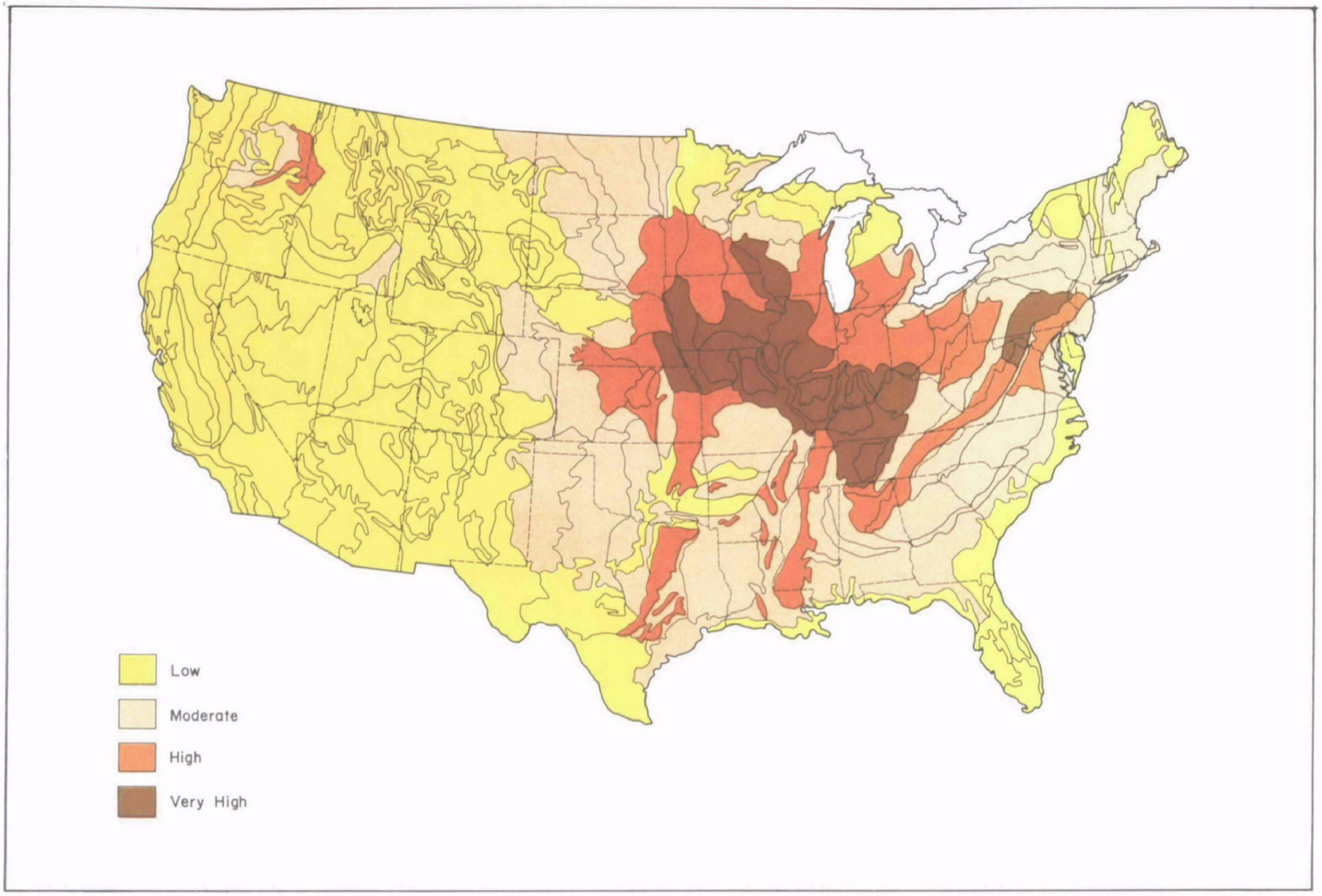


Figure 9.–Relative potential contribution of cropland to watershed sediment yields.

Figure 9 shows generalized regional differences in potential sediment from cropland erosion by water. An estimated erosion-potential index for each Land Resource Area (LRA) was multiplied by the percentage of the LRA in cropland. The erosion-potential index for an LRA was derived as the acreage-weighted average of indexes for all the respective land-use capability subclasses represented on the cropland. The index for each subclass was an estimate of the erosion that would occur on its predominant soil and slope if it were continuously in a row crop or grain-fallow system with no conservation practices. The map reflects differences in sediment-delivery ratios only to the extent that they may be reflected in the cropland densities. The objective was to show relative *potential;* actual erosion rates for relatively uniform areas can be computed by the Universal Soil Loss Equation, discussed later.

A first approximation of the cropland-sediment potential in a particular region or watershed can be obtained from Figure 9, and the problem can be further defined by reference to Figures 7 and 8. For example, if Figure 9 rates the area low but water quality samplings show excessive sediment in a stream, Figure 8 may suggest rangeland as the most likely source. If the area is also rated low in Figure 8, existence of one or more of the other special-problem areas listed in Table 1 would be suspected. A rating of moderate in Figure 9 with a relatively low percentage rating in Figure 7 would suggest that only a relatively small portion of the area needs attention but that treatment on that portion may need to be substantial. A moderate rating in Figure 9 with a high rating in Figure 7 would suggest widespread need of relatively simple control measures. A rating of high or very high in Figure 9 would indicate a more critical problem, but the comparisons with Figure 7 ratings would still help to define the problem more accurately with respect to its areal extent and complexity of likely treatment needs. However, high ratings in Figures 7 and 9 do not necessarily mean that agriculture is the source of the stream sediment. One or more of the nonagricultural situations listed in Table 1 may be the primary sediment source. Figure 9 shows *potential* hazard, not current practices. Adequate control practices may already exist on the problem cropland. The Soil and Water Conservation Districts or the Soil Conservation Service can supply data on how much of the potential problem acreage is already controlled under existing conservation plans.

An alternative procedure for appraising the cropland sediment hazard and treatment needs in a relatively homogeneous region is to apply the individual-field approach to a hypothetical field that is representative of the soil and topographic features of the cropland in the region. This approach utilizes the soil-loss prediction technique described below.

3.3b The Universal Soil Loss Equation (USLE)

The map in Figure 9 has serious limitations in that it does not reflect the large local differences in erosion hazard. Gross-erosion prediction and control planning can be much more accurate on a field basis. More than 40 years of erosion research by the U. S. Department of Agriculture in cooperation with state agricultural experiment stations has identified the major erosion factors and determined numerical relationships of these factors to soil loss rates. The USLE combines these factors and relationships to predict average annual soil losses from sheet and rill erosion by rainfall and its associated runoff on specific field slopes.

Basically, the USLE has no geographic bounds, but its application requires knowledge of the local values of its individual factors. Its applicability in some regions is presently limited by lack of research data from which to obtain factor evaluations that are truly representative of the climatic, physical and cultural conditions. In the factor definitions below, the most serious knowledge gaps are noted in parentheses. However, the available information is adequate for the equation to provide useful guides on most of our country's cropland.

The equation is:

$$A = R\,K\,LS\,C\,P$$

where A is the estimated average annual soil loss in tons per acre and the other terms are defined as follows:

R is the rainfall and runoff erosivity index. Its local value can generally be obtained by interpolating between the iso-value lines of Figures 10a and 10b. (Exceptions are the Coastal Plains of the Southeast and the area that is shaded in Figure 10a. R values presently used in the Coastal Plains do not exceed 350. In the shaded region of the Northwest, the map values must be increased to account for effect of runoff from thaw and snowmelt. Estimated adjustments for specific locations in the shaded region can be obtained from the Soil Conservation Service Regional Technical Center, Portland, Oregon. Research is needed to determine the effective R values in these two regions more accurately. For Hawaii, use Figure 10b.)

K is the soil-erodibility factor. It is the average soil loss per unit of R under arbitrarily selected "basic" conditions, and depends on soil properties. The value of K for most of the U.S. mainland soils can be obtained from Figure 11 if adequate soil survey information is available. Values for specific

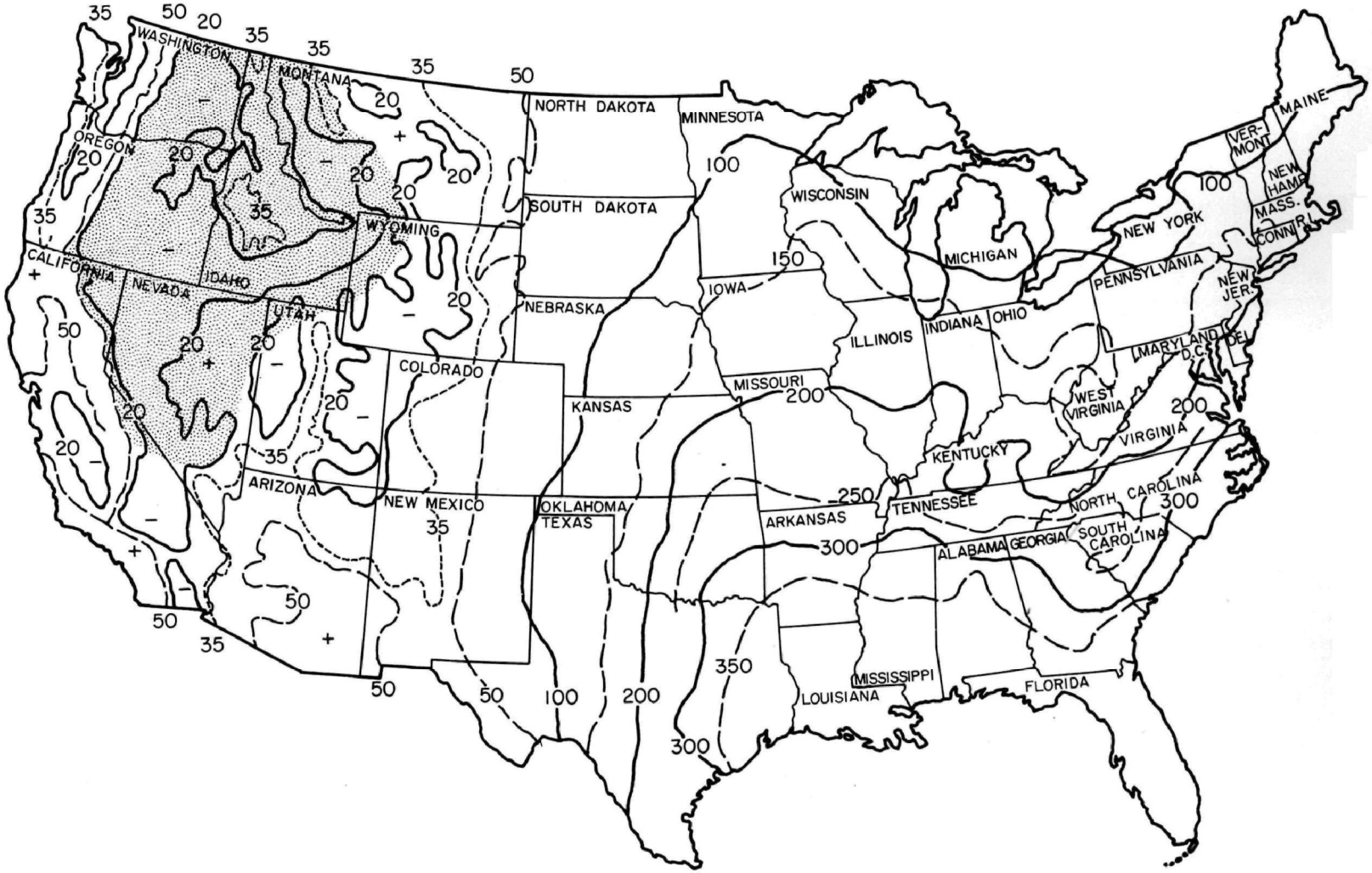


Figure 10a.—Average annual values of the rainfall-erosivity factor, R.

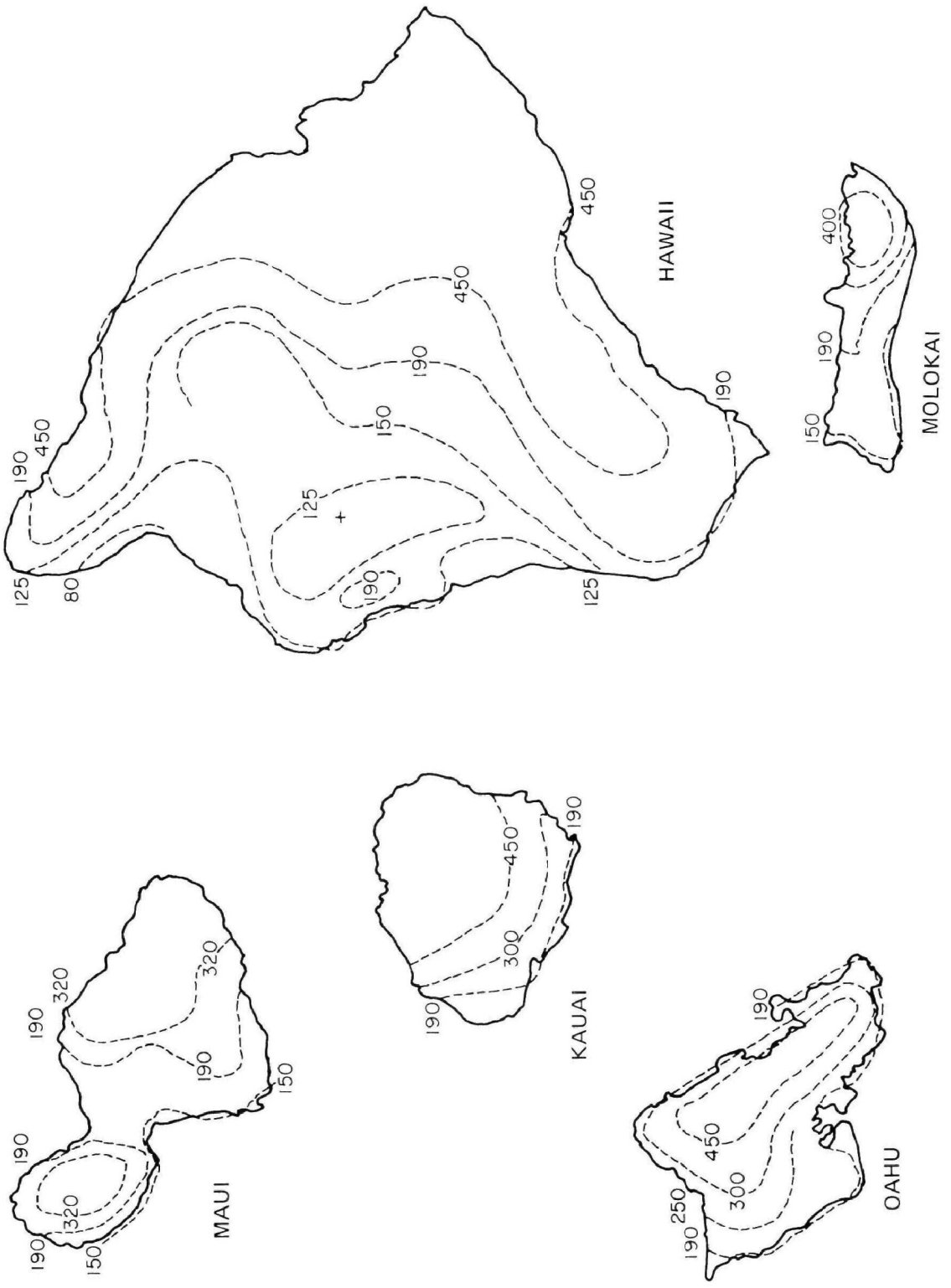


Figure 10b.- Estimated average annual values of the rainfall-erosivity factor, R, in Hawaii.

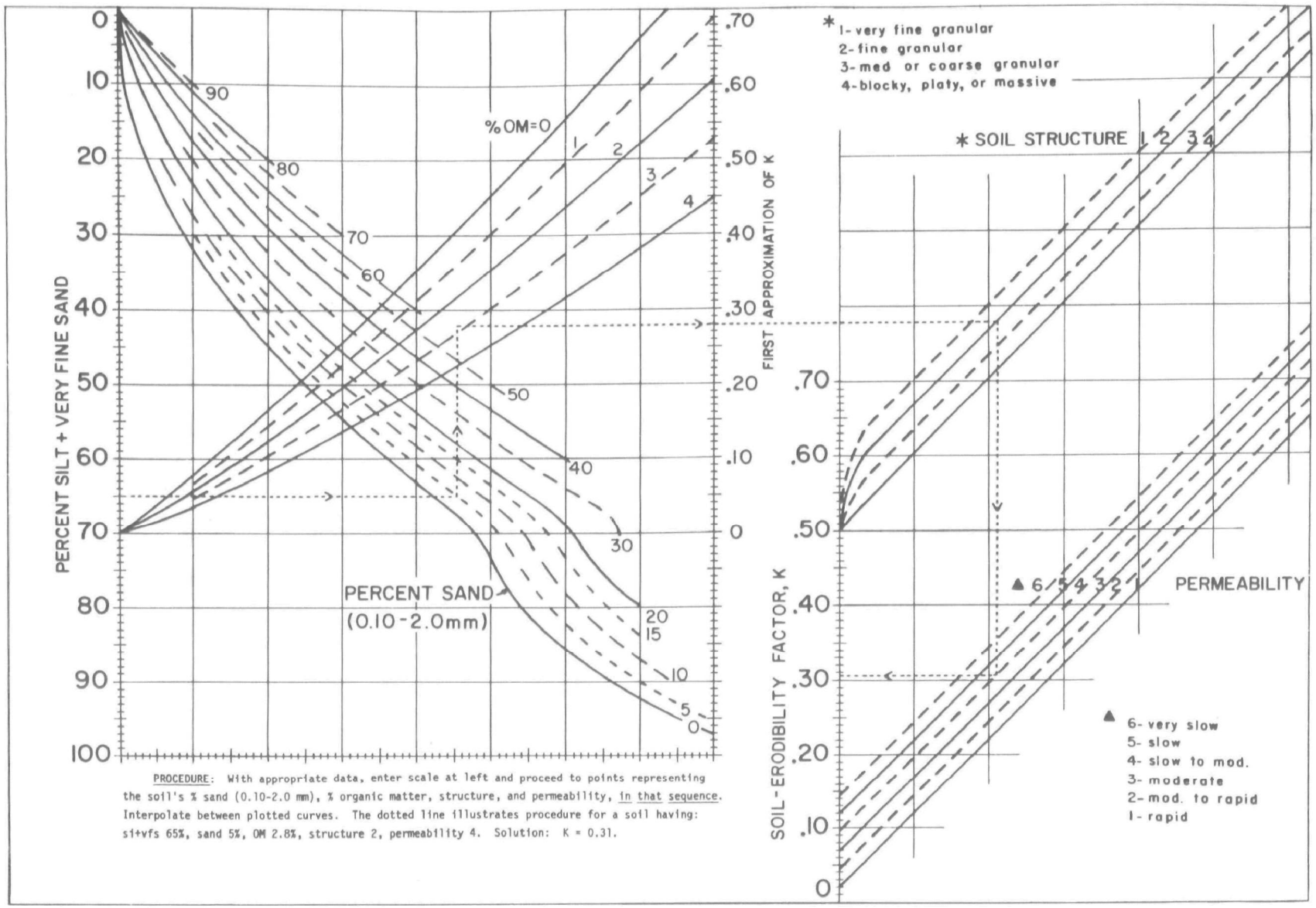


Figure 11.–Nomograph for determining soil-erodibility factor, K, for U.S. Mainland soils.

soils are also available from state and local offices of the Soil Conservation Service. Gross approximations based primarily on soil texture can be obtained from Table 2a. Values for ten benchmark soils in Hawaii are given in Table 2b. (Figure 11 is less accurate for high-clay subsoils and sandy loams than for the broad intermediate range of medium-textured soils.)

LS is a dimensionless topographic factor that represents the combined effects of slope length and steepness. Values of LS for uniform slopes are given in Table 3. (The relationships on which the table is based were derived from data taken on slopes no steeper than 18 percent and no longer than 300 feet. How much these dimensions can be exceeded before these relationships change has not been determined.)

C is the cover and management factor. C values range from 0.001 for well-managed woodland to 1.0 for tilled, continuous fallow. C for a given cropping and management system varies with rainfall distribution and planting dates. Generalized values for illustrative purposes are given in Table 4. Local values can be computed by a procedure published in Agriculture Handbook No. 282, or computed values may be obtained from the Soil Conservation Service.

P is the factor for *supporting* practices. Its value can be obtained from Table 5. With no support practices, P = 1.0.

Factors R, K, and LS are relatively fixed for a given location. Their product is the basic erosion-potential index, I, for the particular combination of rainfall pattern, soil properties and topographic features. This is the average annual soil loss that would occur without any vegetation or erosion-reducing practices. Multiplying this potential by appropriate values of factors C and P reduces it for effects of the cropping system, cultural management, and supporting control practices, so that the complete equation predicts average annual soil loss for specific cropland situations.

With the soil loss equation, estimating average annual erosion rates at a particular site is a routine procedure. Appropriate values of R, K, LS, C, and P are selected from the sources indicated above. The product of all five factors is the soil loss estimate for the cropping and management system represented by the selected C and P values.

The USLE can be very useful as a planning guide and is the most feasible method available for calculating sheet and rill erosion from specific land areas in most of the United States. However, soil losses computed by the equation must be accepted as *estimates* rather than as absolutes. Derivations of site values of the equation's five factors are based on relationships derived from the erosion research of the past 40 years. These relationships can, in specific situations, be significantly influenced by interactions with other variables. Local weaknesses in some of the primary factor values were pointed out above. Sediment from gullies and channel erosion is not included in USLE estimates.

The soil loss equation and supporting data tables were designed to predict *longtime average* losses for specific conditions. Specific-year losses may be substantially greater or smaller than the annual averages because of differences in the number, size and timing of erosive rainstorms and in other weather parameters. The fre-

Table 2a. Indications of the general magnitude of the soil-erodibility factor, K[1]

Texture class	Organic matter content		
	<0.5%	2%	4%
	K	K	K
Sand	0.05	0.03	0.02
Fine sand	.16	.14	.10
Very fine sand	.42	.36	.28
Loamy sand	.12	.10	.08
Loamy fine sand	.24	.20	.16
Loamy very fine sand	.44	.38	.30
Sandy loam	.27	.24	.19
Fine sandy loam	.35	.30	.24
Very fine sandy loam	.47	.41	.33
Loam	.38	.34	.29
Silt loam	.48	.42	.33
Silt	.60	.52	.42
Sandy clay loam	.27	.25	.21
Clay loam	.28	.25	.21
Silty clay loam	.37	.32	.26
Sandy clay	.14	.13	.12
Silty clay	.25	.23	.19
Clay		0.13-0.29	

[1] The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values. For specific soils, use of Figure 11 or Soil Conservation Service K-value tables will provide much greater accuracy.

quency distribution of the rainfall factor, R, differs by location, but the following generalities provide some indication of the magnitude of yearly variations in R value: less than average about 60 percent of the time; greater than average about 40 percent of the time; 10 percent probability of being 50 percent greater than average; 5 percent probability of being 75 percent greater than average. A single extreme runoff event shortly after crop seeding on clean-tilled seedbed could erode as much soil as the annual average for the rotation, but the probability of this is small.

3.3c Sediment Delivery Ratios

The soil loss equation computes gross sheet and rill erosion but does not directly predict downstream sediment yield. Sediment yield equals the gross erosion minus what is deposited enroute to the place of measurement. Materials derived from sheet and rill erosion often move only short distances and may lodge in areas remote from the stream system. They may remain in the same fields in which they originated or be deposited on more level slopes.

The sediment delivery ratio is defined as the ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point. Where this ratio is known or can be closely approximated from known parameters, the sediment yield is estimated by computing the gross erosion and multiplying it by the sediment delivery ratio. This method of computing sediment yields at points downstream has been used extensively and for many years by the Soil Conservation Service, particularly in the humid sections of the country.

Many factors influence the sediment delivery ratio. No general equation for watershed delivery ratios has been derived, but several observed relationships provide guidelines for approximating them.

Size of drainage area is an important factor, because the distance of sediment transport to downstream points is greater in the larger watersheds, and the opportunities

Table 2b. Soil erodibility (K) values for ten benchmark soils of Hawaii.

Order	Suborder	Great group	Subgroup	Family	Series	K
Ultisols	Humults	Tropohumults	Humoxic Tropohumults	Clayey, kaolinitic, isohyperthermic	Waikane	0.10
Oxisols	Torrox	Torrox	Typic Torrox	Clayey, kaolinitic, isohyperthermic	Molokai	.24
Oxisols	Ustox	Eutrustox	Tropeptic Eutrustox	Clayey, kaolinitic, isohyperthermic	Wahiawa	.17
Vertisols	Usterts	Chromusterts	Typic Chromusterts	Very fine, montmorillonitic, isohyperthermic	Lualualei	.28
Aridisols	Orthids	Camborthids	Ustollic Camborthids	Medial, isohyperthermic	Kawaihae (Extremely stony phase)	.32
Inceptisols	Andepts	Dystrandepts	Hydric Dystrandepts	Thixotropic, isothermic	Kukaiau	.17
Inceptisols	Andepts	Eutrandepts	Typic Eutrandepts	Medial, isohyperthermic	Naolehu (Variant)	.20
Inceptisols	Andepts	Eutrandepts	Entic Eutrandepts	Medial, Isohyperthermic	Pakini	.49
Inceptisols	Andepts	Hydrandepts	Typic Hydrandepts	Thixotropic, isohyperthermic	Hilo	.10
Inceptisols	Tropepts	Ustropepts	Vertic Ustropepts	Very fine, kaolinitic, isohyperthermic	Waipahu	.20

Table 3. Values of the erosion equation's topographic factor, LS, for specified combinations of slope length and steepness.[1]

% Slope	Slope length (feet)											
	25	50	75	100	150	200	300	400	500	600	800	1000
0.5	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17	0.19	0.20
1	0.09	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.22	0.24	0.26
2	0.13	0.16	0.19	0.20	0.23	0.25	0.28	0.31	0.33	0.34	0.38	0.40
3	0.19	0.23	0.26	0.29	0.33	0.35	0.40	0.44	0.47	0.49	0.54	0.57
4	0.23	0.30	0.36	0.40	0.47	0.53	0.62	0.70	0.76	0.82	0.92	1.0
5	0.27	0.38	0.46	0.54	0.66	0.76	0.93	1.1	1.2	1.3	1.5	1.7
6	0.34	0.48	0.58	0.67	0.82	0.95	1.2	1.4	1.5	1.7	1.9	2.1
8	0.50	0.70	0.86	0.99	1.2	1.4	1.7	2.0	2.2	2.4	2.8	3.1
10	0.69	0.97	1.2	1.4	1.7	1.9	2.4	2.7	3.1	3.4	3.9	4.3
12	0.90	1.3	1.6	1.8	2.2	2.6	3.1	3.6	4.0	4.4	5.1	5.7
14	1.2	1.6	2.0	2.3	2.8	3.3	4.0	4.6	5.1	5.6	6.5	7.3
16	1.4	2.0	2.5	2.8	3.5	4.0	4.9	5.7	6.4	7.0	8.0	9.0
18	1.7	2.4	3.0	3.4	4.2	4.9	6.0	6.9	7.7	8.4	9.7	11.0
20	2.0	2.9	3.5	4.1	5.0	5.8	7.1	8.2	9.1	10.0	12.0	13.0
25	3.0	4.2	5.1	5.9	7.2	8.3	10.0	12.0	13.0	14.0	17.0	19.0
30	4.0	5.6	6.9	8.0	9.7	11.0	14.0	16.0	18.0	20.0	23.0	25.0
40	6.3	9.0	11.0	13.0	16.0	18.0	22.0	25.0	28.0	31.0	--	--
50	8.9	13.0	15.0	18.0	22.0	25.0	31.0	--	--	--	--	--
60	12.0	16.0	20.0	23.0	28.0	--	--	--	--	--	--	--

[1] Values given for slopes longer than 300 feet or steeper than 18% are extrapolations beyond the range of the research data and, therefore, less certain than the others. Adjustments for irregularity of slope are discussed in Volume II.

for deposition enroute are more numerous. The sediment discharged to large rivers is usually less than one-fourth of that eroded from the land surface. Sediment delivery ratios vary widely for any given size of drainage area, but limited data have shown that, roughly, they vary inversely as the 0.2 power of drainage area. Rough estimates of delivery ratios can be made from the following tabulation:

Drainage Area (Square Miles)	Sediment Delivery Ratio
0.5	0.33
1	.30
5	.22
10	.18
50	.12
100	.10
200	.08

However, the above estimates should be tempered with judgment and consideration of other factors, such as texture, relief, type of erosion, the sediment transport systems, and areas of deposition within the watershed. For example, when the eroding soil is very high in silt or clay, the delivery ratio will be higher than indicated in the tabulation; when the texture is coarse, it will be lower. A transport system with a high channel density generally has a high delivery ratio. The condition of the channels (whether clogged or open, meandering or straight) influences velocity and consequently the delivery ratio. High stream gradients are generally associated with steep slopes and high relief and provide efficient transport of eroded material. The opposite is true for low stream gradients.

The shape of the land surface is an inherent feature of the physiographic region in which the watershed is located. High relief is often indicative of high sediment delivery ratios. The relief/length ratio apparently has a substantial effect on the delivery ratio. The relief is the difference between the average elevation of the watershed divide at the headwaters of the main stem drainage and the elevation of the streambed at the point of sediment yield measurement. Length is the maximum valley length, measured essentially parallel to the main

Table 4. Generalized values of the cover and management factor, C, in the 37 states east of the Rocky Mountains.[1]

Line no.	Crop, rotation, and management[3]	Productivity level[2]	
		High	Mod.
		C value	
Base value: continuous fallow, tilled up and down slope		1.00	1.00
CORN			
1	C, RdR, fall TP, conv (1)	0.54	0.62
2	C, RdR, spring TP, conv (1)	.50	.59
3	C, RdL, fall TP, conv (1)	.42	.52
4	C, RdR, wc seeding, spring TP, conv (1)	.40	.49
5	C, RdL, standing, spring TP, conv (1)	.38	.48
6	C, fall shred stalks, spring TP, conv (1)	.35	.44
7	C(silage)-W(RdL, fall TP) (2)	.31	.35
8	C, RdL, fall chisel, spring disk, 40-30% rc (1)	.24	.30
9	C(silage), W wc seeding, no-till pl in c-k W (1)	.20	.24
10	C(RdL)-W(RdL, spring TP) (2)	.20	.28
11	C, fall shred stalks, chisel pl, 40-30% rc (1)	.19	.26
12	C-C-C-W-M, RdL, TP for C, disk for W (5)	.17	.23
13	C, RdL, strip till row zones, 55-40% rc (1)	.16	.24
14	C-C-C-W-M-M, RdL, TP for C, disk for W (6)	.14	.20
15	C-C-W-M, RdL, TP for C, disk for W (4)	.12	.17
16	C, fall shred, no-till pl, 70-50% rc (1)	.11	.18
17	C-C-W-M-M, RdL, TP for C, disk for W (5)	.087	.14
18	C-C-C-W-M, RdL, no-till pl 2d & 3rd C (5)	.076	.13
19	C-C-W-M, RdL, no-till pl 2d C (4)	.068	.11
20	C, no-till pl in c-k wheat, 90-70% rc (1)	.062	.14
21	C-C-C-W-M-M, no-till pl 2d & 3rd C (6)	.061	.11
22	C-W-M, RdL, TP for C, disk for W (3)	.055	.095
23	C-C-W-M-M, RdL, no-till pl 2d C (5)	.051	.094
24	C-W-M-M, RdL, TP for C, disk for W (4)	.039	.074
25	C-W-M-M-M, RdL, TP for C, disk for W (5)	.032	.061
26	C, no-till pl in c-k sod, 95-80% rc (1)	.017	.053
COTTON[4]			
27	Cot, conv (Western Plains) (1)	0.42	0.49
28	Cot, conv (South) (1)	.34	.40
MEADOW			
29	Grass & Legume mix	0.004	0.01
30	Alfalfa, lespedeza or Sericia	.020	
31	Sweet clover	.025	
SORGHUM, GRAIN (Western Plains)[4]			
32	RdL, spring TP, conv (1)	0.43	0.53
33	No-till pl in shredded 70-50% rc	.11	.18

Table 4. Generalized values of the cover and management factor, C, in the 37 states east of the Rocky Mountains.[1] —Continued

Line no.	Crop, rotation, and management[3]	Productivity level[2]	
		High	Mod.
		C value	
SOYBEANS[4]			
34	B, RdL, spring TP, conv (1)	0.48	0.54
35	C-B, TP annually, conv (2)	.43	.51
36	B, no-till pl	.22	.28
37	C-B, no-till pl, fall shred C stalks (2)	.18	.22
WHEAT			
38	W-F, fall TP after W (2)	0.38	
39	W-F, stubble mulch, 500 lbs rc (2)	.32	
40	W-F, stubble mulch, 1000 lbs rc (2)	.21	
41	Spring W, RdL, Sept TP, conv (N & S Dak) (1)	.23	
42	Winter W, RdL, Aug TP, conv (Kans) (1)	.19	
43	Spring W, stubble mulch, 750 lbs rc (1)	.15	
44	Spring W, stubble mulch, 1250 lbs rc (1)	.12	
45	Winter W, stubble mulch, 750 lbs rc (1)	.11	
46	Winter W, stubble mulch, 1250 lbs rc (1)	.10	
47	W-M, conv (2)	.054	
48	W-M-M, conv (3)	.026	
49	W-M-M-M, conv (4)	.021	

[1] This table is for illustrative purposes only and is not a complete list of cropping systems or potential practices. Values of C differ with rainfall pattern and planting dates. These generalized values show approximately the relative erosion-reducing effectiveness of various crop systems, but locationally derived C values should be used for conservation planning at the field level. Tables of local values are available from the Soil Conservation Service.

[2] High level is exemplified by long-term yield averages greater than 75 bu. corn or 3 tons grass-and-legume hay; or cotton management that regularly provides good stands and growth.

[3] Numbers in parentheses indicate number of years in the rotation cycle. No. (1) designates a continuous one-crop system.

[4] Grain sorghum, soybeans, or cotton may be substituted for corn in lines 12, 14, 15, 17-19, 21-25 to estimate C values for sod-based rotations.

Abbreviations defined:

B - soybeans
C - corn
c-k - chemically killed
conv - conventional
cot - cotton
F - fallow
M - grass & legume hay
pl - plant
W - wheat
wc - winter cover

lbs rc - pounds of crop residue per acre remaining on surface after new crop seeding
% rc - percentage of soil surface covered by residue mulch after new crop seeding
70-50% rc - 70% cover for C values in first column; 50% for second column
RdR - residues (corn stover, straw, etc.) removed or burned
RdL - all residues left on field (on surface or incorporated)
TP - turn plowed (upper 5 or more inches of soil inverted, covering residues)

stem drainage from the watershed divide to the point of yield measurement.

The sediment delivery ratio is usually based on total erosion in the drainage area. This includes channel-type erosion (gullies, valley trenches, streambank erosion, etc.) along with sheet and rill erosion. Gross erosion computations by the soil loss equation do not include channel-type erosion, and this must be computed separately if total sediment yield is desired. The delivery ratios may differ significantly for the sediments from the two types of sources. Channel erosion produces sediment that is immediately available to the transport system, and much of it tends to remain in motion as bedload and suspended sediment. A substantial reduction in the amount of sediment delivered to a stream may sometimes result in a compensatory increase in channel erosion. However, the composition of sediment derived from channel erosion will usually differ substantially from that derived from sheet and rill erosion on cropland.

Settling basins, sediment traps, and vegetative filter strips across the lower end of a slope trap sediments near their origin, but their effect will not be reflected in the sediment delivery ratios tabulated above. Therefore, the portion of the sediment that is trapped by these devices should be deducted from the computed field erosion before applying the delivery ratio. Strip crop data indicate that a 100- to 125-ft. wide filter strip of good sod across the slope should filter about 75 percent of the sediment from normal field runoff on moderate slopes. With a properly designed terrace system, less than 20 percent of the soil eroded from the between-terrace areas is transported completely off the field. The trap efficiencies of settling basins and sediment traps vary with design and location.

3.4 ESTIMATING POTENTIAL PERCOLATION

Water that infiltrates the soil and percolates below the root zone will eventually reach the water table and may carry soluble agricultural chemicals to a well or to a surface stream as groundwater runoff. The amount and frequency of deep percolation depend on the precipitation characteristics, the evapotranspiration potential, the vegetative cover, the soil water storage characteristics in the root zone, the soil and geologic conditions below the root zone, and the amount and timing of direct runoff.

Potential percolation is defined here as the *annual* amount of water that would percolate below the root zone in a field of corn planted in straight rows.

Potential percolation was simulated for each of the four hydrologic soil groups for a 20- to 25-year period using precipitation data for 52 meteorological stations in the contiguous United States. Available water-holding capacity (the difference between field capacity and the wilting point) in the root zone was estimated for the predominant agricultural soils in each Land Resource Area. The root-zone depth was taken as 4 feet for most of the Land Resource Areas. Lesser depths were used in some instances, based on the characteristics of the predominant agricultural soils. Direct runoff was estimated as described in Section 3.2. Potential evapotranspiration estimates were based on smoothed average daily pan evaporation data multiplied by a pan coefficient. The mean annual potential percolation is shown in five classes by Land Resource Areas in Figure 12. Most of the Western United States was omitted for the reasons mentioned in Section 3.2. Mountains, forested, and swamp areas were also omitted because they include insignificant cropland. A detailed description of the procedures used in the simulation, maps of potential percolation for combinations of hydrologic soil groups and available water-holding capacities, and a discussion of the errors involved are given in Appendix B, Volume II.

The potential percolation estimates shown in Figure 12 are based on the assumptions that the soils are uniform with depth and are well-drained. Planting and harvesting dates used were the most likely for the location. Subsurface drainage would not change the model assumptions appreciably unless the effective root zone was significantly different from that used in the simulation. *Because of departures from these assumptions and local differences in soil characteristics, actual percolation losses will vary substantially within Land Resource Areas.* However, Figure 12 should provide a reasonable *ordering* of regions with respect to their potential for leaching of *soluble* agricultural chemicals.

Percolation will be higher than the potential percolation as defined above if the crop being grown has a shallower root system than corn or if the actively transpiring canopy is present for a shorter time. The potential percolation shown in Figure 12 will be an overestimate for poorly drained soils.

More detailed maps of potential percolation could be prepared on a state or watershed basis by using soil survey maps and detailed data on water-holding characteristics of soils included in the descriptions of soil series. These data are available for many states from the Soil Conservation Service or the state agricultural experiment stations.

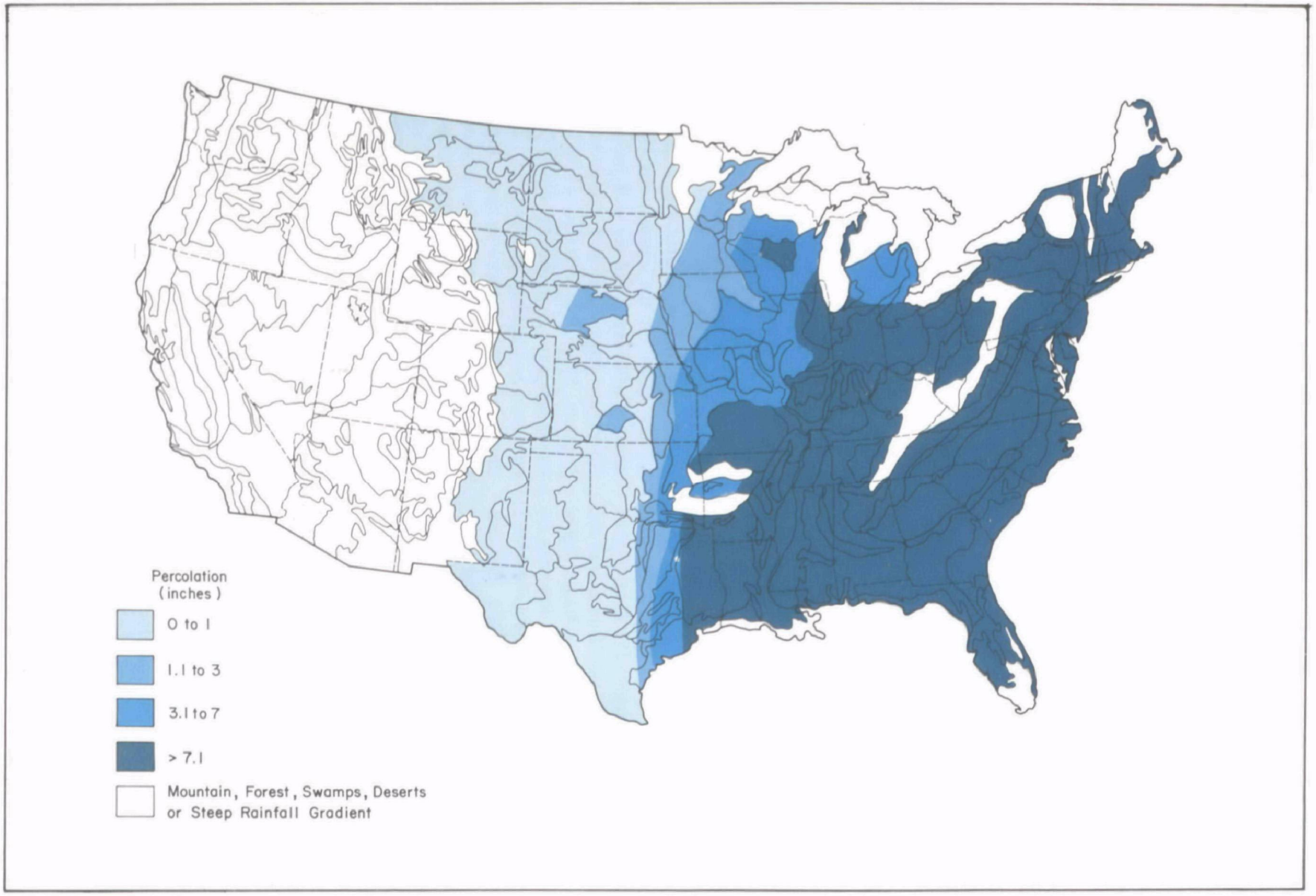


Figure 12.—Average annual potential percolation.

Table 5. Values of support-practice factor, P.

Practice	Land slope (percent)				
	1.1-2	2.1-7	7.1-12	12.1-18	18.1-24
	(Factor P)				
Contouring (P_c)	0.60	0.50	0.60	0.80	0.90
Contour strip cropping (P_{sc})					
R-R-M-M[1]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting (P_{cl})	0.30	0.25	0.30	0.40	0.45
Contour terracing (P_t)[2]	[3] $0.6/\sqrt{n}$	$0.5/\sqrt{n}$	$0.6/\sqrt{n}$	$0.8/\sqrt{n}$	$0.9/\sqrt{n}$
No support practice	1.0	1.0	1.0	1.0	1.0

[1] R = rowcrop, W = fall-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that rowcrop strips are always separated by a meadow or winter-grain strip.

[2] These P_t values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, the P_t values are multiplied by 0.2.

[3] n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

3.5 LOCATION OF CROPLAND AND MAJOR CROP AREAS

Knowledge of the extent of cropland and the types of crops grown in an area is essential to the identification of potential sources of pollutants from agriculture, because the soil management systems employed and the agricultural chemicals used are dictated by the cropping pattern. The information presented in this section will help to define those areas requiring particular attention.

The contiguous 48 states contain 1.9 billion acres of land, of which approximately 24% is cropland. Figure 6 shows the geographical distribution of cropland as a percentage of the Land Resource Areas. Figures 13 through 19 show the distribution of acreages for corn, sorghum, wheat, cotton, soybeans, orchards, and vegetables. These particular crops are shown because of their importance from the standpoint of acreage, chemical use, or both. Although the acreage has increased for many crops since these figures were compiled, it is believed that the geographical distribution has changed only slightly. More detailed information for smaller areas can be obtained from state offices of the Agricultural Stabilization and Conservation Service, Soil Conservation Service, or other agencies. Comparison of the information shown in these figures with that shown in the Land Resource Area maps (Figures 3 and 4 for direct runoff, Figure 9 for erosion, and Figure 12 for percolation) will provide a clear indication of both the potential problem areas and those areas where agricultural runoff and percolation should be of little concern.

3.6 USE OF PLANT NUTRIENTS ON CROPLAND

3.6a Fertilizers

The use of chemical fertilizers to supplement the nutrients supplied by the soil has long been recognized as necessary in most soils for optimizing crop yields and plant quality, and reducing erosion by increasing vegetative cover. Limiting fertilizer to less than optimum rates would require additional cropland to maintain production and this land would be poorer and may be more erodible. Fertilizers containing the plant nutrients nitrogen (N), phosphorus (P), and potassium (K) are now used abundantly on the commercial crops of the United States. The nutrients N and P are of most concern with respect to water pollution. Numerous other chemicals are applied in fertilizer either as impurities or for specific nutritional problems. At present there

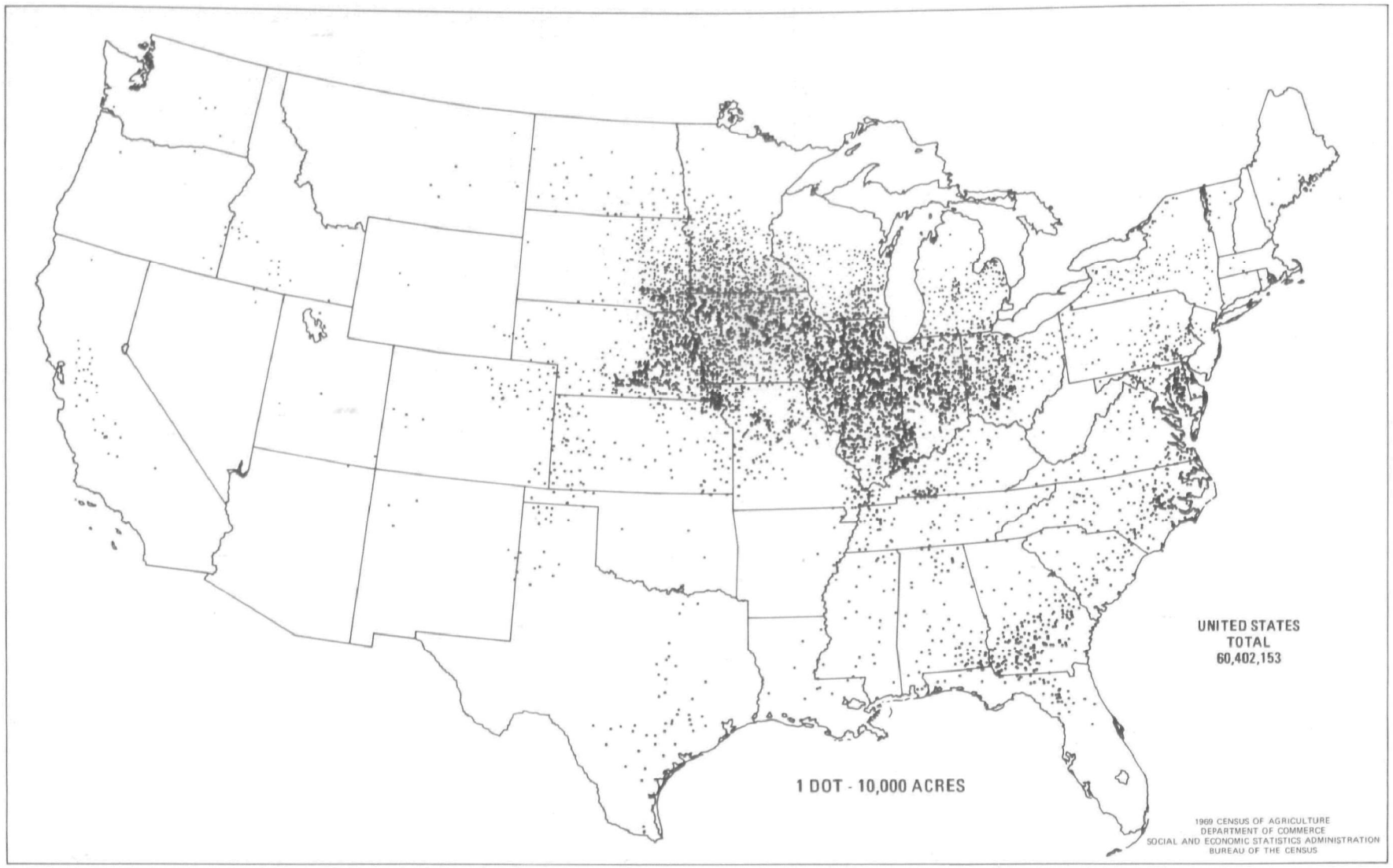


Figure 13.–Corn harvested for all purposes.

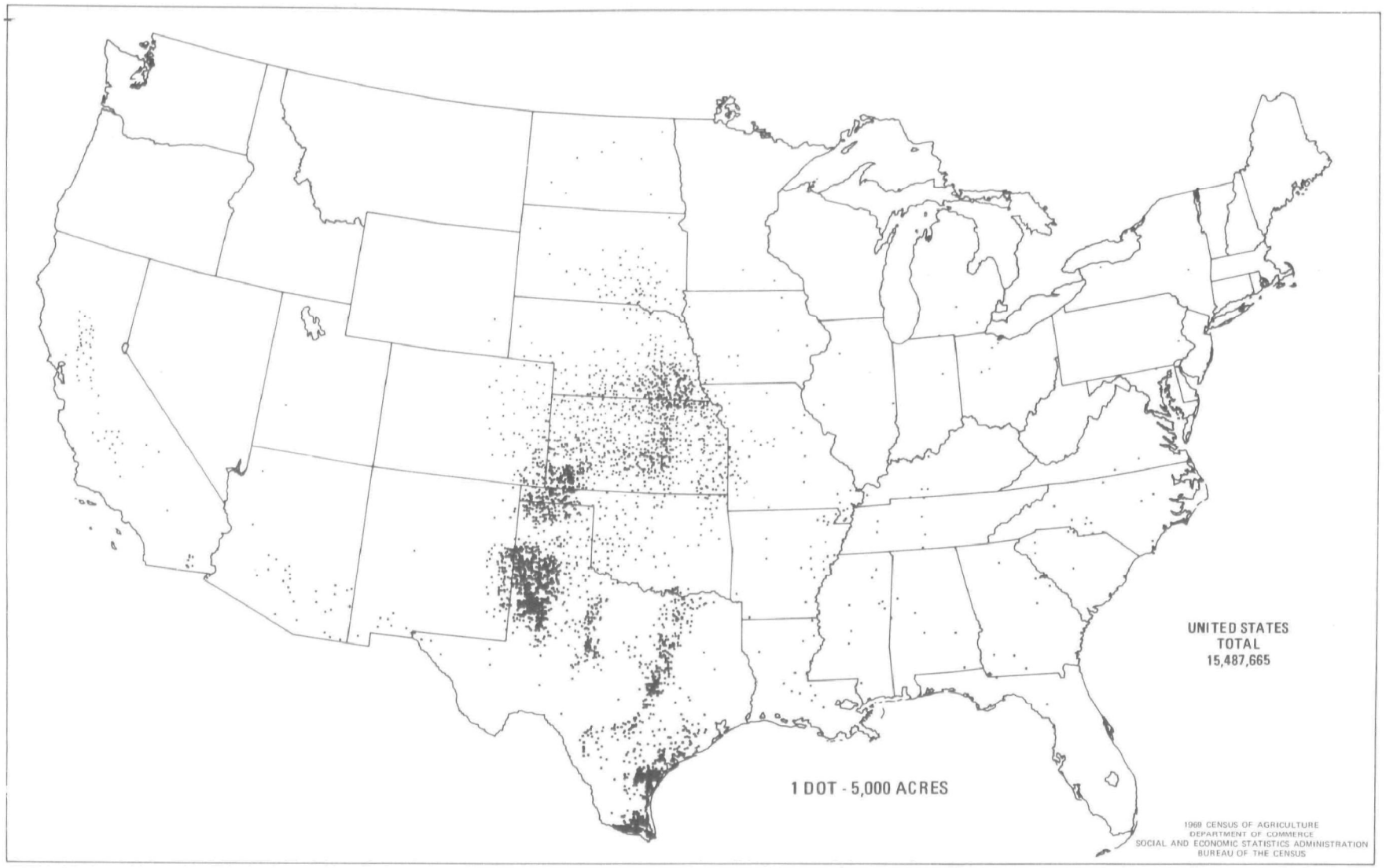


Figure 14.–Sorghums harvested for all purposes except sirup.

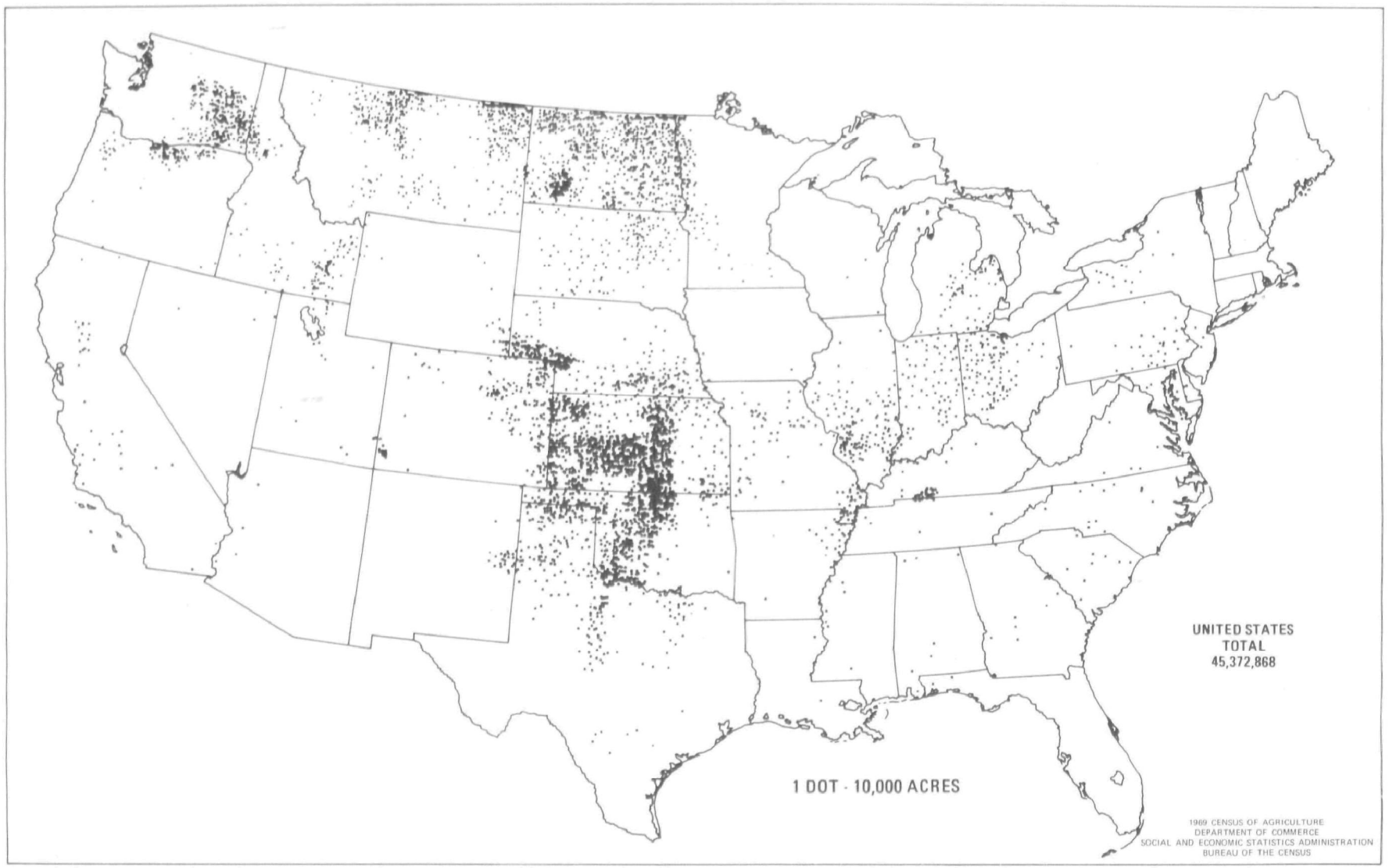


Figure 15.–Wheat harvested.

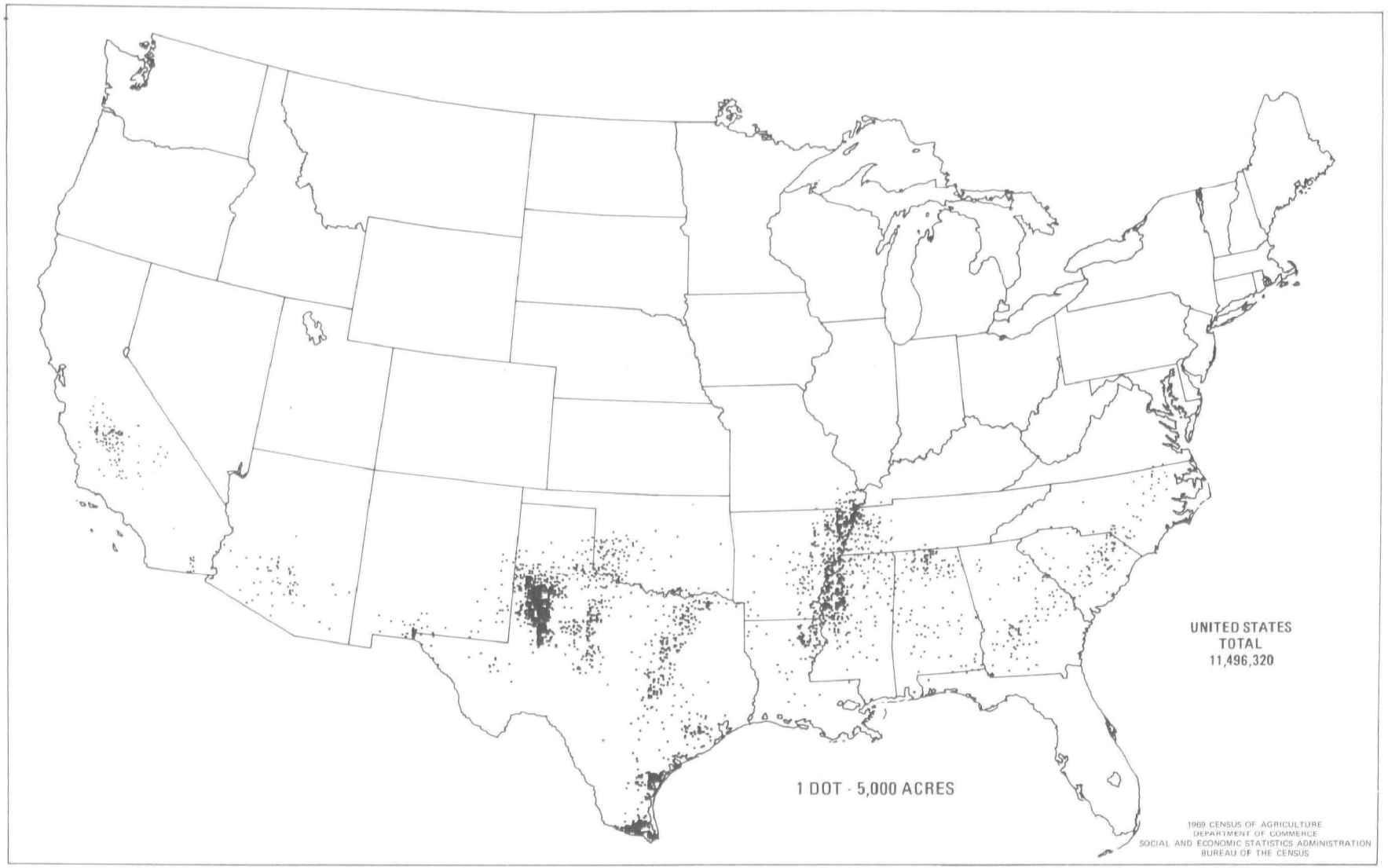


Figure 16.–Cotton harvested.

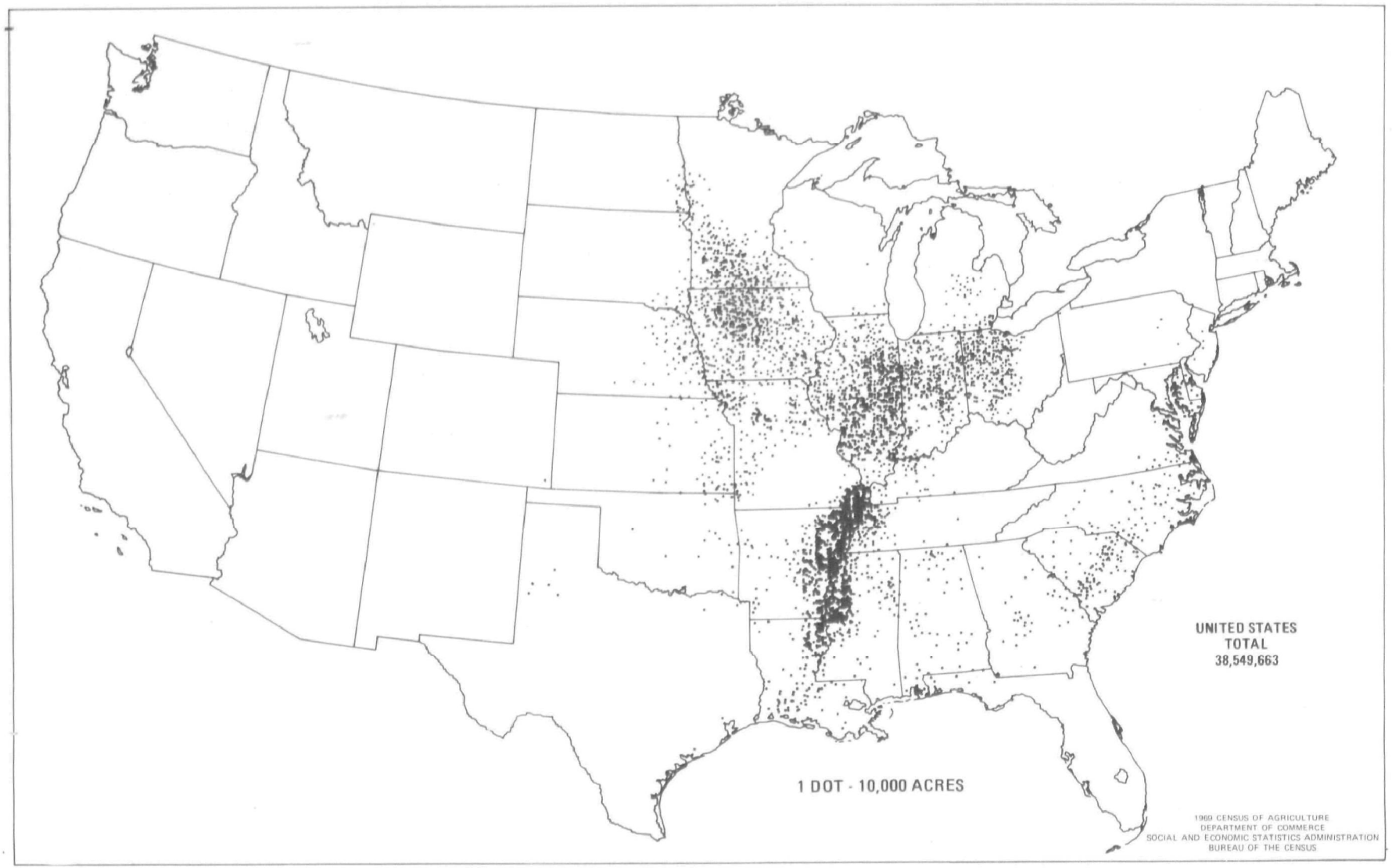


Figure 17.–Soybeans harvested for beans.

Figure 18.–Land in orchards.

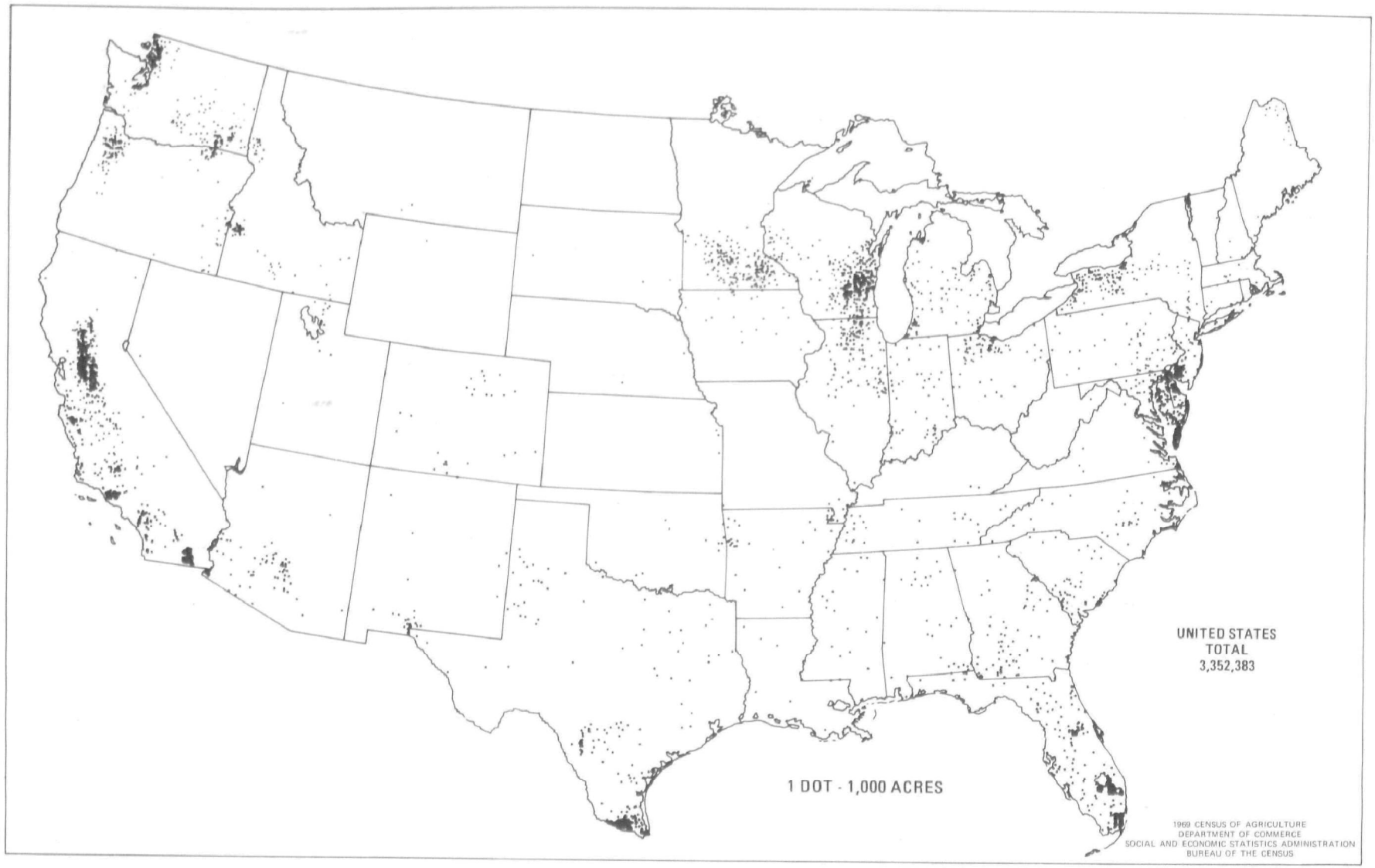


Figure 19.—Vegetables harvested for sale.

is no indication that these other chemicals will ever pose a significant problem. Although high concentrations of nitrate-nitrogen in drinking water may be toxic to animals and humans, the usual problem is one of increasing the N and P contents of impounded water. This can result in accelerated eutrophication. Eutrophication refers to natural or artificial addition of nutrients to bodies of water and to the effects of added nutrients.

The potential for pollution from fertilizers will generally be highest where large acreages are treated with high rates of fertilizers. Large acreages treated with low rates of fertilizers or small acreages treated with high rates will usually not have a significant effect on navigable waters, although they might be of concern under localized conditions. Table 6 gives the percentage of the acreage in different crops that is fertilized and the average rate of fertilization. These values, however, are national averages and more detailed data should be obtained for assessing specific areas. Nevertheless, combining this kind of information with maps showing the distribution of the different crops, such as Figures 13 to 19, will help define potential problem areas. For example, the states of Nevada, Utah, and Wyoming have relatively little land in crops or orchards and, thus, pollution from fertilizer would only be a problem in localized areas, if at all. Another example is the wheat areas such as in Montana and North Dakota. A smaller percentage of wheat land is fertilized, particularly in drier areas, and the rates applied to wheat are usually only about half or less of those commonly applied to corn or cotton. Consequently, extensive potential fertilizer pollution problems are less likely in these areas than in areas where corn and cotton are the major crops.

Nutrients can be applied singly or in combinations. Some examples of common fertilizers that contain a single nutrient or two nutrients are given in Table 7 with the percent of nutrient in each. In addition to these materials, superphosphate can be ammoniated to produce fertilizers with a range of nitrogen and phosphorus contents. Several materials can be mixed or blended together to produce a great variety of nutrient contents. Granulated mixes have uniform granules with good physical properties and nearly the same amount of each nutrient in each pellet. Bulk blends are simple physical mixes that are not as homogenous as granulated mixes but may be cheaper. Fertilizers containing various nutrient contents can also be prepared as liquids, suspensions, or slurries. If the fluid fertilizer contains any free ammonia, it must be handled under pressure and injected into the soil in a manner similar to anhydrous ammonia.

Table 7. Plant-available nutrients in common fertilizers.

	Nutrient Content
Nitrogen	
Anhydrous Ammonia	82% N
Urea	45% N
Ammonium Nitrate	33.5% N
Liquid Nitrogen Solution	28-38% N
Ammonium Sulfate	21% N
Calcium Cyanamide	21% N
Calcium Nitrate	16% N
Sodium Nitrate	16% N
Urea-Formaldehyde	38% N
Phosphorus	
Rock Phosphate	2% P
Normal Superphosphate	9% P
Concentrated Superphosphate	21% P
Phosphoric Acid	23% P
Potassium	
Muriate of Potash (KCl)	51% K
Potassium Sulfate (K_2SO_4)	43% K
Sulfate of Potash-Magnesia	19% K
Multinutrient	
Monoammonium Phosphates	11-16% N, 8-20% P
Diammonium Phosphates	16-18% N, 20% P
Ammonium Polyphosphates	10-15% N, 14-30% P
Potassium Nitrate	13% N, 37% K

Table 6. Acres receiving fertilizer and average fertilizer rates of four crops in the United States in 1974.

Crop	Acres harvested (million)	Percent fertilized		Pounds/acre rate	
		N	P	N	P
Corn	63.7	94	87	103	27
Cotton	13.1	79	58	78	23
Soybeans	52.5	22	28	15	18
Wheat	64.1	66	46	46	17

States have laws requiring that all fertilizer sold must meet certain requirements, be registered with a state agency, and be properly labeled. The label is usually required to carry a statement of the net weight, brand, grade, guaranteed analysis, and name and address of the registrant. The grade is a series of three numbers giving the percent of elemental nitrogen (N), available phosphorus (P_2O_5) and soluble potash (K_2O) in that order. Some states are changing from the oxide basis (P_2O_5 and K_2O) to an elemental basis (P and K). The available phosphorus is usually measured by citrate solubility. The percentages given in Table 7 are for available P, but with the exception of rock phosphate, the total is only 1 or 2 percent higher than the citrate-soluble amount. Rock phosphate has about 14 percent total P. The percent of the citrate-soluble P that is water-soluble ranges from 85 to 100. All the potassium carriers listed are completely water-soluble.

The importance of water solubility of phosphate fertilizers has been controversial. Highly water-soluble materials are important for starter fertilizers, for short-season, fast-growing crops, and when the fertilizer is applied in bands or rows. When the fertilizer is broadcast, or applied to long-season crops, acid soils, or high-phosphorus soils, the source material is less important. Rock phosphate is very insoluble and too slowly available for most crops.

The nitrate in the fertilizers moves with water and is easily leached, whereas the ammonium is adsorbed to the soil and not easily leached. Urea is converted to ammonium in a few days while the conversion of cyanamid takes longer. Urea-formaldehyde provides a slow release of nitrogen over the growing season.

Farmers may purchase a mixed fertilizer that contains more of one nutrient than recommended because it is cheaper or the desired ratio of nutrients is not available. This can lead to some degree of overfertilization. The excess nutrients will usually be P and K since the amounts of N required usually predominate. Some crops, particularly vegetables, may require special fertilization practices. Rice is the only major crop that has a special requirement, and that is the use of an ammonium or ammonium-producing compound under the flooded conditions.

Many forms of nitrogen are added to the soil. Once applied, this nitrogen, as well as other forms of nitrogen in the soil, is subject to many microbial transformation processes and the basic transport processes–direct runoff, erosion, and percolation. Leaching, the transport of soluble salts by percolating water, can carry nitrate-nitrogen vertically through the soil profile to ground water and laterally downhill where it may emerge to join the soluble nitrogen in the direct runoff. How long it takes to travel the subsurface route depends on the length of the path and on the amount of water available for movement. Nitrogen in an organic form is associated with the soil particles and is moved by erosion. Nitrate can be produced in water bodies by microbes decomposing organic matter, nitrifying ammonium, and indirectly from nitrogen fixed by algae. Nitrate, ammonium, and phosphate occur in precipitation. The phosphate concentrations are usually quite low while the nitrogen concentrations are often higher than those in runoff water from unfertilized land. Sources of these nutrients in the precipitation are principally industrial centers, power plants, animal feed lots, etc.

A fundamental consideration before controls can be applied is the *identification of the primary transport processes* operating in the system. Conditions conducive to each of the transport processes can be defined. For example, the potential for nitrogen leaching is high whenever percolating water and nitrate-nitrogen exist simultaneously. Percolation increases with increasing permeability and decreases with increasing water-holding capacity of the soil. Generally, sandy soils are the most permeable and have the lowest water-holding capacity, loams are intermediate, and clays have the lowest permeability and highest water-holding capacity. As mentioned, nitrate must be present for nitrogen leaching to occur. Nitrate is not adsorbed by the soil and can, consequently, be moved. Ammonium adsorbs on clay particles and is not subject to leaching. However, microorganisms can convert ammonium ions to nitrate.

The potential for transport of N and P in overland flow obviously is high when fertilizers are applied to *sloping lands and left on the surface*. This is not a normal practice on cultivated land; farmers conventionally plow down surface-applied fertilizers or inject anhydrous ammonia beneath the surface. With no-till practices, fall-sowed small grains, or on rough hay or pasture lands, however, applied fertilizers are often left on the surface. Thus, nutrients may move in direct runoff if they are not leached into the soil. Another source of nutrients in overland flow is the leaching by water of both dead and live plant tissues on the surface. This is most noticeable with no-plow practices where plant residues are left on the surface to reduce sediment movement. Concentrations of soluble nutrients in the runoff water are increased, but the total transport of N and P is probably lower than from bare soil because sediment loss and, usually, the amount of runoff are less.

Nitrogen transport by erosion is expected when the surface soil has a high organic matter content, because organic nitrogen is the principal form of nitrogen in

sediment. The nitrogen in organic matter in surface soils generally ranges from 0.07 to 0.3 percent. The organic matter content of soils varies with climate and management. Cultivation and warm temperature accelerate the decomposition of organic matter and dry climates limit the production of vegetative material, which replenishes the organic matter.

The eroded material usually has a higher organic matter content than the original soil because organic matter particles are lighter than most mineral particles and tend to remain in suspension. Also, the silt and clay particles are more erodible and are higher in organic matter content than sand particles. The nutrient content of sediment is generally about 50 percent higher than that of the soil, but values as high as fivefold are not unknown. As a result of this enriching process, a reduction in erosion may not give a proportional reduction in nitrogen transport, because the coarser particles are more easily controlled than the finer particles. However, over a large watershed there are other erosion processes in addition to surface erosion. Sediments from gully and bank erosion, which are low in organic matter content, tend to lower the average organic matter composition of the eroded material. The ultimate composition of the sediment is, therefore, modified by two opposing processes.

Phosphorus moves primarily by erosion because phosphate adsorbs strongly on soil particles, although some soluble phosphorus compounds do move in runoff water. The total P content of soils ranges from 0.01 to 0.13 percent. The P content of surface soils reflects farm management, while that of subsoils is a result of geologic conditions. Fertilizer phosphorus applied in soluble orthophosphate form soon converts to insoluble forms in the soil. This conversion prevents leaching and permits a buildup of phosphorus in the plow layer. As with nitrogen, the P concentration is higher in sediment than in the original soil, because phosphorus is associated with the finer particles. Thus, reducing the sediment transport may not reduce the phosphorus transport proportionately. Sediments from gully and bank erosion may reduce the phosphate concentration in solution as a result of their high phosphate adsorption capacities. Only a small part of the N and P moved with the sediment is immediately available to aquatic organisms. Another part can slowly become available through biophysiochemical reactions.

3.6b Animal Wastes

Animal wastes are applied to agricultural lands both to improve soil fertility and structure and to dispose of the wastes. Before supplies of synthetic nitrogen fertilizers became readily available, manure was a major source of nitrogen for crop production. Today, commercial fertilizer is the major source of nitrogen, supplying over 9 million tons. Manure furnishes about 1.2 million tons and legumes about 2 million tons. Manure increases the organic matter content of the soils, which increases the infiltration capacity and, thus, reduces runoff and erosion.

The pollution potential from using manure with poor management can be substantially higher than that from using commercial fertilizers, because nearly all manure is spread on the soil surface and can contain large amounts of soluble carbon, nitrogen, and phosphorus compounds. These constituents can be easily lost if runoff occurs before the manure is incorporated in the soil. Also, it is difficult to adequately determine the amount of nitrogen added in the waste and the rate at which the nitrogen will become available for plant uptake. Consequently, too much manure may sometimes be applied, resulting in nitrate leaching.

Animal wastes are usually applied within a few miles of their production site. The principal sources of manure are confined beef and dairy cattle, swine, and poultry. Figures 20, 21, 22, 23, and 24 show the geographical distribution of these sources and the estimated amounts of manure available for application to land in various locations. These estimates, however, should be considered only as a first approximation and should be refined for smaller areas with more recent and detailed information. These maps can be used in conjunction with the maps presented previously to estimate pollution potential from direct runoff and leaching. For example, application of dairy wastes (Figure 21) to Land Resource Area (LRA) 104 (Figure 2) with an annual mean direct runoff of 3 to 5 inches (Figure 3) will have a higher pollution potential than applying beef cattle waste (Figure 20) to LRA 77 (Figure 2) with a mean annual direct runoff of less than 1 inch (Figure 3). The *pollution potential* from animal wastes is *greatest* when manure is spread on snow or frozen ground. Because the simulation procedure used to estimate potential direct runoff did not account for frozen ground, Figures 25 and 26 are helpful in determining whether or not the application of manure on frozen ground is a potential problem. Figure 25 shows the average annual snowfall and some indication of the snowmelt potential. Figure 26 shows the mean depth of frost penetration and in conjunction with Figure 25 indicates the potential for snowmelt runoff on frozen ground. These maps indicate that the pollution potential from applying manure on land during the winter would not be high in LRA 77 but could be in LRA 104.

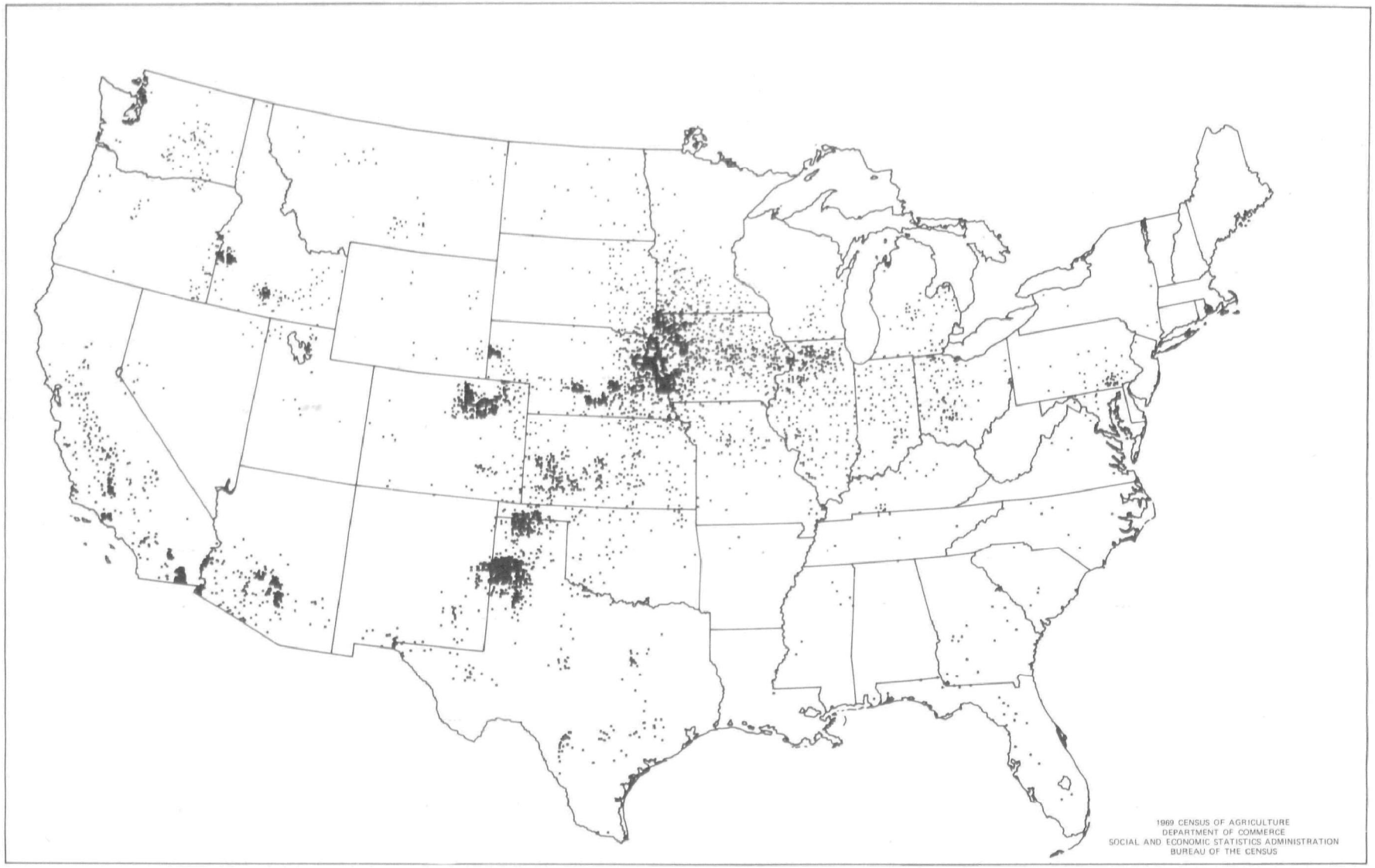


Figure 20.–Cattle Fattened on Grain and Sold for Slaughter. (The U.S. total is about 23 million, representing about 13 million tons per year of manure (dry weight) containing 330 thousand tons of N and 100 thousand tons of P. Each dot represents 5 thousand head and about 2800 tons per year of manure.)

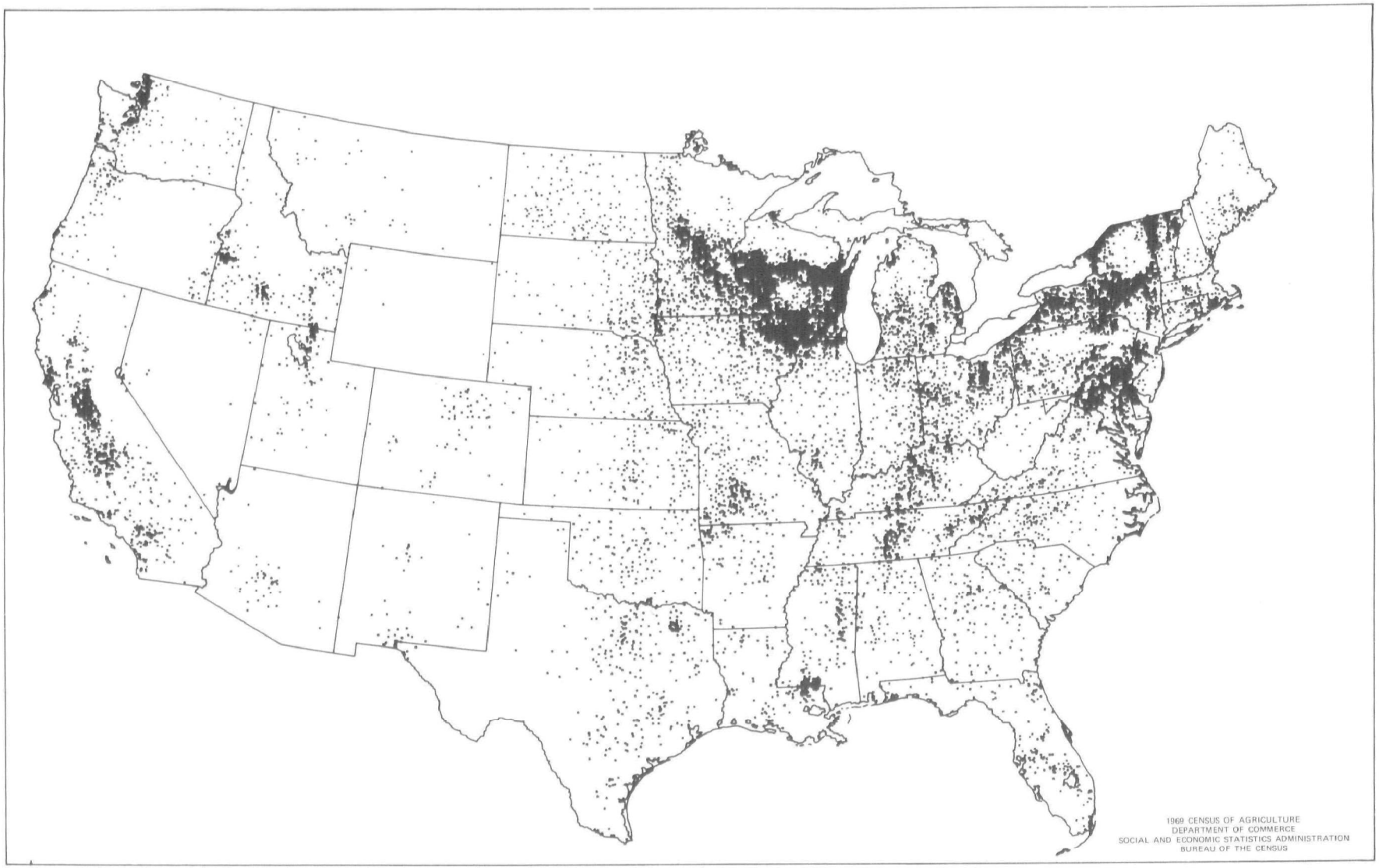


Figure 21.–Milk Cows. (The U.S. total is about 11 million, representing about 17 million tons per year of manure (dry weight) containing 330 thousand tons of N and 100 thousand tons of P. Each dot represents 1 thousand milk cows and about 16 hundred tons per year of manure.)

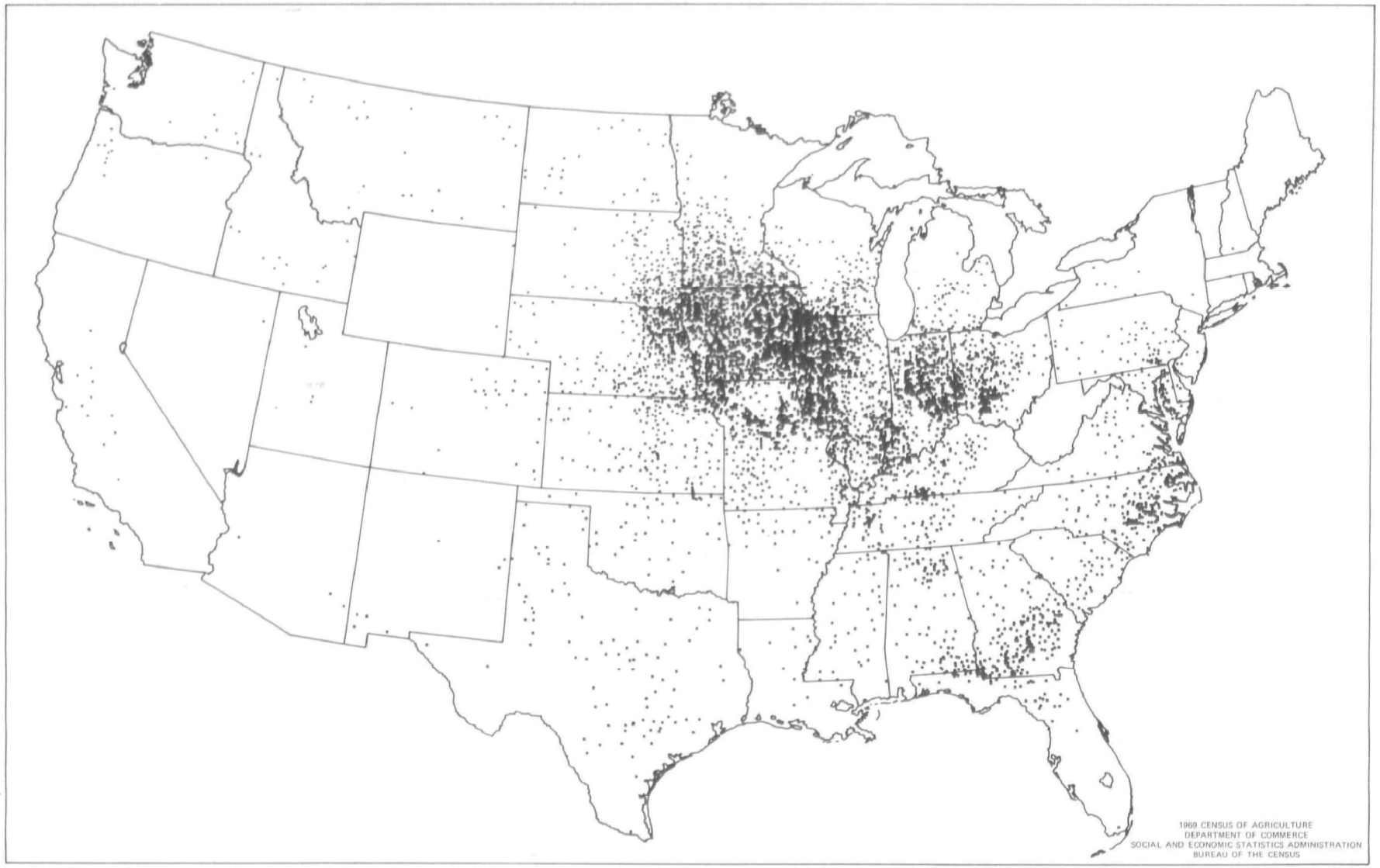


Figure 22.–Hogs and Pigs. (The U.S. total is about 55 million, representing about 11 million tons per year of manure (dry weight) containing 300 thousand tons of N and 110 thousand tons of P. Each dot represents 10 thousand hogs and about 2 thousand tons per year of manure.)

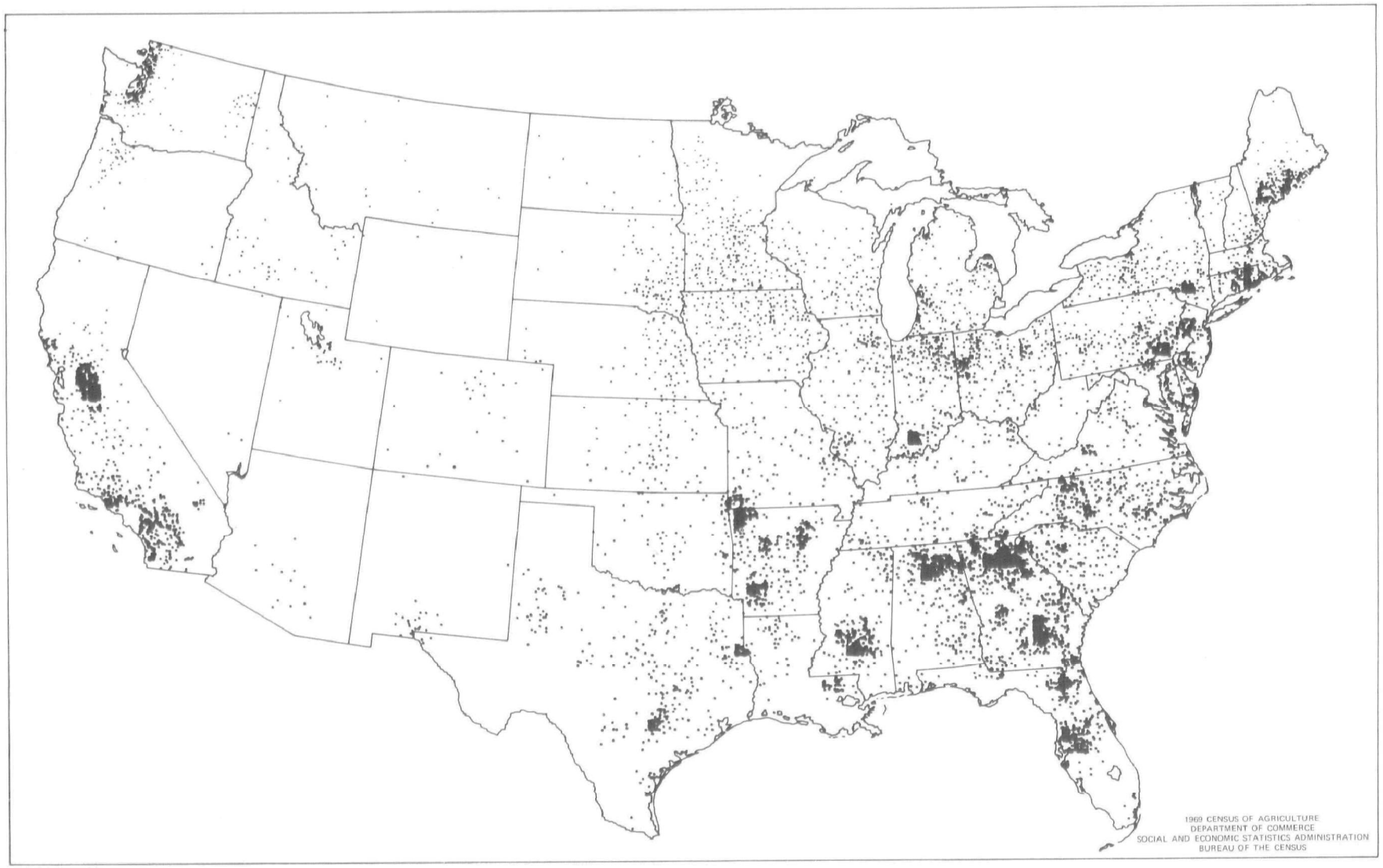


Figure 23.–Chickens 3 Months Old or Older. (The U.S. total is about 370 million, representing about 2.8 million tons per year of manure (dry weight) containing 125 thousand tons of N and 50 thousand tons of P. Each dot represents 50 thousand chickens and about 400 tons of manure.)

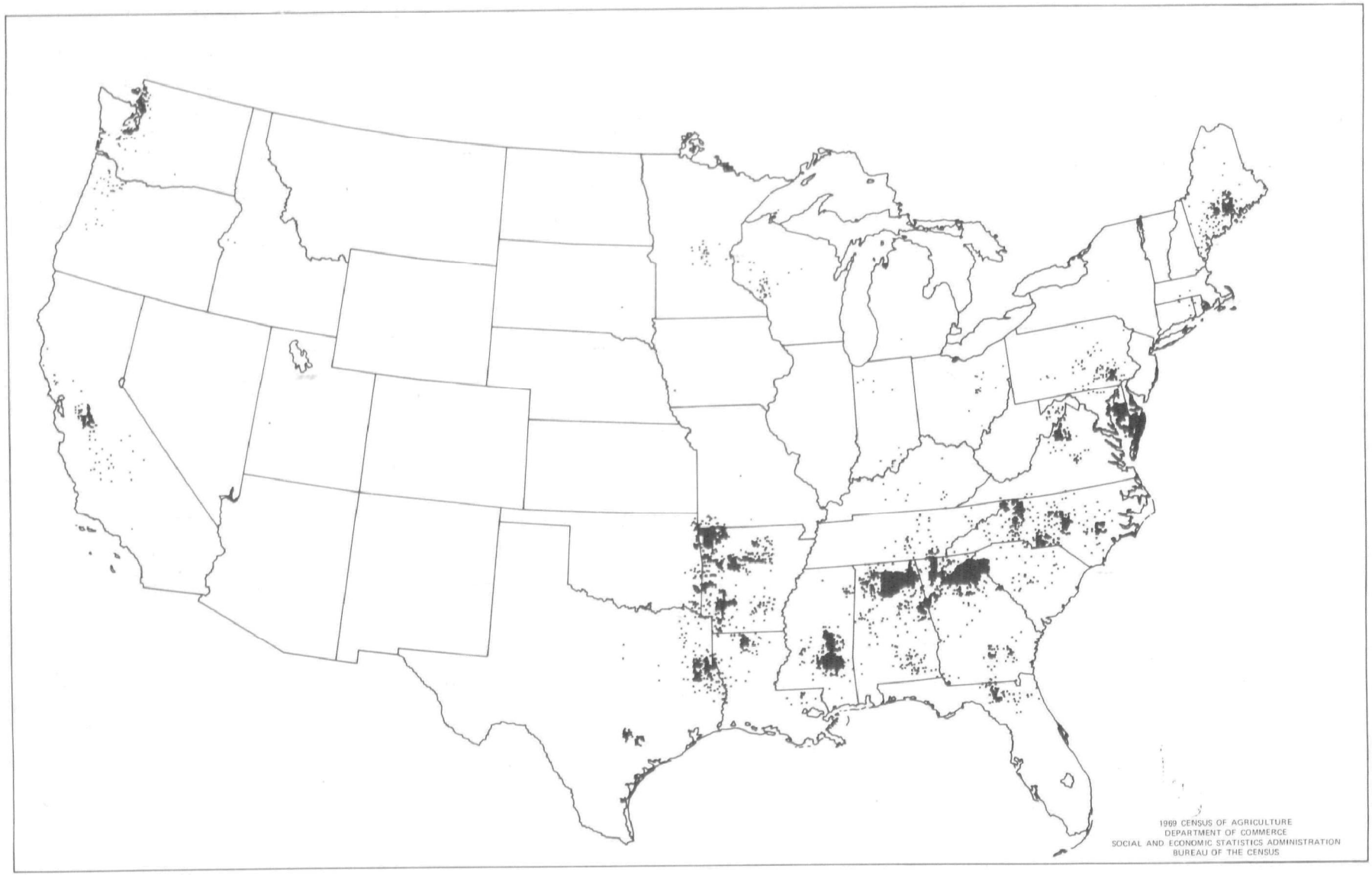


Figure 24.–Broilers and Other Meat-Type Chickens. (The total sold annually in the U.S. exceeds 2.5 billion, representing about 3.2 million tons per year of manure (dry weight) containing 120 thousand tons of N and 40 thousand tons of P. Each dot represents 500 thousand chickens and about 650 tons of manure.)

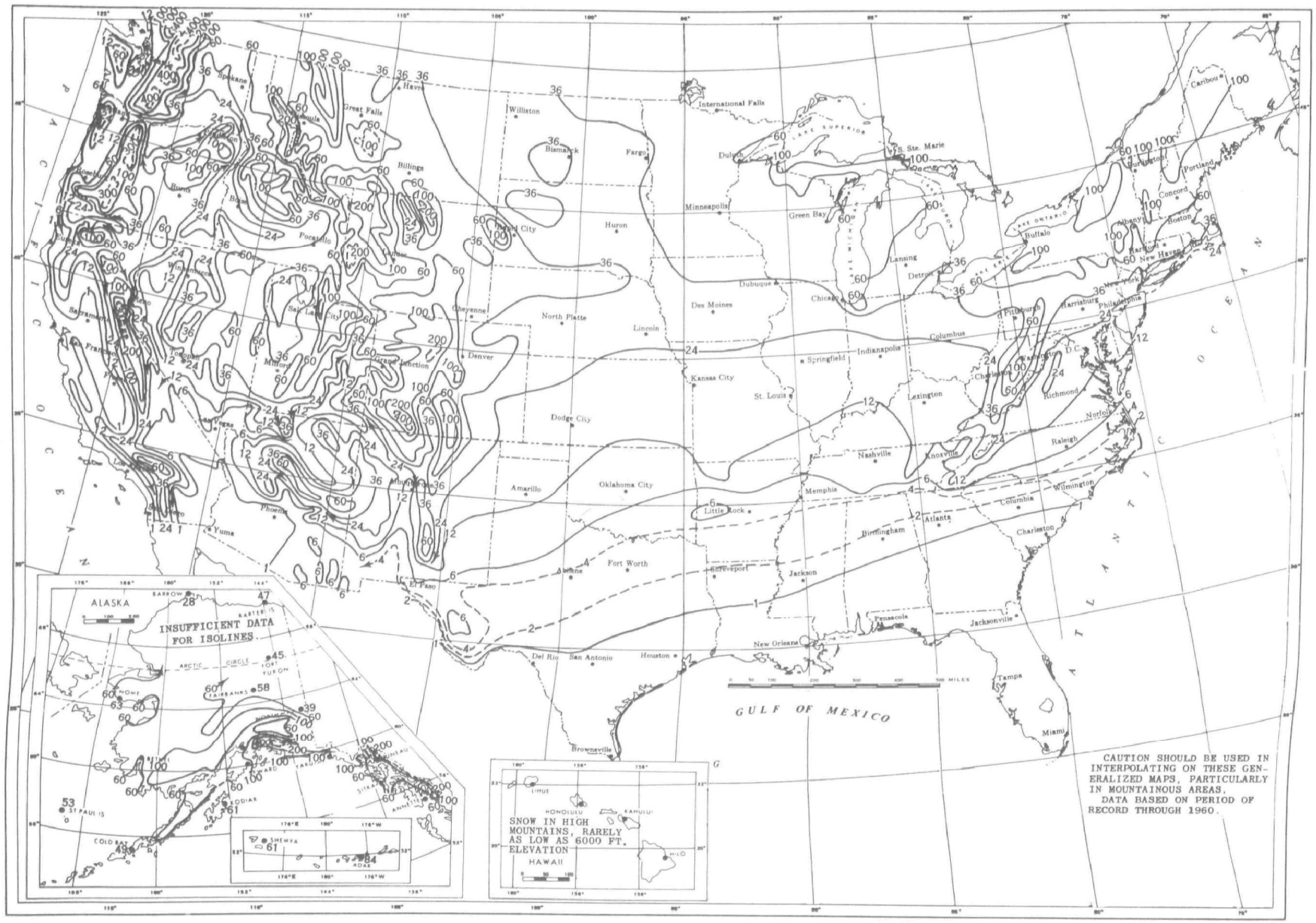


Figure 25.—Mean annual total snowfall, inches.

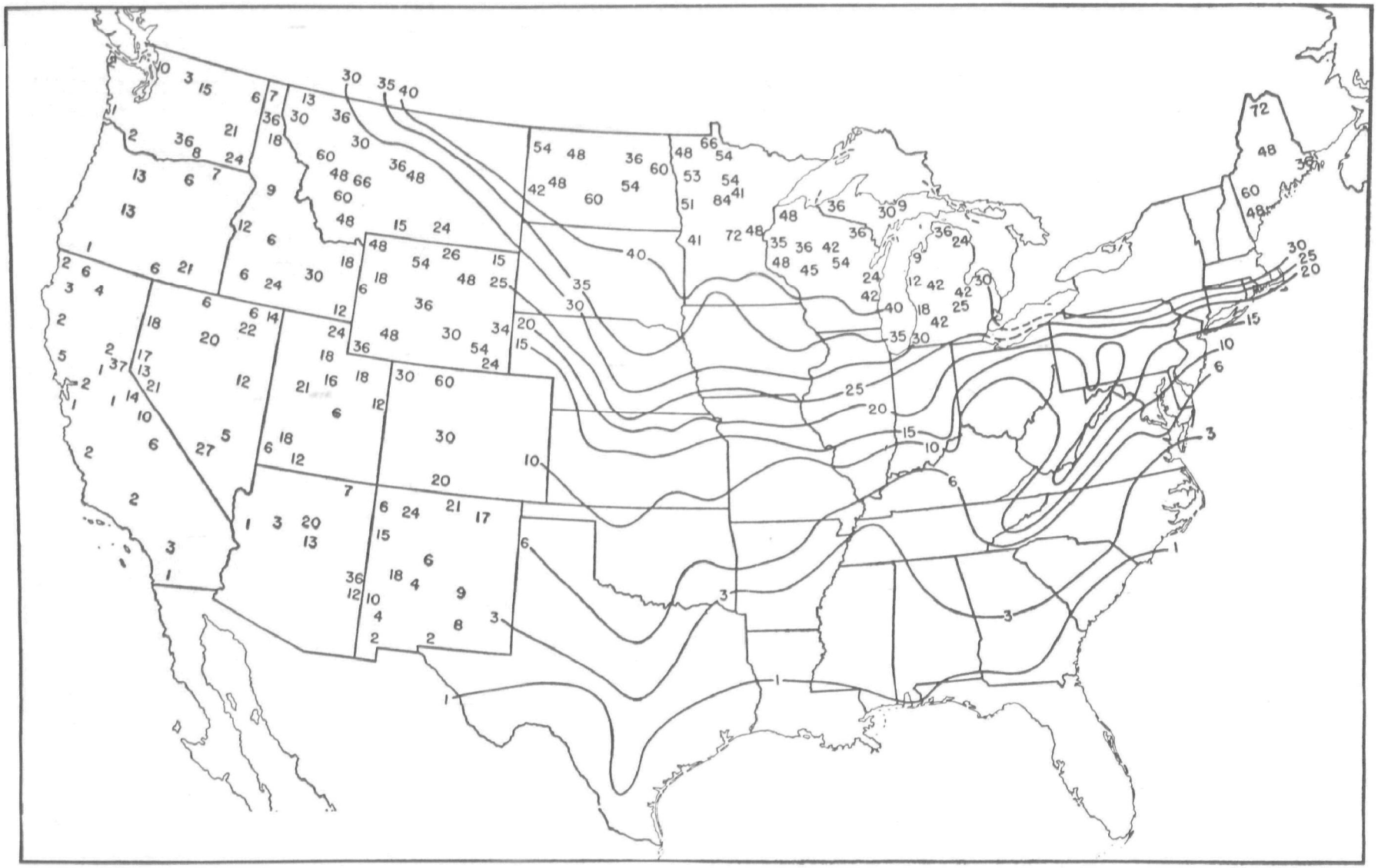


Figure 26.–Depth of frost pentration, inches.

3.7 USE OF PESTICIDES ON CROPLAND

The use of chemicals to control crop pests has increased sharply in the last three decades and is still rising, particularly that of herbicides. From 1964 to 1969, the acreage of U. S. cropland treated for weed control increased by more than 42 percent, and the acreage treated for insect control increased more than 22 percent. In 1971, over 158 million acres of land were treated with herbicides, 65 million with insecticides, and almost 7.5 million with fungicides (some receiving more than one type of chemical). These represent 41, 17, and 2 percent of the nonpasture cropland, respectively. The distribution of treated cropland acreage as of 1969 is shown in Figure 27 for herbicides and in Figure 28 for insecticides. These distributions probably have changed little in the intervening years. Juxtaposition of the chemical treatment maps with the Land Resource Area maps for direct runoff (Figures 3 and 4) or erosion (Figure 9) will help pinpoint potential areas of concern with respect to environmental pollution by pesticides transported off the treated fields in runoff water and sediment.

Many investigations of losses of various agricultural pesticides in runoff from treated land have been reported. *Nearly all lead to the same general conclusion: except when heavy rainfall occurs shortly after treatment, concentrations are very low and the total amount of pesticide that runs off the land during the crop year is less, often much less, than 5 percent of the application.* Nevertheless, some chemicals are highly toxic to fish or other aquatic fauna and can persist in the aquatic environment for a long time, so that even very low levels of these pesticides in runoff may be of environmental concern. *On the other hand, many agricultural chemicals are not acutely toxic to animal life, do not persist from one crop season to the next, and do not accumulate in food chain organisms; they may, consequently, be used at normal application rates without fear of causing unacceptable environmental damage.*

Herbicides, insecticides, and fungicides commonly used on cropland are listed in Tables 8a, 9a, and 10a, respectively, along with certain properties of each chemical that relate to pollution in runoff. The more widely used trade names of the pesticides are given, along with corresponding common names of the primary listing, in Tables 8b, 9b, and 10b. Table 11 lists the pesticides that may be used on the major crops of the United States without geographic restriction. Other pesticides are also registered, but may be used only in specific areas of the country. The Cooperative Extension Service of each state can supply the complete list of pesticides registered for each locality. In addition to the name of the pesticide, each registration specifies the dosage, residue tolerances, formulations, and use limitations and may include the name of the pest or pests to be controlled. All registrations are listed in the "EPA Compendium of Registered Pesticides," which may be purchased from the Superintendent of Documents, U.S. Government Printing Office.

The predominant transport mode, which indicates the partitioning of the compound between water and soil, is important in the movement of the chemicals in runoff and is shown for each pesticide in Tables 8a, 9a, and 10a. The transport modes were taken wherever possible from field experiments reported in the literature or were estimated from water solubilities of the chemicals where no experimental data exist. The best criterion of how a chemical partitions is its adsorption isotherm (curve showing amount adsorbed at different solution concentrations), as measured by mixing solutions of the chemical with known quantities of soil. However, published information on adsorption of individual compounds is fragmentary and water solubilities were used instead because, in general, the more water-soluble a compound is, the more it will appear in the aqueous phase of runoff rather than in the sediment. The solubility of some compounds depends heavily on the formulation used; amines, for example, are far more water-soluble than esters having the same active ingredient. Often, more pesticide can be lost in the runoff water than in the sediment even when pesticide concentration is higher in the latter, because the amount of water moved is so much greater than the amount of sediment transported.

Acute oral toxicity to rats and 48- or 96-hour toxicities to susceptible species of fish, usually rainbow trout or bluegills, in static water tests are standard indexes of mammalian and fish toxicity and are included in the tables to permit a general evaluation of the hazard that might exist if residues of specific chemicals occur in runoff. Higher LD_{50} (lethal dose for 50 percent of the rats being tested) and LC_{50} (lethal concentration for 50 percent of the fish being tested) values denote lower toxicity. Where more than one toxicity value is reported in the literature, the values denoting higher toxicity are shown. Fish toxicity values represent concentrations in water; pesticides adsorbed on sediment in the water are less toxic to fish than when dissolved in water.

The persistence in soil of most of the individual herbicides has been reported in the literature and is shown in the last column of Table 8a. The values correspond to the time required for 90 or more percent of the applied pesticide to disappear from the site of

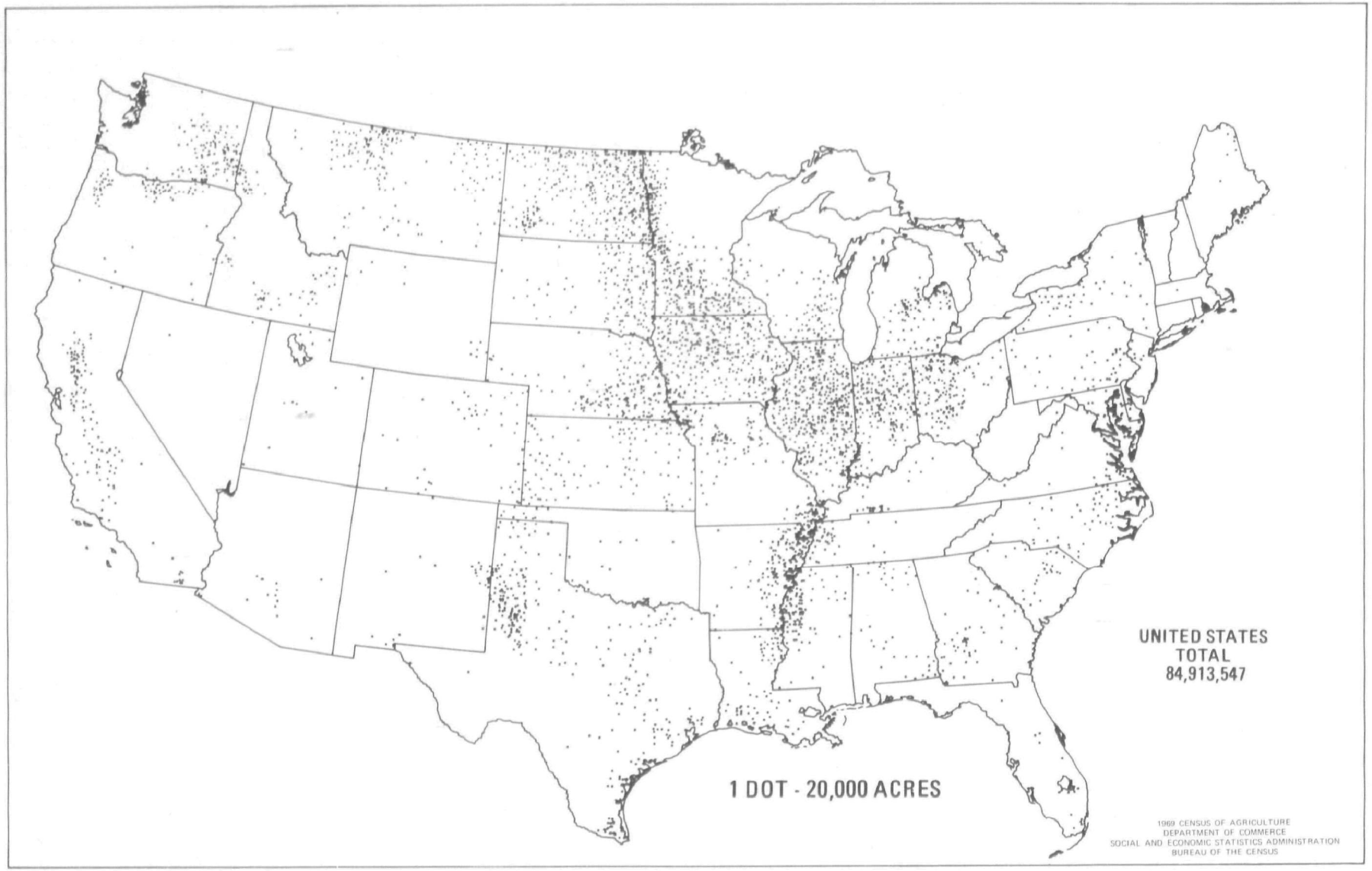


Figure 27.–Acreage of crops treated with herbicides.

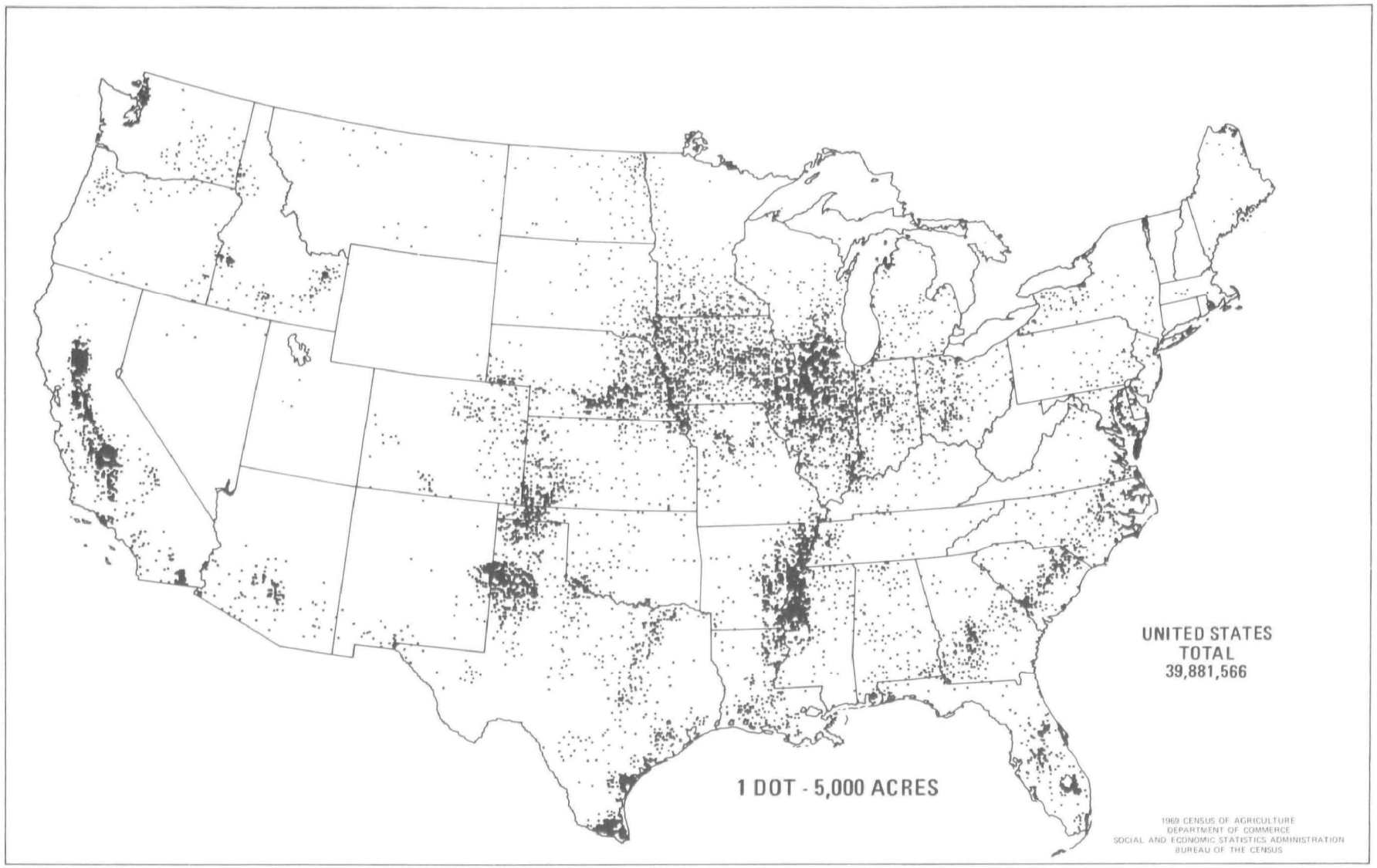


Figure 28.—Acreage of non-hay crops treated with insecticides.

Table 8a. Agricultural herbicides: types, transport modes, toxicities, and persistence in soil

Common Names of Herbicides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]		Approximate Persistence in Soil, days
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter	
Alachlor	AM	SW	1200	2.3	40-70
Ametryne[5]	TZ	SW	1110	Low toxicity	30-90
Amitrole	TZ	W	2500	>50	15-30
Asulam	CB	W	>8000	[6] 5000	25-40
Atrazine	TZ	SW	3080	12.6	300-500
Barban	CB	S	1350	[7] 1.3	20
Benefin	NA	S	800	[6] 0.03	120-150
Bensulide	AM	S	770	0.72	500-700
Bentazon	DZ	W	1100	190	
Bifenox	AR	S	4600	1.8	40-60
Bromacil	DZ	W	5200	70	700
Bromoxynil	NT	SW	250	0.05	
Butylate	CB	S	4500	4.2	40-80
Cacodylic Acid	AS	S		[8] >40	
CDAA	AM	W	700	2.0	20-40
CDEC	CB	SW	850	4.9	20-40
Chloramben	AR	W	3500	[6] 7.0	40-60
Chlorbromuron	UR	SW	2150	0.56	
Chloroxuron	UR	S	3700	[8] >15	300-400
Chlorpropham	CB	SW	1500	[6] 10	120-260
Cyanazine	TZ	SW	334	4.9	
Cycloate[5]	CB	SW	2000	4.5	120-220
2,4-D Acid	PO	W	370	[9] >50	10-30
2,4-D Amine	PO	W	370	[8] >15	10-30
2,4-D Ester	PO	S	500-875	[8] 4.5	10-30
Dalapon	AL	W	6590	>100	15-30
2,4-DB	PO	S	300	4.0	
DCPA	AR	S	3000	>500	400
Diallate	CB	S	395	5.9	120
Dicamba	AR	W	1028	35	
Dichlobenil	NT	S	3160	10-20	60-180
Dinitramine	NA	S	3000	6.7	90-120
Dinoseb	PH	SW	5	[7,10] 0.4	15-30
Diphenamid	AM	W	970	25.0	90-180
Diquat	CT	S	400	12.3	>500
Diuron	UR	S	3400	>60	200-500
DSMA	AS	S	600	>15	
Endothall	PH	W	38	1.15	
EPTC	CB	SW	1360	19.0	30
Fenac[5]	AR	SW	1780	7.5	350-700
Fenuron	UR	W	6400	53	30-270
Fluometuron	UR	SW	7900	[10] >60	
Fluorodifen	AR	S	15000	0.18	
Glyphosate	AL	S	4320	Low toxicity	150
Isopropalin	NA	S	5000	Toxic	150
Linuron	UR	S	1500	16.0	120
MBR 8251	AM	SW	633	312	
MCPA	PO	SW	650	10.0	30-180
Metribuzin	TZ	W	1930	>100	150-200
Molinate	CB	W	501	0.29	80
Monuron	UR	SW	3500	1.8	150-350
MSMA	AS	S	700	>15	
Naptalam	AR	W	1770	>180	20-60

Table 8a. Agricultural herbicides: types, transport modes, toxicities, and persistence in soil—(continued)

Common Names of Herbicides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]		Approximate Persistence in Soil, days
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter	
Nitralin	NA	S	2000	Low toxicity	
Nitrofen	PO	S	2630	Toxic	
Oryzalin	AM	S	>10000	Low toxicity	
Paraquat	CT	S	150	[6] 400	>500
Pebulate[5]	CB	S	921	[11] 6.3	50-60
Phenmedipham	CB	S	2000	[10] 20	100
Picloram	AR	W	8200	2.5	550
Profluralin	NA	S	2200	Toxic	320-640
Prometone[5]	TZ	S	1750	[9] >1.0	>400
Prometryne[5]	TZ	S	3750	[9] >1.0	30-90
Pronamide[5]	AM	S	5620		60-270
Propachlor[5]	AM	W	710	1.3	30-50
Propanil[5]	AM	S	1384	>10.0	1-3
Propazine[5]	TZ	S	5000	>100	200-400
Propham	CB	W	5000	[6] 32	20-60
Pyrazon	DZ	W	2500	[12] 40	30-60
Silvex	PO	SW	375	[9] 0.36	
Simazine	TZ	S	5000	5.0	200-400
2,4,5-T	PO	W	300	0.5-16.7	
TCA	AL	W	3370	[13] >2000	20-70
Terbacil	DZ	W	5000	[14] 86	700
Terbutryne[5]	TZ	SW	2400	Low toxicity	20-70
Triallate[5]	CB	S	1675	4.9	30-40
Trifluralin	NA	S	3700	[6] 0.1	120-180
Vernolate[5]	CB	SW	1625	9.6	50

[1] Chemical type designations: AL, aliphatic acids; AM, amides and anilides; AR, aromatic acids and esters; AS, arsenicals; CB, carbamates and thiocarbamates; CT, cationics; DZ, diazines; NA, nitroanilines; NT, nitriles; PH, phenols and dicarboxylic acids; PO, phenoxy compounds; TZ, triazines and triazoles; UR, ureas.

[2] Where movement of herbicides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, and SW denotes those that will most likely move in appreciable proportion with both sediment and water.

[3] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[4] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[5] Trade name; no corresponding common name exists.

[6] 24-hour LC_{50}.

[7] For goldfish.

[8] For killifish.

[9] For spot.

[10] LC_{100}.

[11] For mullet.

[12] For harlequin fish.

[13] For catfish.

[14] For sunfish.

Table 8b. Often-used trade-name synonyms of agricultural herbicides

Trade Name	Name in Table 8a	Trade Name	Name in Table 8a
AAtrex	Atrazine	Lasso	Alachlor
Alanap	Naptalam	Lorox	Linuron
Amiben	Chloramben	Maloran	Chlorbromuron
Amino Triazole	Amitrole	Milogard	Propazine
Avadex	Diallate	Modown	Bifenox
Avadex BW	Triallate	Norex	Chloroxuron
Balan	Benefin	NPA	Naptalam
Banvel	Dicamba	Ordram	Molinate
Basanite	Dinoseb	Paarlan	Isopropalin
Betanal	Phenmedipham	Planavin	Nitralin
Betasan	Bensulide	Prefar	Bensulide
Baladex	Cyanazine	Preforan	Fluorodifen
Bromex	Chlorbromuron	Premerge Dinitro	Dinoseb
Butoxone	2,4-DB	Princep	Simazine
Butyrac	2,4-DB	Pyramin	Pyrazon
Caparol	Prometryne	Ramrod	Propachlor
Carbyne	Barban	Randox	CDAA
Casoron	Dichlobenil	Ro-Neet	Cycloate
Chloro-IPC	Chlorpropham	Ryzelan	Oryzalin
CIPC	Chlorpropham	Roundup	Glyphosate
Cobex	Dinitramine	Sencor	Metribuzin
Dacthal	DCPA	Sinbar	Terbacil
Destun	MBR 8251	Sinox	Dinoseb
DNBP	Dinoseb	Soyex	Fluorodifen
Dowpon	Dalapon	Stam F-34	Propanil
Dymid	Diphenamid	Surflan	Oryzalin
Enide	Diphenamid	Sutan	Butylate
Eptam	EPTC	Telvar	Monuron
Eradicane	EPTC	Tenoran	Chloroxuron
Far-Go	Triallate	Tordon	Picloram
Furloe	Chlorpropham	Treflan	Trifluralin
Igran	Terbutryn	Vegadex	CDEC
IPC	Propham	Vernam	Vernolate
Karmex	Diuron		

Table 9a. Agricultural insecticides and miticides: types, transport modes, and toxicities

Common Names of Insecticides-Miticides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]	
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter
Aldicarb[5]	CB	W	0.93	
Aldrin	OCL	S	35	0.003
Allethrin	PY	S	680	0.019
Azinphos ethyl[6]	OP	S	7	0.019
Azinphos methyl	OP	S	11	0.010
Benzene hexachloride	OCL	S	1000	0.79
Binapacryl	N	U	120	0.04
Bux[6]	CB	S	87	0.29
Carbaryl	CB	SW	500	1.0
Carbofuran[5]	CB	W	8	0.21
Carbophenothion	OP	S	10	0.23
Chlorbenside	S	S	3000	
Chlordane	OCL	S	335	0.010
Chlordimeform	N	W	162	1.0
Chlorobenzilate[6]	OCL	S	700	0.71
Chlorpyrifos	OP	U	97	0.020
DDT	OCL	S	113	0.002
Demeton[5]	OP	W	2	0.081
Diazinon[5,6]	OP	SW	76	0.030
Dicofol[6]	OCL	S	684	0.10
Dicrotophos	OP	W	22	8.0
Dieldrin	OCL	S	46	0.003
Dimethoate	OP	W	185	9.6
Dioxathion	OP	S	23	0.014
Disulfoton	OP	S	2	0.040
Endosulfan	OCL	S	18	0.001
Endrin	OCL	S	7.3	0.0002
EPN	OP	S	8	0.10
Ethion	OP	S	27	0.23
Ethoprop	OP	U	61.5	1.0
Fensulfothion[5]	OP	SW	2	[7] 0.15
Fonofos[6]	OP	S	8	0.03
Heptachlor	OCL	S	90	0.009
Landrin[6]	CB	SW	178	0.95
Lindane	OCL	S	88	0.018
Malathion	OP	W	480	0.019
Metaldehyde	O	W	1000	>100.0
Methidathion	OP	U	25	
Methomyl	CB	U	17	~0.9
Methoxychlor	OCL	S	5000	0.007
Methyl demeton[6]	OP	W	65	4.0
Methyl parathion[6]	OP	SW	9	1.9
Mevinphos	OP	W	4	0.017
Mexacarbate	CB	SW	22.5	1.73
Monocrotophos	OP	W	21	7.0
Naled	OP	S	250	0.078
Ovex	S	S	2000	0.70
Oxythioquinox	S	S	1100	0.096
Parathion	OP	S	4	0.047
Perthane[6]	OCL	S	>4000	0.007
Phorate[5]	OP	SW	1	0.0055
Phosalone	OP	S	96	3.4
Phosmet[6]	OP	S	147	[8] 0.03

Table 9a. Agricultural insecticides and miticides: types, transport modes, and toxicities–(continued)

Common Names of Insecticides-Miticides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]	
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter
Phosphamidon	OP	W	11	8.0
Propargite[6]	S	U	2200	0.03
Propoxur	CB	W	95	[9] 0.025
TDE	OCL	S	3360	0.009
TEPP	OP	W	1	[9] 0.39
Tetrachlorvinphos	OP	S	4000	0.53
Tetradifon	OCL	SW	14000	1.10
Thionazin	OP	W	12	[7] 0.10
Toxaphene	OCL	S	69	0.003
Trichlorfon	OP	W	275	0.16

[1] Chemical type designations: CB, carbamates; N, miscellaneous nitrogenous compounds; O, cyclic oxygen compounds; OCL, organochlorines; OP, organophosphorus compounds; PY, synthetic pyrethrin; S, aromatic and cyclic sulfur compounds.

[2] Where movement of insecticides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, SW denotes those that will most likely move in appreciable proportion with both sediment and water, and U denotes those whose predominant mode of transport cannot be predicted because properties are unknown.

[3] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[4] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[5] Registered as both insecticide and nematicide. Nematodes are controlled only on limited acreage and predominantly in the Southern states, but application rates when used as nematicides are 2- or 3-fold higher than when used as insecticides.

[6] Trade name; no corresponding common name exists.

[7] 24-hour LC_{50}

[8] For killifish

[9] For minnows

Table 9b. Often-used trade-name synonyms of agricultural insecticides and miticides

Trade Name	Name in Table 9a	Trade Name	Name in Table 9a
Acaraben	Chlorobenzilate	Imidan	Phosmet
Azodrin	Monocrotophos	Kelthane	Dicofol
Basudin	Diazinon	Lannate	Methomyl
Baygon	Propoxur	Marlate	Methoxychlor
BHC	Benzene Hexachloride	Meta-Systox	Methyl demeton
Bidrin	Dicrotophos	Mocap	Ethoprop
Cygon	Dimethoate	Morestan	Oxythioquinox
Dasanit	Fensulfothion	Morocide	Binapacryl
DDD	TDE	Neguvon	Trichlorfon
Delnav	Dioxathion	Omite	Propargite
Dibrom	Naled	Phosdrin	Mevinphos
Dimecrom	Phosphamidon	Prolate	Phosmet
Dipterex	Trichlorfon	Rabon	Tetrachlorvinphos
Di-Syston	Disulfoton	Sevin	Carbaryl
Dursban	Chlorpyrifos	Spectracide	Diazinon
Dyfonate	Fonofos	Supracide	Methidathion
Dylox	Trichlorfon	Systox	Demeton
Ethyl Guthion	Azinphos ethyl	Tedion	Tetradifon
Fundal	Chlordimeform	Temik	Aldicarb
Furadan	Carbofuran	Thimet	Phorate
Galecron	Chlordimeform	Thiodan	Endosulfan
Gamma-BHC	Lindane	Trithion	Carbophenothion
Gardona	Tetrachlorvinphos	Zectran	Mexacarbate
Guthion	Azinphos methyl	Zinophos	Thionazin
		Zolone	Phosalone

Table 10a. Agricultural fungicides: transport modes and toxicities

Common Names of Fungicides	Predominant Transport Mode[1]	Toxicity[2]	
		Rat, Acute Oral LD_{50}, mg/kg	Fish[3] LC_{50}, mg/liter
Anilazine	S	2710	0.015
Benomyl	S	>9590	0.5
Captafol	S	5000	[4] 0.031
Captan	S	9000	0.13
Carboxin	SW	3200	2.2
Chloranil	W	4000	5.0
Chloroneb	U	11000	>4200.0
Cycloheximide	W	2.5	1.3
DCNA	S	4040	
Dichlone	S	1300	0.047
Dichlozoline	U	3000	
Dinocap	S	980	[5] 0.14
Dodine	W	1000	0.9
ETMT	U	2000	
Fenaminosulf	W	60	23.0
Ferbam	SW	>17000	[4] 12.6
Folpet	S	>10000	[6] 1.56
Maneb	S	6750	[7] 1.0
Metiram	U	6400	>4.2
Nabam	W	395	[4] 21.1
Ocycarboxin	W	2000	
Parinol	U	>5000	[8] ~5.0
PCNB	S	1650	0.7
SMDC	W	820	[7] 1.0
Thiram	S	375	[4] 0.79
TPTH	U	108	
Zineb	S	>5200	0.5
Ziram	W	1400	[4] 1.0

[1] Where movement of fungicides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, SW denotes those that will most likely move in appreciable proportion with both sediment and water, and U denotes those whose predominant mode of transport cannot be predicted because properties are unknown.

[2] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[3] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[4] For catfish

[5] For harlequin fish

[6] For mullet

[7] LC_{100}

[8] For fathead minnow

Table 10b. Often-used trade-name synonyms of agricultural fungicides

Trade Name	Name in Table 10a	Trade Name	Name in Table 10a
Actidione	Cycloheximide	Phaltan	Folpet
Benlate	Benomyl	Phygon	Dichlone
Botran	DCNA	Plantvax	Oxycarboxin
Cyprex	Dodine	Polyram	Metiram
DCNA	Botran	Spergon	Chloranil
Demosan	Chloroneb	Terrachlor	PCNB
Difolatan	Captafol	TMTD	Thiram
Dexon	Fenaminosulf	Vapam	SMDC
Dyrene	Anilazine	Vitavax	Carboxin
Karathane	Dinocap		
Parnon	Parinol		

Table 11. Major crops and principal pesticides registered for use on them throughout the United States

Crop	Herbicides		Insecticides and miticides	
Alfalfa	Benefin	EPTC	Azinphos methyl	Methomyl
	Chlorpropham	MCPA	Carbaryl	Methoxychlor
	2, 4-DB	Nitralin	Carbofuran	Methyl parathion
	Diallate	Propham	Carbophenothion	Mevinphos
	Dinoseb	Simazine	Demeton	Naled
	Diuron	Trifluralin	Diazinon	Parathion
			Dimethoate	Phorate
			Disulfoton	Phosmet
			Endosulfan	Toxaphene
			Malathion	Trichlorfon
Corn	Atrazine	Dalapon	Bux	Heptachlor[a]
	Butylate	DCPA	Carbaryl	Landrin
	CDAA	Dicamba	Carbofuran	Malathion
	CDEC	Dinoseb	Carbophenothion	Methomyl
	Chloramben	Diuron	Chlordane[a]	Methoxychlor
	Cyanazine	EPTC	Diazinon	Methyl parathion
	2, 4-D	Linuron	Disulfoton	Mevinphos
		Paraquat	EPN	Parathion
		Prometryne	Ethoprop	Phorate
		Propachlor	Fensulfothion	Tetrachlorvinphos
		Simazine	Fonofos	Toxaphene
				Trichlorfon
Cotton	Bensulide	EPTC	Aldicarb	EPN
	Cacodylic acid	Fluometuron	Azinphos methyl	Ethion
	DCPA	MSMA	Carbaryl	Malathion
	Dintramine	Nitralin	Carbophenothion	Methidathion
	Diphenamid	Paraquat	Chlordane[a]	Methyl parathion
	Diuron	Prometryne	Chlordimeform	Monocrotophos
	DSMA	Propachlor	Chlorobenzilate	Naled
	Endothall	Trifluralin	Demeton	Parathion
			Diazinon	Phorate
			Dicofol	Phosphamidon
			Dicrotophos	Propargite
			Dimethoate	Toxaphene
			Disulfoton	Trichlorfon
			Endosulfan	
			Endrin	
Fruit crops	Bromacil	Diuron	Azinphos methyl	Lindane
	Chlorpropham	EPTC	BHC	Malathion
	2, 4-D	Naptalam	Binapacryl[a]	Metaldehyde
	Dalapon	Paraquat	Carbaryl	Methoxychlor
	DCPA	Simazine	Carbophenothion	Methyl parathion
	Dichlobenil	Terbacil	Chlordane[a]	Mevinphos
	Dinoseb	Trifluralin	Chlordimeform	Naled
	Diphenamid		Chlorobenzilate	Ovex
			Demeton	Oxythioquinox
			Diazinon	Parathion
			Dicofol	Perthane
			Dimethoate	Phosalone
			Dioxathion	Phosmet
			Endosulfan	Phosphamidon
			EPN	Propargite
			Ethion	Tetrachlorvinphos
				Tetradifon
				Toxaphene

Table 11. Major crops and principal pesticides registered for use on them throughout the United States—Continued

Crop	Herbicides		Insecticides and miticides	
Peanuts	Alachlor Benefin 2, 4-DB Dinitramine Dinoseb	Diphenamid Naptalam Nitralin Vernolate	Carbaryl Diazinon Fensulfothion Fonofos Malathion Methomyl	Monocrotophos Parathion Phorate Toxaphene Trichlorfon
Rice	Chlorpropham 2, 4-D MCPA Molinate	Propanil Silvex 2, 4, 5-T	Carbaryl Chlordane[a] Disulfoton	Malathion Methyl parathion Parathion Toxaphene
Small grains[b]	Bromoxynil 2, 4-D Diallate	Dicamba Dinoseb MCPA	Chlordane[a] Demeton Diazinon Disulfoton Endosulfan Endrin	Heptachlor[a] Malathion Methyl parathion Parathion Toxaphene Trichlorfon
Sorghum	Atrazine Bifenox CDAA 2, 4-D Dalapon	Dicamba Linuron Paraquat Propachlor Propazine	Carbaryl Carbophenothion Demeton Diazinon Dimethoate Disulfoton Ethion	Malathion Methyl parathion Mevinphos Parathion Phorate Toxaphene
Soybeans	Alachlor Barban Bifenox CDEC Chloramben Chloroxuron Chlorpropham Dalapon 2, 4-DB DCPA Dinitramine	Dinoseb Diphenamid Fluorodifen Linuron Naptalam Nitralin Paraquat Trifluralin Vernolate	Azinphos methyl Carbaryl Carbophenothion Chlordane[a] Diazinon Disulfoton EPN	Heptachlor[a] Malathion Methomyl Methoxychlor Methyl parathion Parathion Toxaphene Trichlorfon
Sugarbeets	Barban Chlorpropham Cycloate Dalapon Diallate EPTC Paraquat	Pebulate Phenmedipham Propham Pyrazon Trifluralin	Aldicarb Carbaryl Carbophenothion Demeton Diazinon Disulfoton Endosulfan EPN Fensulfothion	Fonofos Malathion Methyl parathion Parathion Phorate Trichlorfon
Sugarcane	Ametryn Atrazine 2, 4-D Dalapon Fenac	Fluometuron Simazine Trifluralin	Azinphos methyl Carbofuran Diazinon	Endosulfan Endrin Fonofos Parathion

Table 11. Major crops and principal pesticides registered for use on them throughout the United States—Continued

Crop	Herbicides		Insecticides and miticides	
Tobacco	Benefin	Pebulate	Azinphos methyl	Fonofos
	Diphenamid		Carbaryl	Heptachlor[a]
	Isopropalin		Carbofuran	Malathion
			Chlordane[a]	Methidathion
			Diazinon	Methyl parathion
			Dimethoate	Monocrotophos
			Disulfoton	Parathion
			Endosulfan	Trichlorfon
			Ethoprop	
			Fensulfothion	
Vegetable crops	Barban	Dinoseb	Azinphos methyl	Lindane
	Bensulide	Diphenamid	BHC	Malathion
	CDAA	Endothall	Carbaryl	Metaldehyde
	CDEC	EPTC	Carbophenothion	Methomyl
	Chloramben	Flurodifen	Chlordane[a]	Methoxychlor
	Chlorbromuron	Linuron	Demeton	Methyl parathion
	Chloroxuron	Nitralin	Diazinon	Mevinphos
	Chlorpropham	Paraquat	Dicofol	Naled
	Dalapon	Propham	Dimethoate	Parathion
	DCPA	Trifluralin	Disulfoton	Perthane
	Diallate	Vernolate	Endosulfan	Phorate
			EPN	Phosphamidon
			Ethion	Tetradifon
			Fensulfothion	Toxaphene
			Fonofos	Trichlorfon
			Heptachlor[a]	

[a] Registration status under review.
[b] Wheat, oats, barley, millet, rye.

application under most conditions. Many of the missing values, as well as those of the insecticides in Table 9a, may be estimated by referring to Figure 29, which indicates the persistence, as defined above, of broad classes of pesticides. Persistence is a quite variable characteristic that may be influenced by such factors as climate; soil texture, moisture content, acidity, and temperature; and microbiological activity in the soil. Furthermore, members of a given class often vary widely in their persistence under the same soil conditions. The values shown in the figure represent the behavior of the longer-lived members of the classes under moderate conditions.

In evaluating the potential environmental impact of specific pesticides in runoff, persistence and toxicity should be considered together, because a toxic compound that rapidly degrades will pose only a temporary threat when residues are transported from treated areas. Pesticide residues dissolved in runoff water are more difficult to control and move greater distances in drainage streams than those adsorbed on sediments; hence, they are potentially more hazardous to the environment. Some highly soluble pesticides, especially salt formulations of the acid herbicides, are mobile in soil and move downward with percolating rainwater. Thus, they are less available for removal in direct runoff. Fortunately, even the most mobile herbicides rarely contaminate the ground water, because the adsorption capacity in most soils above the water table is sufficient to retain the chemicals until they decompose. However, in an area with high percolation potential (Figure 12), some groundwater contamination is a possibility.

The movement of pesticides on sediment is affected by the enrichment process, discussed above under Section 3.6a, in much the same way as is nutrient movement. Pesticides are adsorbed primarily on organic soil colloids, which remain in suspension longer than the coarser soil particles. A reduction in erosion may, therefore, not reduce pesticide loss proportionately.

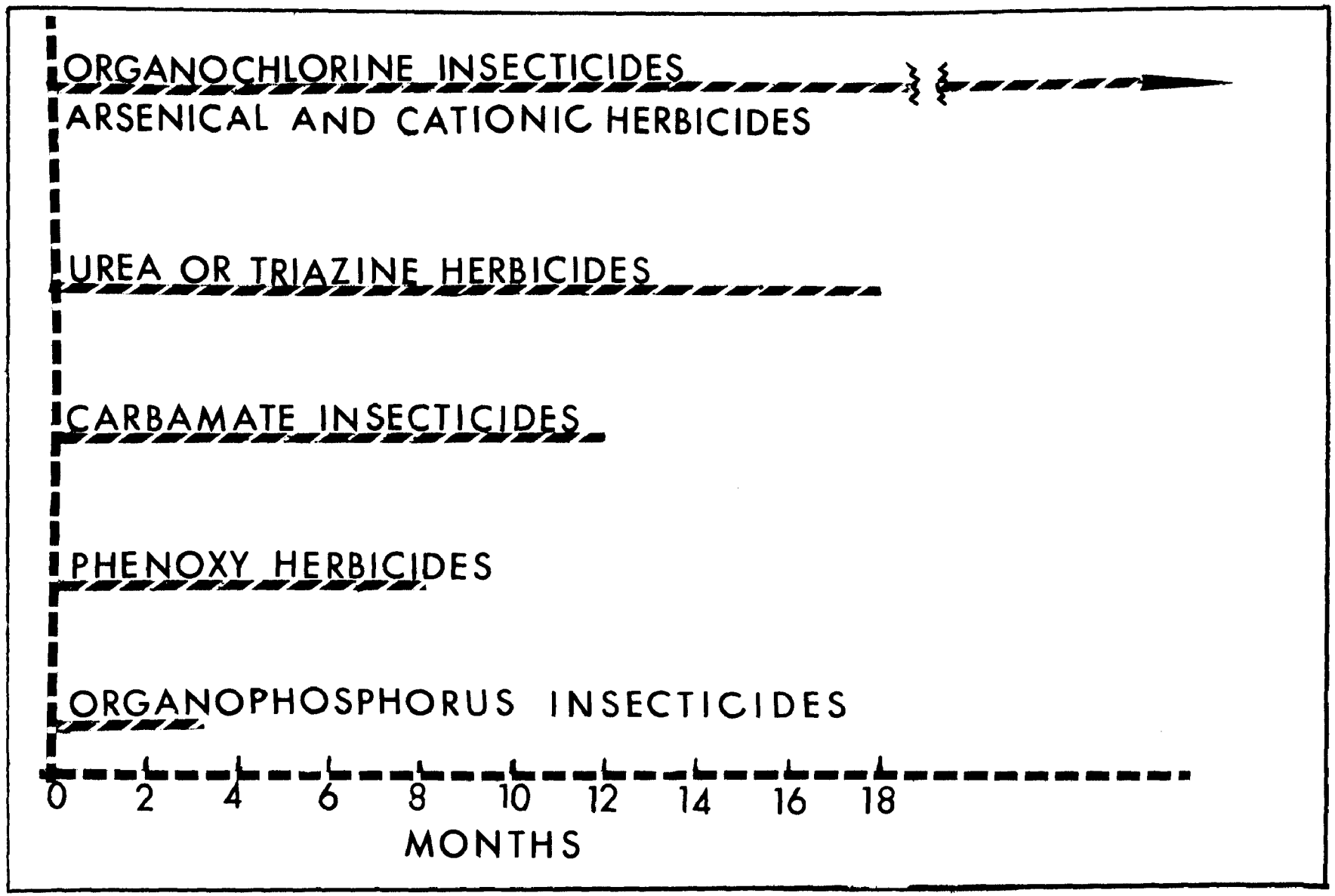


Figure 29.–Maximum persistence of classes of pesticides in soils under moderate climatic conditions.

SECTION 4

POLLUTION CONTROL PRACTICES

The approach used in identifying potential pollution problems in Section 3 was based on Land Resource Areas, which are broad geographic entities. Control measures, on the other hand, must be applied to individual fields and are applicable wherever deemed necessary, irrespective of geographic location. The following discussions deal with the various measures that can be taken to prevent or control pollution problems. Practices that are primarily directed to the control of erosion, the reduction of runoff, the management of fertilizers or animal wastes, and the management of pesticides are each dealt with in separate sections. It should be recognized, however, that important interrelationships exist among the four groups of practices that may affect the choice of a particular practice in a given situation. For example, the introduction of a conservation tillage practice to control erosion may result in the use of greater amounts of chemicals to control crop pests, so that the net benefit to the quality of the drainage streams may not be as great as might be expected. Some of the more important interrelationships are described in the discussions of individual control practices, and the flow charts presented in Section 6 also call attention to these interrelationships. Some practices are listed and discussed that are marginal in most cases. However, in some circumstances, one of these practices could be the best recommendation.

4.1 PRACTICES TO CONTROL EROSION

The goal of control practices is to keep erosion rates within tolerances compatible with good water quality, wholesome environment, and preservation of the productive capacity of the land. Where rainfall is adequate for crop production, some of it generally falls at intensities greater than the rate at which the soil can absorb it even under the most favorable conditions, and the excess runs off. However, erosion can usually be controlled by practices that minimize raindrop impact on the soil surface and weaken the erosive forces of the runoff by reducing its velocity and channelization.

Distribution of erosive rains within the year differs significantly for different sections of the country, as shown in Figure 30. When the major concentrations of erosive rainfall coincide with periods of little or no soil cover, most of the year's erosion is likely to occur within a relatively short period. With the conventional practice of seeding crops on plowed and smoothed seedbeds, the soil has very little protection during the first 2 months after crop seeding. On the Western Plains and in the Great Lakes Region, from 40 to 50 percent of the year's erosive rainfall normally occurs within 2 months after the average planting dates for corn, soybeans, and grain sorghum. In most of the Corn Belt and the eastern parts of Kansas, Oklahoma, and Texas, the corresponding percentage is about 35; and in the lower Mississippi Valley and Southeast, about 20 to 25. In the dryland grain-growing region of the Pacific Northwest, about 80 to 90 percent of the year's erosion occurs in the winter months, when the soil frequently has little cover because the grain is seeded so late in the fall. It is particularly important that control practices be highly effective during these critical periods.

In many situations, erosion can be controlled with *agronomic practices* that improve crop residue management, cropping sequences, seeding methods, soil treatments, tillage methods, and timing of field operations. Generally, farming parallel to the field contours will further reduce erosion. However, contouring and some of the agronomic control practices are not effective where slope length or the area from which runoff concentrates is excessive. They must then be *supported* by practices such as terraces, diversions, contour furrows, contour listing, contour strip cropping, waterways, and control structures.

Table 12 lists the principal types of erosion-control practices and some of their favorable and unfavorable features. Under many conditions, it may be necessary to apply various combinations of these practices. Modifications of specific practices within these general types affect their adaptability and also their effectiveness. The general types of practices are discussed below, with particular reference to their relation to pollution control.

Figure 30.–Monthly distribution of erosive rainfall as percentage of annual.

Table 12. Principal types of cropland erosion control practices and their highlights.

No.	Erosion Control Practice	Practice Highlights
E 1	No-till plant in prior-crop residues	Most effective in dormant grass or small grain; highly effective in crop residues; minimizes spring sediment surges and provides year-round control; reduces man, machine and fuel requirements; delays soil warming and drying; requires more pesticides and nitrogen; limits fertilizer- and pesticide placement options; some climatic and soil restrictions.
E 2	Conservation tillage	Includes a variety of no-plow systems that retain some of the residues on the surface; more widely adaptable but somewhat less effective than E 1; advantages and disadvantages generally same as E 1 but to lesser degree.
E 3	Sod-based rotations	Good meadows lose virtually no soil and reduce erosion from succeeding crops; total soil loss greatly reduced but losses unequally distributed over rotation cycle; aid in control of some diseases and pests; more fertilizer-placement options; less realized income from hay years; greater potential transport of water soluble P; some climatic restrictions.
E 4	Meadowless rotations	Aid in disease and pest control; may provide more continuous soil protection than one-crop systems; much less effective than E 3.
E 5	Winter cover crops	Reduce winter erosion where corn stover has been removed and after low-residue crops; provide good base for slot-planting next crop; usually no advantage over heavy cover of chopped stalks or straw; may reduce leaching of nitrate; water use by winter cover may reduce yield of cash crop.
E 6	Improved soil fertility	Can substantially reduce erosion hazards as well as increase crop yields.
E 7	Timing of field operations	Fall plowing facilitates more timely planting in wet springs, but it greatly increases winter and early spring erosion hazards; optimum timing of spring operations can reduce erosion and increase yields.
E 8	Plow-plant systems	Rough, cloddy surface increases infiltration and reduces erosion; much less effective than E 1 and E 2 when long rain periods occur; seedling stands may be poor when moisture conditions are less than optimum. Mulch effect is lost by plowing.
E 9	Contouring	Can reduce average soil loss by 50% on moderate slopes, but less on steep slopes; loses effectiveness if rows break over; must be supported by terraces on long slopes; soil, climatic, and topographic limitations; not compatible with use of large farming equipment on many topographies. Does not affect fertilizer and pesticide rates.
E 10	Graded rows	Similar to contouring but less susceptible to row breakovers.
E 11	Contour strip cropping	Rowcrop and hay in alternate 50- to 100-foot strips reduce soil loss to about 50% of that with the same rotation contoured only; fall seeded grain in lieu of meadow about half as effective; alternating corn and spring grain not effective; area must be suitable for across-slope farming and establishment of rotation meadows; favorable and unfavorable features similar to E 3 and E 9.
E 12	Terraces	Support contouring and agronomic practices by reducing effective slope length and runoff concentration; reduce erosion and conserve soil moisture; facilitate more intensive cropping; conventional gradient terraces often incompatible with use of large equipment, but new designs have alleviated this problem; substantial initial cost and some maintenance costs.
E 13	Grassed outlets	Facilitate drainage of graded rows and terrace channels with minimal erosion; involve establishment and maintenance costs and may interfere with use of large implements.
E 14	Ridge planting	Earlier warming and drying of row zone; reduces erosion by concentrating runoff flow in mulch-covered furrows; most effective when rows are across slope.
E 15	Contour listing	Minimizes row breakover; can reduce annual soil loss by 50%; loses effectiveness with post-emergence corn cultivation; disadvantages same as E 9.
E 16	Change in land use	Sometimes the only solution. Well managed permanent grass or woodland effective where other control practices are inadequate; lost acreage can be compensated for by more intensive use of less erodible land.
E 17	Other practices	Contour furrows, diversions, subsurface drainage, land forming, closer row spacing, etc.

E 1. No-Till Plant in Prior-Crop Residues

The term "no-till" as used in this manual refers to planting in narrow slots opened by a fluted coulter or other device, without tillage. The crop residues remain distributed over the soil surface throughout the year. The planting can be in chemically killed meadow or winter cover, small-grain stubble, chopped cornstalks, or other crop residues. The residue mulch protects the soil surface against erosion during the highly vulnerable crop-establishment period and is also effective during the growing season and after harvest.

Where residues are adequate to provide nearly complete surface cover, no-till planting can be the most effective year-round erosion-control practice compatible with intensive grain production. No-till planting in chemically-killed sod can reduce soil loss to less than 5% of that from the conventional plow, smooth, plant and cultivate system. Uniformly distributed cornstalks at a rate of 3 tons or more per acre can reduce soil loss by about 85% on moderate slope lengths. However, lesser rates of residues are less effective (Table 4), and supporting practices are still needed when slope lengths are excessive. No-till planting without surface residues is not recommended as an erosion-control practice. Use of no-tillage for soybeans following corn reduces erosion potential and may produce greater yields than plow-based systems. No-till planting reduces man and machine hours and soil compaction by implements. Where the residue cover is adequate, it also reduces sealing and crusting of the soil surface.

The advantages of no-till may be partially offset by problems that are inherent in no-plow systems. More herbicides and insecticides are usually required than with plow systems, and nitrogen and phosphorus can be leached from the plant residues left on the surface. However, any increase in runoff pollution by soluble chemical compounds is usually offset by a greater reduction in sediment-transported compounds. Elimination of tillage reduces the options for fertilizer placement and eliminates the soil loosening associated with inversion plowing. More nitrogen is sometimes needed to maintain yields. An initial outlay for equipment modification or replacement may be required. Residue mulch on the surface retards drying and warming of the soil surface in the spring and may delay planting or seedling emergence. No-till planting in complete residue cover is usually not recommended on fine-textured soils in the northern states, but other forms of conservation tillage (E 2) may be adaptable.

Reports from the Northwest point out that no-till techniques for winter wheat as now used in that region lead to serious weed problems, poor seedling development in heavy residues, and reduced yields, and that plant toxicity problems may exist where crops are planted in heavy residues.

E 2. Conservation Tillage Practices

Some of the limitations of no-till planting can be alleviated by use of conservation tillage systems that have broader adaptability but are somewhat less effective. These systems usually replace moldboard plowing with some form of non-inversion tillage that retains some of the residue mulch on the surface. In some of the systems, a chisel, field cultivator, or disk is used over the entire area. In others, row zones are tilled while the inter-row zones are left untilled with the residue cover intact. Strip tillage overcomes some of the disadvantages of no-till and is highly effective when the rows are across slope. If they are up and down slope, the runoff may be channeled to flow in the tilled zone, where it can still be quite erosive.

Conservation tillage systems can be suited to a broader range of soil and climatic conditions than no-till, and options for fertilizer placement are usually more than for no-till. Crop yields are as good as, and sometimes higher than, those with the plow-based systems. Some of the practices require equipment modification, but man and machine hours and soil compaction by implements are usually reduced.

The degree of effectiveness of a particular system or machine depends on the surface conditions induced. The effectiveness is directly related to the amount of residues left on the surface, amount of residues mixed into the upper few inches of topsoil, surface roughness, and ridges or residue strips on the contour; it is inversely related to the amount of soil pulverization.

E 3. Sod-Based Rotations

Sod-based rotations have been successfully used for many years to reduce erosion from the conventional plow-based systems in regions adapted to rotation meadows. Soil loss from a good quality grass and legume meadow is negligible, and when the sod is plowed out, residual effects improve infiltration and leave the soil less erodible. These effects are very substantial in the first year after sod is inverted and remain significant during the second year. With good fertility management, annual soil losses from 4-year rotations of wheat, hay, and 2 years of conventionally planted corn usually average about one-third of those from conventionally planted continuous corn.

Sod-based rotations with conventional tillage allow more fertilizer placement options, provide better control

of some plant diseases and pests, and have less soil-temperature problems than no-till or mulch tillage systems. Legumes in the meadow mixture can help meet nitrogen requirements.

But there are disadvantages. Substituting hay for corn, soybeans, grain sorghum, or cotton on a substantial portion of a farmer's potential cash-crop acreage is likely to reduce his income because of lower cash value of the hay crop. Meadow crops have a high mineral requirement. Where hay is removed, higher fertilizer rates are needed to maintain stands. The potential for transport of soluble phosphorus is greater from meadows than from row crops, but sediment-transported P is much less. Wireworms, cutworms and army worms are more prevalent in first-year corn after meadow.

For off-site sediment control, another consideration is the unequal distribution of soil loss within a rotation cycle (Figure 31). In this example, just 5 of the 48 months in the rotation cycle accounted for half of the total soil loss. The first 2 months of the second-year corn accounted for 28%. No-till planting the second-year corn in chopped cornstalk residues would greatly reduce the hazard of high 1-year sediment yields and would cut the average annual soil loss for the 4-year rotation in half. The rotation soil loss could be further reduced by no-till planting the first-year corn in chemically killed sod instead of turning the meadow.

E 4. Meadowless Rotations

Rotating two kinds of row crop, or a row crop and small grain, has far less erosion-control potential than sod-based systems, but such rotations aid in control of some diseases and pests and usually reduce the amount of herbicides required. A row crop and fall-seeded grain system reduces erosion by shortening the time the soil is bare. Soybeans following corn or grain sorghum lose less soil than second-year soybeans. Conversely, corn after soybeans has a higher erosion potential than corn after corn. Small grain seeded in disked corn residues will likely lose from 50 to 70% less soil than grain planted on a plowed and fitted seedbed. Soil loss from corn planted on plowed wheat land is nearly equal to that from plowed corn land where the residues are incorporated. However, winter grain chemically killed at corn-planting time provides an excellent condition for no-till planting of corn.

Where the growing season is long enough to permit following winter grain with soybeans in a 1-year system, the double cropping shortens the time when the soil surface is poorly protected and the grain residue reduces erosion from the soybeans.

E 5. Winter Cover Crop

When corn or sorghum is harvested for grain only, leaving the shredded stalks on the field will probably provide more protection during the winter than a late-seeded small grain winter cover on plowed ground. However, a winter cover seeded early enough to attain good fall growth is beneficial following crops that leave little residue cover, and on fields where the corn stover is harvested for silage or other use. If the cover crop is chemically killed and left in place for no-till planting of a row crop, it also provides excellent control during the crucial May and June period.

Where soil wetness in spring is a problem, such as on the claypan soils, the early spring growth of a wheat cover crop can enable earlier corn planting by removing excess water from the soil. Conversely, where soil moisture supplies are critical, the water used for growth of the winter cover may deprive the ensuing crop of needed moisture and thereby reduce yields.

E 6. Improved Soil Fertility

Improving soil fertility and general crop management to increase crop yields has the additional advantage of substantially reducing soil erosion. This reduction is attributable to improved crop canopy, increased water use by the plants, and availability of more residues for soil protection. The magnitude of potential soil loss reduction through improved crop productivity is indicated by the differences in the paired C values of Table 4.

E 7. Timing of Field Operations

Erosion data indicate that fall plowing for corn will generally increase the annual soil loss at least 10% relative to spring plowing, and by two to tenfold relative to no-plow systems where residues are retained on the surface. The soil is exposed to the erosive forces of thaw runoff and early spring rains, and soil porosity at planting time is less than with spring plowing. However, fall plowing facilitates more timely planting where wetness is a problem in early spring and may thereby increase yield averages. It is usually recommended on nearly level soils of moderately fine to fine texture.

The precise timing of field operations also influences erosion losses. Early-seeded wheat protects against erosion by spring thaw and snowmelt more than does late-seeded wheat. Delaying spring plowing and corn planting beyond the optimum dates usually increases the erosion potential, because the most erodible period is then during a time of greater rainfall erosivity.

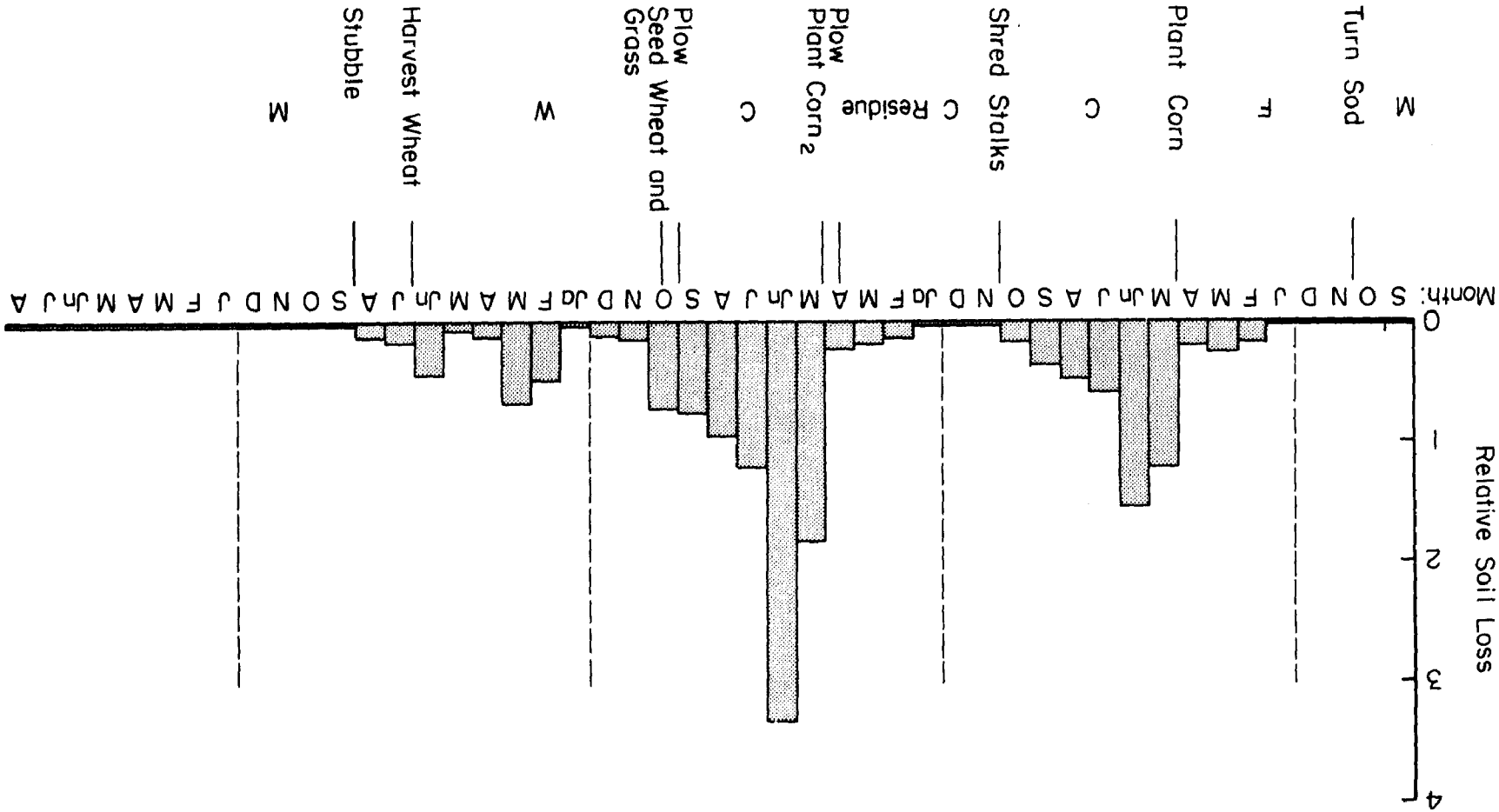


Figure 31.—Average monthly distributions of soil loss from a 4-year rotation of meadow-corn-corn-wheat in western Iowa.

E 8. Plow-Plant Systems

In plow-plant and wheeltrack-plant systems the field is turnplowed but secondary tillage is minimized. The plant residues are covered, but the surface remains rough and cloddy after planting. The rough surface decreases sealing, increases surface detention of excess water, and reduces runoff velocity. Erosion from moderate rains is greatly reduced, but if the plow layer becomes saturated and runoff is substantial, the surface has no protection. The principal disadvantage is difficulty in obtaining stands. Weeds must be chemically controlled if the rough surface is to be maintained. This is not a common practice but may be advantageous in some situations.

E 9. Contouring

Contouring is a supporting practice that is widely recommended where drainage is not a problem. The crop rows follow the field contours across the slope. This slows the movement of excess rainfall from the field and thereby reduces soil detachment and increases infiltration. Contouring provides excellent erosion control for moderate rainstorms, but is ineffective if the capacity of the rows to hold or conduct runoff is exceeded. The *average* soil loss reduction from contouring is about 50% on moderate slopes, but less on steeper slopes.

Contouring is not effective on long slopes unless supported by terraces or runoff diversions. Length limits given in Agriculture Handbook No. 282 for the conventional plow-based systems are listed in Table 13. Adjusted limits for conservation tillage practices that retain substantial amounts of residues on the surface throughout the year are also given.

Following field contour lines with mechanized equipment is time consuming, and point rows are often involved. On much of the cropland topography, the practice is incompatible with use of massive multiple-row equipment. On poorly drained soils, contouring may aggravate wetness problems.

E 10. Graded Rows

Graded rows are land-formed to a precise gradient. This improves surface drainage and decreases the likelihood of row breakovers.

E 11. Contour Strip Cropping

Strips of sod alternated with strips of row crop, across the slope, are much more effective than contouring alone. The sod strips serve as filters if rows break. High-quality sod strips reportedly have filtered 75% or more of the suspended soil from the runoff from the cultivated strips. Stripcrop systems generally use a 4-year rotation—2 years of meadow, 1 of row crop, and 1 of small grain in which new meadow is established. This system reduces the field soil loss to about half of the average for the same rotation contour farmed without the alternating strips, or about 25% of the rotation average with rows up and down a moderate slope. Stripcropping 3-year systems of meadow, row crop and small grain is less effective. Alternate strips of corn and spring-seeded small grain do not significantly reduce water erosion.

The practice has the same limitations as those listed for sod-based rotations and for contouring. However, it also has all the advantages of both, plus a large additional reduction in soil loss. Strip cropping has not been generally adopted in the western part of the Corn Belt because the strips of low-growing meadow give increased access of hot winds to corn strips in late July and early August and result in greater drought damage to the corn.

Table 13. Approximate length limits for contouring[1].

Slope (%)	Length (feet)	
	Conventional tillage[2]	Mulch cover[3]
2	400	500
4 to 6	300	375
8	200	250
10	100	125
12	80	100

[1] Slope-length limits depend also on runoff rate, soil erodibility, and type of vegetation, but the relationships have not been established. When the lengths in the table are exceeded, factor P should be assumed equal to 1.0 unless the field is terraced. However, the approximate lengths shown in this table are not sufficiently accurate to serve as terrace spacing guides.

[2] Limits given in Agriculture Handbook No. 282 for systems in which the crop residues are removed or covered by inversion plowing.

[3] Limits adjusted upward for effects of at least 50% residue cover during crop establishment and after harvest.

E 12. Terraces

Terrace systems support contouring by acting as a safety measure to prevent serious rills and field gullies when contour rows break. They reduce slope length by dividing the overall slope into segments equal to the horizontal terrace spacing. Excess water is "walked" off

the field through nearly level terrace channels to a grassed outlet or is removed through a subsurface drain. Shortening the effective slope lengths decreases soil loss from the strips between the terraces, and up to 80% of the soil that is moved from the between-terrace strips is deposited in the terrace channels. For resource conservation, only the reduction in erosion between the terraces is usually credited. However, for sediment and pollution control purposes, the large amount of deposition in the channels is also creditable.

Terrace systems have the highest initial cost of all the conservation practices, and they require continuous maintenance. However, they permit more intensive cropping on sloping land, and on long slopes they are needed to supplement agronomic and cultural practices because the effectiveness of these practices breaks down when slope lengths exceed certain limits (Table 13). Optimum horizontal spacing of the terraces depends on the slope steepness, soil, rainfall, and crop management. Standard formulas are readily available.

The conventional gradient terrace systems make the use of large farm equipment difficult because of the winding rows and because the distance between the terraces is not uniform. This difficulty is largely alleviated by use of parallel grass-backslope terraces with subsurface drains. However, these terraces are not adaptable to all conditions, and construction costs are higher than for conventional systems. Level closed-end terraces reduce erosion and have little runoff. They can be a major pollution-abatement practice.

E 13. Grassed Outlets

Grassed outlets are stabilized channels that receive the drainage from contoured or graded rows or from terrace channels and remove it from the field. They are a highly effective erosion-control practice. Disadvantages include establishment and maintenance problems and incompatibility with use of large farm equipment and with use of herbicides to control grass in the row crops.

E 14. Ridge Planting

The rows are planted on existing or preformed ridges from which the residues have been moved to the between-row furrows. The ridges warm and dry more quickly and facilitate earlier planting. When the ridges are on the contour or very slight row gradient, they function as small, closely spaced terraces and are very effective. The practice is less effective when the rows are not on the contour, but large amounts of residues in the furrows can substantially reduce soil loss even with row gradients up to 6 or 8%. Disadvantages include problems with stand establishment, fertilizer placement, and weed control. If the ridges break, deep rilling may occur.

E 15. Contour Listing

The rows are planted in contoured furrows, which reduce the velocity of water movement down the slope. Row breakover during crop establishment is much less likely than with standard contouring. If the corn is cultivated, the furrows are gradually closed and, therefore, are less effective after the corn has developed a canopy cover. The practice is most effective during the crop establishment period, which is the time when erosion hazards are greatest. The problems and disadvantages are similar to those listed for contouring (E 9). In plot studies, the reduction in annual soil loss has averaged about 50%.

E 16. Change in Land Use

Change in land use is sometimes the only solution. Properly managed hay or pasture furnishes adequate erosion control over a wide range of slopes throughout most humid sections of the country. Managed permanent woodland with duff and underbrush cover permits almost no erosion. Sometimes, a change to annual cropping of small grains and other closely seeded crops, with appropriate tillage practices and residue management, will suffice.

E 17. Other Practices

Contour furrows are sometimes used instead of terraces.

Diversions are sometimes used to channel excess water from a field where terraces are not needed.

Subsurface drainage systems provide another means of removing excess water without erosion.

Land forming can sometimes alleviate the problems of irregular topography for contouring or terracing and also improves surface drainage.

Rows on 30-inch spacing hasten development of an effective canopy and provide a more complete canopy cover than the traditional 40- or 42-inch spacing. Tests have shown some associated reduction in erosion, particularly during the first 2 months of the crop year.

Vegetative sediment filters, settling basins, and sediment traps represent another approach to sediment reduction. They are not erosion control practices, but they can be very effectively used to trap sediments near their source.

The above list covers only the major *types* of control practices, not all the specific forms. Also, practices that are basically the same may be known by different names in different sections of the country. Several alternative field-tested erosion control practices are available for any particular geographic region, but the options are not the same for all regions or for all fields within a region. Use of a specific practice may be limited by soil, climatic, or topographic restraints. Some of these restraints can be overcome by changing specific details of the practice to suit local conditions. Also, the relative importance of raindrop impact, surface runoff, and topographic features as erosion-producing factors is not the same for different regions such as the humid Central Valley, the wheat belt of the Pacific Northwest, and the coastal plains of the Southeast. The dominance of one of these factors over the others influences the type and specific form of control practice needed.

Potential soil loss reductions by the various types of agronomic practices were not quantified in the preceding discussion because the effectiveness of a given type of practice depends on its specific form and on the crop system and general management level with which it is used.

4.1a Quantifying Potential Soil Loss Reductions

The cover and management factor, C, of the soil loss equation that was introduced in Section 3.3b is evaluated for *specific* agronomic practices in combination with specified crop systems. Illustrative C values were presented in Table 4. These values can be used to estimate how much a change from one crop-and-management system to another would reduce soil loss. For example, conventionally planted continuous corn with residues turned under in spring (line 5) has a C-value of 0.38 for the high productivity level. For continuous corn that is no-till planted in a 70% surface cover of fall-shredded stalks (line 16), C = 0.11. Therefore, the estimated reduction in soil loss by changing from the first practice to the second is (0.38-0.11)/0.38 = 0.71, or 71%. This procedure can also be used to estimate the erosion reduction from improved soil fertility and crop management (practice E 6). In line 16 of Table 4, for example, C = 0.18 for the moderate productivity level and 0.11 for the high productivity level. The estimated soil loss reduction attainable by increasing the average annual corn yield from about 50 bushels to more than 75 bushels and retaining the same percentage of the residues on the surface would be (0.18-0.11)/0.18 = 0.39, or 39%.

Factor C is the ratio of the average soil loss with a given combination of cropping and cultural practices to the erosion-potential index defined in Section 3.3b. Since the erosion-potential index is determined by the location's soil, rainfall pattern and topographic features, it has a fixed value for a given land area. Therefore, the C values for alternative practices for that area are fractions of the same number and the procedures used in the preceding paragraph are mathematically valid.

Potential reductions by supporting practices, such as contouring, terracing, etc., can be estimated from Table 5 by subtracting the appropriate P value from 1.0. Potential reductions by combinations of supporting practices (Table 5) and agronomic practices (Table 4) are computed as progressive reductions. Changing from the system in line 5 to the one in line 15 would decrease C from 0.38 to 0.12, but changing from line 5 with tillage up and down slope to line 15 supported by contour strip-cropping on a 10% slope would reduce the combined value of C and P from 0.38 to (0.12 x 0.6). The estimated soil loss reduction by the two concurrent changes would be (0.38-0.072)/0.38 = 81%.

These estimates of potential reduction are helpful guides, based on averages. However, both C and P are affected by interactions with physical and farm-operator variables and are, therefore, not identical for all situations.

4.1b Selecting Erosion Control Practices for Specific Land Areas

The combination of agronomic and supporting practices required to reduce soil loss to any specific limit is dictated by the severity of the erosion hazard and the effectiveness of each of the various practices that can be adapted to the situation. Erosion hazards often differ widely within a relatively small geographic area. Therefore, control practices can be most accurately prescribed on an individual-field basis. However, plans can be developed for larger areas if they allow flexibility in practice selection to correspond with differences in soil type and slope characteristics.

With the help of the soil loss equation, erosion control planning can be a process of systematic decision-making based on logical evaluation of the alternatives for land use and treatment. For this purpose, the equation is used with a numerical soil loss tolerance, T, which is the maximum allowable erosion rate based on the particular soil and environment. This rate can be either a prescribed standard or a voluntary goal selected by the farmer or the community. (T values will be discussed later.)

The soil loss equation (A = R x K x LS x C x P) estimates the average annual soil loss from sheet and rill erosion (A), in tons per acre, for specific combinations

of rainfall pattern (R), soil type (K), topographic features (LS), crop system and cultural management (C) and supporting erosion control practices (P). Procedures and data for estimating local values of the equation's individual terms were presented in Section 3.3b.

For practice selection, it is convenient to substitute the maximum allowable soil loss, T, for A in the equation and to rearrange the terms into the form: maximum CP = T/RKLS.[1] The product R x K x LS is the computed estimate of the site's erosion-potential index (Section 3.3b). To hold soil loss below the tolerance, T, the crop system, cultural management and support practices must be such that C x P does not exceed the quotient T ÷ RKLS. Each of these terms has a numerical value for the particular land area, so the maximum permissible CP value is defined. For example, if in a given situation the tolerance goal were 5 tons per acre, the rainfall-erosivity index 190, the soil factor 0.32, and the topographic factor 1.4, the product of factors C and P would not be permitted to exceed 5/(190 x 0.32 x 1.4), which is 0.059.

With no supporting practice, P = 1.0, and the maximum allowable *C* value would be 0.059. With a supporting practice, the limiting C value would be 0.059 times 1/P, where the value of P is taken from Table 5 and is always less than 1.0.

The maximum C derived by this procedure is the threshold value for entering a regional table of C values such as illustrated by Table 4. Each line in the table denotes a specific crop and management system. All systems for which C is less than the computed threshold value qualify as options for the particular area if the designated crops and practices are suitable for the climate and soil. Supporting practices increase the threshold value and the number of acceptable alternatives.

The practice selection procedure is outlined by successive steps in the erosion flow charts, Figures 36 and 37, and is illustrated by detailed examples in Section 6.

4.1c Tolerance Limits

Nothing in this manual is intended as a recommendation of any specific soil loss tolerance standard, but some of the considerations involved in setting such standards are appropriate.

For conservation planning purposes, the Soil Conservation Service has found tolerances ranging from 5 to 2 tons (depending on characteristics of the soil profile) feasible and adequate when defined in terms of *average* annual soil loss. These limits were selected primarily to conserve or improve the long-range productivity of the cropland; they are not necessarily the most appropriate ones for pollution control.

For controlling water pollution from nonpoint sources, a limit on the potential amount of off-farm sediment would seem more appropriate than a limit on soil movement within field areas. Sediment filters and traps would then also be possible options as control measures. Soil texture and the location of the cropland relative to streams, lakes, reservoirs, or critical areas are also important in determining how much field soil loss could be tolerated. Texture is important because colloidal materials remain in suspension longer than larger particles and are probably the primary carriers of chemical compounds. Soil loss tolerances related to classifications of cropland with reference to location and texture may be more appropriate than a statewide uniform standard.

Short-time peak sediment loads may be more important in pollution control than they are in preservation of the land resource. Limits based on the most erodible crop in the rotation, or perhaps even on seasonal soil loss probabilities, may be appropriate. *However, such limits could not be as low as limits on average annual losses* and would be more difficult to monitor. A tolerance as low as 5 tons per acre on peak-year losses would drastically limit grain production on much of our highly productive cropland. Merits and limitations of tolerance limits based on other than longtime-average soil losses are further discussed in Volume II of this report.

4.2 PRACTICES TO CONTROL DIRECT RUNOFF

Surface runoff from cropland can rarely be eliminated. However, it can be substantially affected by agronomic and engineering practices. If the direct runoff from a summer row crop with straight rows is taken as the basis for comparison, land use and treatment practices can affect direct runoff in two ways: (1) change the volume of runoff, and (2) change the peak rate of runoff. A change in runoff volume will generally change the peak runoff rate in the same direction; however, peak runoff rates can be changed without affecting the volume.

Direct surface runoff volumes can be reduced by measures that: (1) increase infiltration rates, (2) increase surface retention or detention storage, allowing more time for water to infiltrate into the soil, and (3) increase interception of rainfall by growing plants or residues.

[1] In the flow chart, Figure 37, the product RKLS is represented by I, and T/RKLS is represented by λ. Hence, the maximum permissible value of CP is λ and the maximum C is λ/P.

The first two measures are the most important. Infiltration rates are increased by agronomic practices that result in dense vegetative cover, abundant mulch or litter, high soil organic matter content, good soil structure, and good subsurface drainage. A dense vegetative cover not only protects the soil surface from the sealing effect of raindrops but also provides for maximum transpiration loss and lowered soil water content. Subsurface drainage systems drain excess water between storms, thus resulting in higher infiltration rates. Higher fertility levels and management practices that increase vegetative cover result in lower direct runoff. Management practices such as contouring or engineering practices such as contour furrowing, graded terracing, and level terracing can substantially increase surface storage. Dense vegetative cover, mulch, and rough, cloddy surfaces also increase retention and detention storage.

Peak runoff rates can be decreased by treatments that increase the hydraulic resistance of the surface, decrease the land slope, or increase the length of flow path. Such practices or treatments will generally reduce erosion too, but it is difficult to assess the effects on the transport of weakly adsorbed chemicals. A reduction in erosion may reduce the amount of mixing of the soil with water; however, the longer contact time may increase the opportunity for solution of chemicals. Apparently, one way to reduce the loss of agricultural chemicals in direct runoff is to reduce the volume of runoff.

How much direct runoff can be reduced depends on the number and type of control measures used and on the characteristics of the soils and climate of the particular location. A *reduction* of surface runoff may result in a somewhat smaller *increase* in subsurface runoff and deep percolation. Therefore, where leaching is a serious problem, it may not be desirable to reduce surface runoff.

Practices that reduce erosion will usually reduce runoff, although to a lesser extent. Therefore, the first 16 runoff control measures have been assigned the same reference numbers as the identical erosion control measures; only the alphabetical prefixes differ (i.e., Practice R 1 is the same as E 1).

Erosion control practices have been described in detail in the erosion control section, so only those aspects related to runoff control are discussed in the following paragraphs. Runoff control measures and their highlights are summarized in Table 14.

Continuous meadow has the lowest annual and seasonal direct runoff of all the practices in Table 14 with the possible exception of level terraces. Therefore, the percentage reduction in potential direct runoff achieved by a change in land use *from* straight-row summer crops *to* continuous meadow represents the maximum that runoff can be reduced in most instances.

The percentage reduction that can be achieved by runoff control practices varies significantly with the amount of potential direct runoff, as shown by the upper curve in Figure 32. This curve serves as the basis to divide the percent reduction achieved by runoff control practices into three somewhat arbitrary zones, "slight," "moderate," and "substantial," as shown in Figure 32. These three terms are used to describe the amount of runoff reduction in the "practice highlights" in Table 14.

The Soil Conservation Service method was used in a simulation procedure to estimate the mean annual and seasonal reduction in direct runoff that might be achieved by some runoff control methods. The appropriate empirical parameters or "curve numbers" are not available for all practices listed. Where it is stated that a practice reduces direct runoff, such a reduction is relative to direct runoff from a straight-row summer crop (corn, cotton, soybeans).

R 1. No-Till Plant in Prior-Crop Residues

This practice increases infiltration rates by maintaining either a plant canopy or a mulch of plant residues on the surface the entire year. Residues on the surface tend to form small dams, which increase surface storage. The Soil Conservation Service has not developed curve numbers for this practice, but limited data indicate a range of response from an increase in growing-season runoff to a substantial decrease. In general, the high percentage reduction will occur in years of low runoff and for the smaller storms. In some circumstances, soil compaction and reduction of evaporation from the surface due to the residues may lead to increases in runoff.

R 2. Conservation Tillage

Among the many practices that can be included in this classification are those known as till plant, strip tillage, sweep tillage and chisel plant. Only fragmentary data are available to quantify the runoff reduction that might be achieved by each practice. Their relative effectiveness can be judged by the amount of residue left on the surface and the amount of surface storage created by the tillage operation. When used without support practices, runoff will be reduced slightly to moderately. Runoff may be reduced substantially if conservation tillage is used in conjunction with contouring.

Table 14. Practices for controlling direct runoff and their highlights.[1]

No.	Runoff Control Practice	Practice Highlights[2]
R 1	No-till plant in prior crop residues	Variable effect on direct runoff from substantial reductions to increases on soils subject to compaction.
R 2	Conservation tillage	Slight to substantial runoff reduction.
R 3	Sod-based rotations	Substantial runoff reduction in sod year; slight to moderate reduction in rowcrop year.
R 4	Meadowless rotations	None to slight runoff reduction.
R 5	Winter cover crop	Slight runoff increase to moderate reduction.
R 6	Improved soil fertility	Slight to substantial runoff reduction depending on existing fertility level.
R 7	Timing of field operations	Slight runoff reduction.
R 8	Plow plant systems	Moderate runoff reduction.
R 9	Contouring	Slight to moderate runoff reduction.
R 10	Graded rows	Slight to moderate runoff reduction.
R 11	Contour strip cropping	Moderate to substantial runoff reduction.
R 12	Terraces	Slight increase to substantial runoff reduction.
R 13	Grassed outlets	Slight runoff reduction.
R 14	Ridge planting	Slight to substantial runoff reduction.
R 15	Contour listing	Moderate to substantial runoff reduction.
R 16	Change in land use	Moderate to substantial runoff reduction.
R 17	Other practices	
	Contour furrows	Moderate to substantial reduction.
	Diversions	No runoff reduction.
	Drainage	Increase to substantial decrease in surface runoff.
	Landforming	Increase to slight runoff reduction.
R 18	Construction of ponds	None to substantial runoff reduction. Relatively expensive. Good pond sites must be available. May be considered as a treatment device.

[1] Erosion control practices with same number are identical. Limitations and interactions shown in Table 12, Principal Types of Cropland Erosion Control Practices and Their Highlights, also apply to runoff control practices.

[2] The ranges in percent reduction of potential direct growing season runoff for the descriptive terms, "slight," "moderate," and "substantial" are shown in Figure 32.

R 3. Sod-Based Rotations

Long-term average direct runoff can be reduced substantially by sod-based rotations. The amount of reduction depends primarily upon the percent of time that the land is in sod, although the residual effects of the meadow increase infiltration rates and may cause a slight to moderate reduction in direct runoff from a row crop in the following year.

R 4. Meadowless Rotations

Direct runoff may be slightly reduced or increased in the years the field is in small grain, but it apparently has no residual effect on infiltration capacity in the row-crop year. Rotations involving only row crops (corn and soybeans, for example) would have approximately the same direct runoff potential as continuous corn.

R 5. Winter Cover Crop

This practice may reduce direct runoff in the fall, winter, and spring if the crop residues are not plowed under. It would have little or no effect on growing season runoff. Limited data indicate that dormant season runoff may be slightly to moderately reduced. If the residues are plowed under before planting the cover crop, direct runoff may be increased.

R 6. Improved Soil Fertility

High soil fertility leads to a rapid extension of the crop canopy, rapid water removal from the soil by plants, and copious plant residues—all of which tend to increase infiltration rates and reduce runoff. Runoff reduction depends on the fertility level of the standard for comparison. Slight to substantial effects have been reported.

R 7. Timing of Field Operations

Direct runoff can be reduced by planning field operations to minimize the time that the soil is bare. Depending on climatic conditions, fall, winter, and spring runoff may be reduced by leaving crop residues on the surface after harvest and plowing in the spring. Planning field operations solely on the basis of minimizing runoff or erosion losses could result in economic loss to the farmer if bad weather prevented planting at the best time for crop production.

R 8. Plow-Plant Systems

The rough surface left by the plow-plant operation increases infiltration rates and surface storage. Direct runoff may be moderately reduced during the growing season.

R 9. Contouring

Contouring reduces direct runoff by increasing surface storage. Direct runoff will be eliminated or reduced substantially for small storms, but may not be reduced for large storms if the contour ridges are breached by runoff. This practice reduces growing season runoff more than dormant season runoff, because the contour ridges become weathered and less effective as the season progresses. This practice is most effective on slopes of 2 to 8%. It is not usually feasible for slopes of less than 2% or on very irregular topography. Direct runoff reductions achieved by contouring according to the Soil Conservation Service procedure are shown for several locations in Table 15. The reductions range from slight to moderate. For slopes of less than 2%, straight rows across the slope are considered to be as effective as contouring.

R 10. Graded Rows

This practice reduces direct runoff by increasing surface storage and allowing more time for infiltration. Runoff reduction for small storms may not be as great with this practice as with practice R 9. However, this practice will be more effective than R 9 for larger storms. Runoff reduction should be similar to that shown for contouring in Table 15 and should range from slight to moderate.

R 11. Contour Strip Cropping

Contour strip cropping reduces direct runoff by increasing infiltration rates on strips in small grains and meadow and by increasing surface storage on contour-tilled strips. For storms in which the infiltration capacities of meadow or grain strips are not exceeded, some direct runoff from intertilled crops may be infiltrated into grassed waterways or lower strips of meadow or small grains. Although the direct runoff from a given land area is less than it would be if the entire area were in a row crop, the runoff from a row crop strip is probably only slightly less than that from an intertilled contoured field.

R 12. Terraces

Gradient and level terraces reduce direct runoff by increasing surface storage and increasing the time that infiltration can occur. Terraces may also make contouring more effective by shortening the effective length of slope and thereby reducing the likelihood of the contour ridges being breached. Estimates of the percent reduction in direct runoff that might occur for contoured and terraced fields (a combination of practices R 9 and R 12) are shown in Table 15 and are in the moderate to substantial range. Gradient terraces alone (without contouring) may increase direct runoff in some instances, but usually would reduce it slightly.

Level terraces are constructed with the channel level and the ends blocked so that runoff is stored until it can infiltrate. The reduction of runoff depends on how much storage the terraces provide. In areas with low rainfall and permeable soils, surface runoff can be nearly eliminated. In areas where retaining all the rainfall and runoff that accumulates in the channel would damage

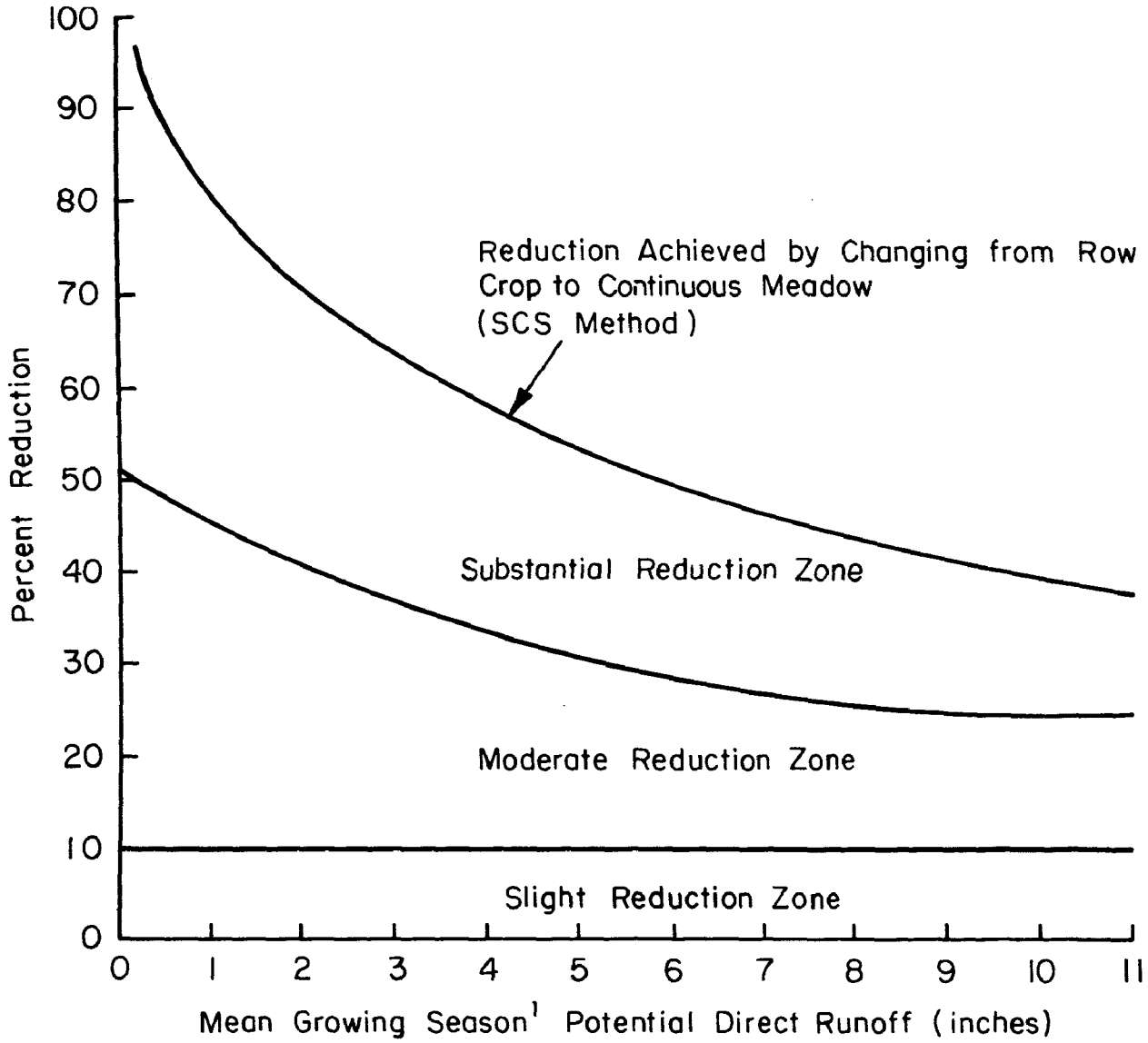


Figure 32.–Definition of ranges of reduction in mean growing season direct runoff.

the crop, outlets must be provided to increase the rate of water removal. Surface runoff will be substantially reduced, but the amount will depend on the design of the terrace system and on climatic and soil factors. By substantially reducing or eliminating surface runoff, subsurface runoff and deep percolation will be increased and may cause a leaching problem.

R 13. Grassed Outlets

No good data are available for grassed outlets, but they may slightly reduce direct runoff.

R 14. Ridge Planting

The amount of direct runoff reduction depends upon the size of the ridges and how closely they follow the contour. Reductions should usually be greater than those shown for the contoured and terraced practice in Table 15.

R 15. Contour Listing

Contour listing can reduce direct runoff by increasing surface storage. In some systems residues are concentrated in the furrows and infiltration rates may also be

Table 15. Potential direct runoff and percentage runoff reduction for selected locations.

Location	Hydrologic[1] soil group	Estimated mean annual direct runoff (inches)	% reduction in annual runoff			Estimated mean growing season direct runoff (inches)	% reduction in growing season runoff		
			Contouring, R 9	Contoured and terraced, R 9, R 12	Meadow R 16		Contouring, R 9	Contoured and terraced, R 9, R 12	Meadow R 16
Wichita, KS	B	2.2	11	22	81	1.7	15	29	80
Columbia, MO	D	5.3	20	37	75	2.9	31	53	68
Columbus, OH	C	3.6	12	21	75	1.0	10	24	73
Des Moines, IA	B	1.6	18	27	89	0.9	24	38	85
Grand Isl., NB	B	1.5	16	23	88	0.9	12	26	90
Sioux Fall, SD	B	1.2	8	16	94	0.7	13	28	95
Cairo, IL	B	4.7	1	9	78	1.3	11	24	80
Indianapolis, IN	C	5.2	11	21	75	1.7	23	42	74
Springfield, IL	B	2.6	12	22	89	1.4	12	24	83
Houston, TX	D	11.3	17	36	52	5.9	17	36	49
Raleigh, NC	B	2.4	16	32	88	1.1	19	39	88
Charleston, WV	C	4.0	14	25	75	1.2	25	36	62
Birmingham, AL	B	7.2	11	21	72	1.8	14	29	74
Columbia, SC	B	4.4	17	31	83	2.3	21	39	82
Dallas, TX	D	8.3	15	32	55	5.1	14	29	53
Little Rock, AR	D	13.4	12	24	58	5.5	11	24	57
Buffalo, NY	B	1.5	13	23	89	0.7	33	54	100
Boston, MA	A	2.2	6	15	94	0.6	11	26	85
Scranton, PA	C	2.6	16	30	82	0.8	21	32	78
Pittsburgh, PA	C	3.2	10	19	83	0.9	22	41	85
Seattle, WA	B	2.9	20	35	85	0.1	33	55	89

[1] More than 4,000 soils in the United States and Puerto Rico have been assigned by the Soil Conservation Service to Hydrologic soil groups A through D on the basis of their runoff potential. Hydrologic group A has low runoff potential; group D has a high runoff potential; and B and C are intermediate. For a more detailed discussion, see Volume II, Appendix A.

increased. Runoff reduction may be somewhat greater than that shown for contour farming (Practice R 9) in Table 15.

R 16. Change in Land Use

A change in land use from row crop to permanent meadow may greatly reduce direct runoff. The amount of reduction for several locations as indicated by the Soil Conservation Service method is shown in Table 15 and in Figure 32. Observations range from a moderate reduction to greater than that shown by the upper curve in Figure 32.

Obviously, substantial local changes in land use will often have serious adverse economic effects on the farmer and the region. A change in land use from straight row summer crops to meadow will give the maximum reduction in direct runoff that can be achieved under usual farming systems. Direct runoff may be reduced still further by conversion to forest.

R 17. Other Practices

Contour furrows are sometimes used to conserve moisture on native range or pasture and will reduce direct surface runoff. The amount of reduction will depend on the size and spacing of the furrows and how closely they follow the contour. The effectiveness of the practice decreases with time as the furrows weather or are overtopped and eroded by surface runoff. In low rainfall areas, contour furrows can almost eliminate surface runoff.

Diversions are sometimes used to channel excess water from a field where a terrace system is not needed for erosion control. Diversions may increase the time of travel and may increase infiltration in the channels. However, they probably will not significantly affect direct runoff.

Drainage is ordinarily installed to improve crop yields. It may either increase or decrease direct runoff that reaches a stream or lake. If it is "pothole" drainage, direct runoff from cropland may reach a stream rather than a local depression. Subsurface drainage will generally reduce direct runoff but may increase total runoff by reducing evaporation and transpiration. Subsurface runoff will be increased and may cause leaching problems.

Land forming may decrease direct runoff by allowing some of the preceding practices to be used. Runoff may increase, however, if soil horizons with lower infiltration rates are exposed or if the soils are compacted.

R 18. Construction of Ponds

Where suitable sites are available, direct runoff may be reduced by constructing ponds to collect runoff from agricultural areas. If the precipitation is low compared to the evaporation, runoff can be reduced. The amount of reduction would depend on the pond's storage capacity relative to the annual runoff from the catchment area. Where actual evapotranspiration equals potential evapotranspiration throughout the year, evaporation loss from the pond will approximately equal evapotranspiration losses from the same area without a pond so runoff will not be reduced, although some of the water will seep through the pond and appear as subsurface or groundwater runoff. The amount of runoff reduction will be highly site-dependent and may range from none to substantial. If the mean detention time in the pond is long enough, it may reduce the peak concentration of dissolved agricultural chemicals discharged to receiving waters. Chemical transformations and deposition of sediment will also take place in a pond, so it can be considered as a treatment device.

Under appropriate climatic conditions, runoff to streams could be reduced by using the water stored in a pond for irrigation.

4.3 NUTRIENT MANAGEMENT PRACTICES

Nutrients are moved from agricultural land by leaching, direct runoff, and in association with sediment from erosion. A number of practices will reduce direct runoff and/or erosion and, thus, reduce nutrient transport. These practices will usually be adequate for controlling overland nutrient transport in addition to sediment and pesticide transport. However, in some cases, such as leaching, additional and/or alternative practices will have to be used to achieve the desired degree of control. These practices involve changing the use of nutrients. A list of these practices and their highlights are given in Table 16.

N 1. Eliminating Excessive Application of Nutrients

To control pollution, one must first eliminate the excessive applications of nutrients. Because we lack the technology to accurately predict the amount of fertilizer required, some growers have tended to overfertilize so that lack of nutrients would not limit yields. However, the energy shortage has caused a dramatic increase in the cost of fertilizer, which should result in a more careful appraisal by farmers of fertilizer use.

Table 16. Practices for the control of nutrient loss from agricultural applications and their highlights.

No.	Nutrient Control Practice	Practice Highlights
N 1	Eliminating excessive fertilization	May cut nitrate leaching appreciably, reduces fertilizer costs; has no effect on yield.
	Leaching Control	
N 2	Timing nitrogen application	Reduces nitrate leaching; increases nitrogen use efficiency; ideal timing may be less convenient.
N 3	Using crop rotations	Substantially reduces nutrient inputs; not compatible with many farm enterprises; reduces erosion and pesticide use.
N 4	Using animal wastes for fertilizer	Economic gain for some farm enterprises; slow release of nutrients; spreading problems.
N 5	Plowing-under green legume crops	Reduces use of nitrogen fertilizer; not always feasible.
N 6	Using winter cover crops	Uses nitrate and reduces percolation; not applicable in some regions; reduces winter erosion.
N 7	Controlling fertilizer release or transformation	May decrease nitrate leaching; usually not economically feasible; needs additional research and development.
	Control of Nutrients in Runoff	
N 8	Incorporating surface applications	Decreases nutrients in runoff; no yield effects; not always possible; adds costs in some cases.
N 9	Controlling surface applications	Useful when incorporation is not feasible.
N 10	Using legumes in haylands and pastures	Replaces nitrogen fertilizer; limited applicability; difficult to manage.
	Control of Nutrient Loss by Erosion	
N 11	Timing fertilizer plow-down	Reduces erosion and nutrient loss; may be less convenient.

Many environmental factors, such as weather, pests, etc., influence the potential yield of a crop and the amount of plant nutrients released by the soil for plant uptake. Experience, either by farmers or extension workers, provides the best estimates of the potential yields for crops under local conditions. Given the potential yield, the nitrogen and phosphorus uptake by the crop can be estimated. The values shown in Table 17 are typical of some leading crops, but the values should be adjusted for yields common to a local area. Sometimes, the soil will provide adequate nutrients, but fertilizers are usually required to supplement the soil supply. The plant use of applied fertilizer varies between 40 and 80% for nitrogen and 15 to 20% for phosphorus.

Fertilizers should not be added unless they are actually needed. Recommendations based simply on "maintenance" or "balance" approaches to replace the nutrients removed by the crop *should be discouraged.* These approaches have been used partly because of a lack of confidence in soil tests. However, soil tests are available that are very useful for predicting fertilizer requirements, particularly phosphorus. In some parts of the country, the "residual" nitrate present in the top 2 feet of soil has been found useful in predicting nitrogen fertilizer needed. In other areas, this nitrate is leached between the time the soil is sampled and the time the plant needs it. The prediction of nitrogen release from soils is more difficult because it is largely controlled by microbiological processes, which are affected by many factors. No rapid soil test is available that provides an adequate estimate of the amount of nitrogen the soil can supply during the growing season, but research for the development of such a test is being conducted. Experience with local field experiments is the best tool currently available to estimate the nitrogen-supplying capacity of the soil and the efficiency of the applied

Table 17. Approximate yields and nutrient contents of selected crops. Values can vary by a factor of two across the country.

Crop		Yield/acre	Lbs N/acre	Lbs P/acre[1]
*Alfalfa		4 tons	200	18
Apples		500 bu	30	4
Barley	grain	40 bu	35	6
	straw	1 ton	15	2
*Beans	(dry)	30 bu	75	10
Bermudagrass		8 tons	200	30
Bluegrass		2 tons	60	8
Cabbage		20 tons	150	16
*Clover	red	2 tons	80	10
*	white	2 tons	130	10
Corn	grain	150 bu	135	24
	stover	4.5 tons	100	16
	silage	25 tons	200	30
Cotton	lint and seed	1 ton	60	12
	stalks	1 ton	45	6
*Cowpea hay		2 tons	120	10
Lettuce		20 tons	90	12
*Lespedeza		2 tons	85	8
Oats	grain	90 bu	55	10
	straw	2 tons	25	8
Onions		7.5 tons	45	8
Oranges		28 tons	85	12
Peaches		600 bu	35	8
*Peanuts	nuts	1.5 tons	110	6
Potatoes	tubers	400 cwt	95	12
	vines	1 ton	90	8
Rice	grain	90 bu	55	12
	straw	2.5 tons	30	4
Rye	grain	30 bu	35	4
	straw	1.5 tons	15	4
Sorghum	grain	60 bu	50	10
	stover	3 tons	65	8
*Soybean	grain	45 bu	160	16
	straw	1 ton	25	4
Sugarbeets	roots	20 tons	85	14
	tops	12 tons	110	10
Sugar cane	stalks	30 tons	100	20
	tops	13 tons	50	10
Timothy		2.5 tons	60	10
Tobacco		1.5 tons	115	10
Tomatoes	fruit	25 tons	145	20
	vines	1.5 tons	70	10
Wheat	grain	50 bu	65	14
	straw	1.5 tons	20	2

*Legumes that do not require fertilizer nitrogen
[1] lbs P = 0.436 lbs P_2O_5

nitrogen. The nutrient contents of some crop residues are also given in Table 17. Residues may be left on the field for erosion protection or removed for livestock feed. The disposition of these residues also has to be considered in fertilizer recommendations. These estimates of potential yield, soil and residue nutrient supplies, and fertilizer efficiency, along with soil tests, can be used to estimate an adequate fertilization level.

N 2. Timing Nitrogen Application

Fertilizer nutrients, particularly nitrogen, are used most efficiently when the time of application closely coincides with the time of absorption by the plant. Consequently, the ideal time to apply an available nitrogen source is when the plant's need is greatest. Sources that must be converted to an available form

need to be applied earlier. For example, nitrate should be applied to corn about 3 to 4 weeks after emergence (Figure 33). This practice is generally known as summer sidedressing and has many environmental advantages. Nitrogen is generally injected as ammonia gas, which converts to nitrate in a couple of weeks, or granular materials are mixed into the soil. Consequently, the nitrogen is unlikely to be lost in runoff and is taken up rapidly by the plant, so the leaching potential is greatly reduced. Since weather is the most unpredictable variable in crop production, delayed fertilization allows a reduced rate of fertilizer to be applied to late-planted or drought-retarded crops. There are disadvantages that make many growers reluctant to use this practice. Rainfall must be sufficient to move the nitrogen down into the root zone, but wet periods can delay applications until yields are decreased. Also, root pruning during delayed fertilization may reduce plant growth. Present storage and transportation facilities may not be adequate and should be considered. Large applications of fertilizers close to young plants can be toxic. Split application, applying part of the fertilizer preplant and the rest as a summer sidedressing, is an effective way to avoid the toxic effects.

For summer row crops, nitrogen is most often applied 2 to 3 weeks before planting, although some is applied in the fall. Fall fertilization is convenient, because the farmer is less busy and it benefits the fertilizer dealer by spreading out the distribution period. Fall fertilization, recommended in some areas, is generally limited to incorporating ammonium fertilizer into soils, except sands, at soil temperatures of 50° F or less. Ammonium ions do not leach, and their biochemical conversion to mobile nitrate ions is greatly reduced below this temperature. However, because the conversion is not completely stopped until the soil freezes, the variations in temperature and rainfall patterns across regions can result in different leaching potentials. The runoff-producing characteristics and the water-holding capacities of the soil are major characteristics controlling percolation and, thus, affect the leaching potential. In general, sandy soils have low runoff characteristics and low water-holding capacities so that the potential for percolation is high. Figure 34 shows the estimated average fraction of fall-applied ammonium that was nitrified and leached below the root zone in selected Land Resource Areas. The estimates were made from calculations of the amount of ammonium converted and the amount of water percolating through the root zone of the predominant soil in each Land Resource Area. Corn was used to represent summer row crops. Twenty to twenty-five years of weather records were used to provide the average estimates presented. Average losses in excess of 10% are probably real and, thus, present a potential nitrate leaching hazard. However, the estimated losses in Figure 34 neglect the possibility that part of the nitrate may be denitrified, thus reducing the pollution hazard. Some denitrification is quite possible, and the loss estimates shown cannot be used to predict the amount of nitrate that might reach a water body. In any event, the possibility of denitrification reducing pollution should not be a controlling factor in recommending this practice. A detailed description of the calculations used for preparing Figure 34 is given in Volume II.

Figure 35 shows leaching losses from spring-applied ammonium fertilizers applied 2 weeks prior to planting. These losses were estimated in a manner similar to those shown in Figure 34. Losses are significant in a few areas. In these areas, summer sidedressing must be seriously considered as the method of applying at least part of the nitrogen.

N 3. Using Crop Rotations

The rotation of crops requiring little (small grains, grasses) or no fertilizer nitrogen (soybeans and other legumes) with crops requiring large amounts can reduce the long-term average amount of nitrogen available for leaching. Including a deep-rooted crop, such as alfalfa, in a rotation can also decrease nitrate leaching, because the plants can utilize nitrates from depths below the normal rooting zone. Even though alfalfa is a legume and normally obtains most of its nitrogen from the air, it will absorb nitrate if present. Rotations often offer advantages for erosion and pesticide control, as well as for nutrient control, and should be considered whenever applicable. The use of sod crops usually requires an animal enterprise for economic use and would probably reduce the amount of cash crops grown or lead to the cropping of less fertile and more erosive land.

N 4. Using Animal Wastes for Fertilizer

One advantage of using animal wastes as fertilizer is that the nitrogen becomes available over a longer period of time. Consequently, less nitrate is available at any one time for leaching. A disadvantage is that nitrogen release will continue after the crop is harvested, and this nitrate will be subject to leaching during the fall and winter months.

There are three major considerations in using animal wastes to supply nitrogen for crop production: (1) determining the amount of nitrogen actually being applied to the land; (2) preventing loss of nitrogen before incorporation with the soil; and (3) determining

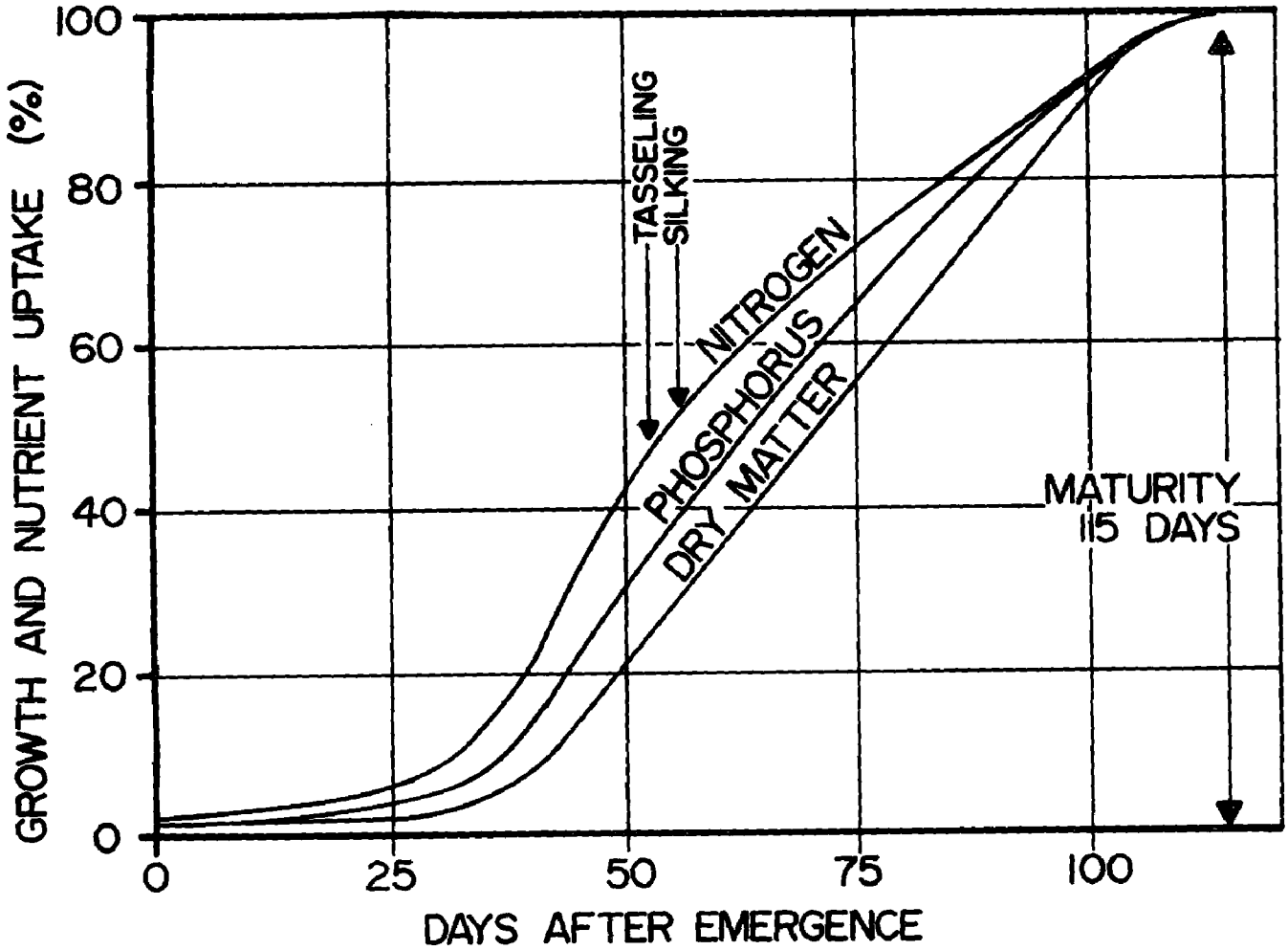


Figure 33.–Corn growth and nutrient uptake.

the rate that the incorporated nitrogen will become available for crop uptake. The use of commercial fertilizers offers a relatively high degree of control for each of these factors. This added control, coupled with the fact that commercial fertilizers are generally more easily and more quickly applied, accounts for the preferred use of commercial fertilizers by many farmers. Manure improves soil physical properties and provides several plant nutrients, but not always in the correct proportions. Manure applications can cause salinity problems, but seldom if application rates are limited to those necessary to supply adequate nitrogen for crop production, commonly from 5 to 15 tons per acre.

The manure, whether applied as a liquid, slurry, or solid, should be incorporated with the soil as quickly as feasible and preferably on the day of application. This is necessary to reduce volatilization losses of nitrogen and prevent pollution of runoff water. Where incorporation is not feasible, such as on frozen ground or pastures, special care is required. Manure should not be applied to frozen fields if runoff from snowmelt occurs, as discussed in Section 3.6b. This may require facilities for storing the manure until a suitable time for land application. Whenever animal wastes are used, the practices N 8, Incorporating Surface Applications; N 9, Controlling Surface Applications; and N 11, Timing Fertilizer Plowdown, should be considered.

N 5. Plowing-Under Green Legume Crops

Legumes can supply substantial amounts of nitrogen to the soil. The quantities of nitrogen fixed will depend on the plant, which acts as the host for the nitrogen-fixing bacteria, and the environmental conditions. Amounts as high as 500 lbs/A. have been reported, but more commonly reported values range from about 80 lbs/A. for red clover to 200 lbs/A. for alfalfa. Like

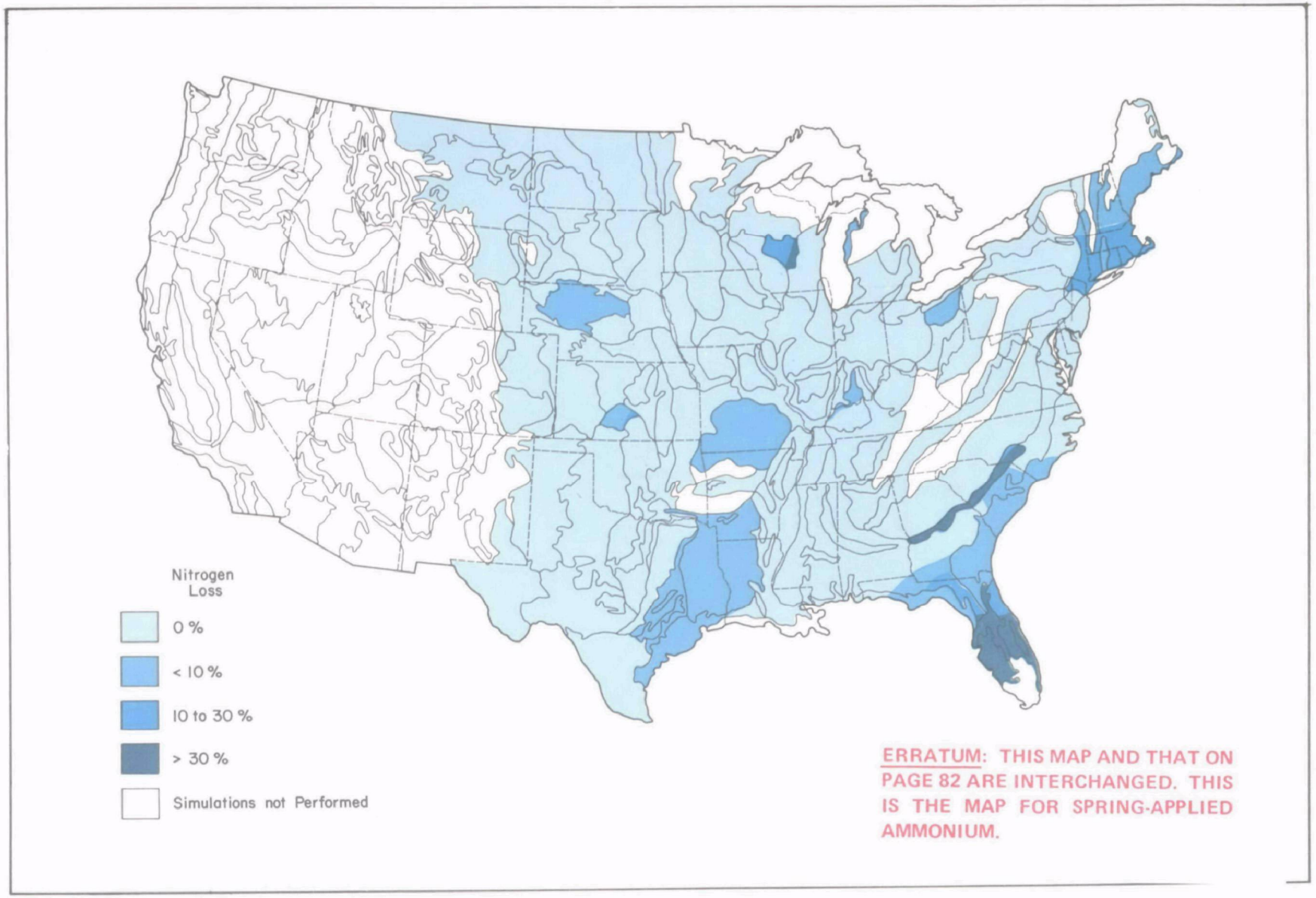
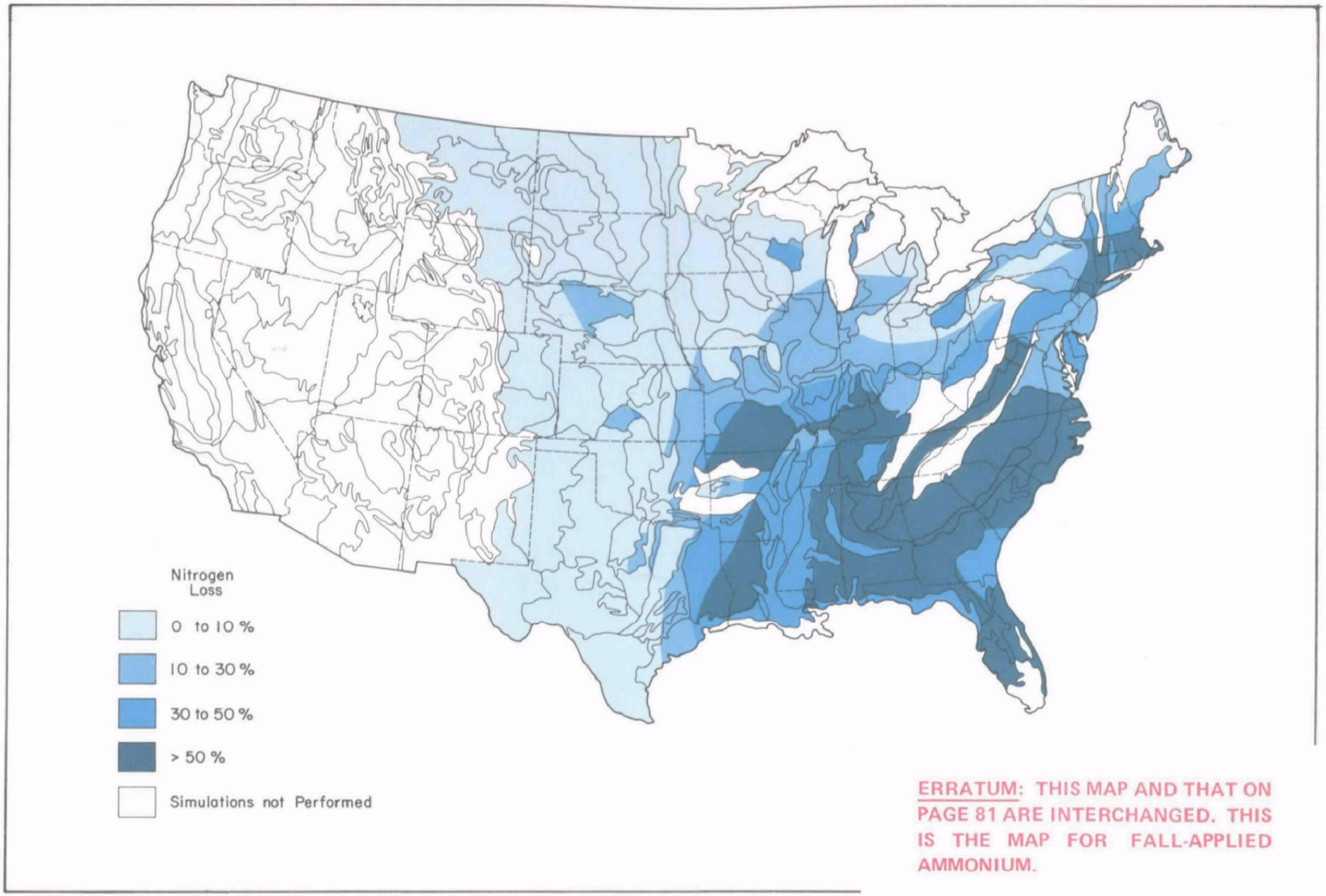


Figure 34.–Potential nitrate loss by leaching from fall-applied ammonium to corn.



ERRATUM: THIS MAP AND THAT ON PAGE 81 ARE INTERCHANGED. THIS IS THE MAP FOR FALL-APPLIED AMMONIUM.

Figure 35.–Potential nitrate loss by leaching from spring-applied ammonium to corn.

fertilizers, some of this nitrogen can be lost as the legume decomposes. When legumes are used as the principal source of nitrogen for nonlegume crops, careful planning is required. A summer legume can be grown and plowed under, but this practice does not allow any benefit from the legume other than providing soil fertility. If rotations are used, a system of leaving a legume on the land for 2 to 5 years will help supply nitrogen for subsequent crops and also allow economic benefit from the legume crop. Major difficulties are the loss of cash crop income, the lack of legumes adapted to the particular soil and climate, and the need of a livestock enterprise.

N 6. Using A Winter Cover Crop

The use of winter cover crops, such as small grains, can reduce nitrate leaching in two ways. First, the cover crop extracts soil water during fall and spring so that less water is available for leaching. Second, the crop will utilize nitrate remaining from the preceding crops. Some of this nitrogen will become available to the succeeding crop following the plowing under of the cover crop. Winter erosion is also decreased. In low rainfall areas, the moisture used by the cover crop will decrease the yield of the cash crop.

N 7. Controlling Fertilizer Release or Transformation

Slowly available nitrogen compounds have been developed that release their nitrogen over a long period of time. Also, nitrification inhibitors have been synthesized to reduce the rate at which ammonium fertilizers are nitrified. These allow the expanding root system to absorb the nitrogen both as ammonium and nitrate throughout the growth period. Further development of these compounds could be very significant in increasing the use efficiency of fertilizer nitrogen and reducing leaching losses. However, their use is not yet economically feasible in most cases and, also, too much nitrate could be released in the fall in some cases.

N 8. Incorporating Surface Applications

Applications should be timed so that the period between spreading and incorporating is as short as feasible, particularly in areas where, and at times when, direct runoff is likely. Loss of fertilizer and manure in runoff water from cultivated fields is generally not great, since farmers normally inject anhydrous ammonia or liquid fertilizers into the soil and plow under broadcast applications. Hay and pasture land, and the use of conservation tillage systems for erosion control, can present special challenges for managing nutrients because of limited opportunities for incorporation. Nutrient management practices N 9, Controlling Surface Applications, and N 10, Using Legumes in Haylands and Pastures, must be carefully considered as a part of these systems to insure that nutrient pollution is not accentuated.

N 9. Controlling Surface Applications

Often fertilizer applications cannot be incorporated on hayland, pastures, or cropland in no-plow tillage systems. If not, one must try to apply the fertilizer when the runoff potential is low (Figure 5). An example is to delay applying manure or fertilizer to frozen sloping lands until snowmelt runoff has stopped. However, the fertilizers applied prior to an extended dry period may be very ineffectively used. Another possibility is to apply the fertilizer in a fluid form. The fluid is a liquid or suspension of microcrystals which permits quicker movement into the soil than the slower dissolving granules. Some fall-planted small grains are pastured during the winter, top-dressed with nitrogen in the spring, and harvested for grain in the late spring. This topdressing would be a potential problem if runoff were high following the application. In this case, the option of topdressing and its potential loss must be compared with the loss from applying all the nitrogen at planting.

N 10. Using Legumes in Haylands and Pastures

Legumes have root nodules containing bacteria that form organic nitrogen compounds from the nitrogen gas in the air. The decomposition of old legume roots and residue can provide sufficient nitrogen for the grasses in a grass-legume mixture. This eliminates the need for nitrogen, but not phosphate, fertilizers. If the phosphate level in the soil is high when the meadow is started, phosphate fertilizer does not need to be applied often. Maintaining a healthy, high-yielding mixture is difficult because the grasses tend to crowd out the legumes.

N 11. Timing Fertilizer Plowdown

When surface-applied fertilizers are incorporated by plowing or disking, the resultant land surface is quite susceptible to erosion. Shortening the time that the surface is vulnerable to erosion will reduce the amount of erosion and loss of associated nutrients. Changing the time of application and incorporation from fall to spring could, however, overtax an already crowded schedule.

4.4 PESTICIDE MANAGEMENT PRACTICES

Clearly, a reduction in runoff or erosion will also reduce loss of applied pesticides, and practices that control runoff and erosion should always be considered in pesticide pollution control. In addition to these practices, a number of options exist, and are often used, that involve manipulation of the pesticide itself. These can be used alone or in conjunction with the runoff and erosion control measures. Table 18 lists 15 such practices, divided into two groups based on their applicability.

Obviously, good basic management of the chemicals should be practiced wherever pesticides are used, whether or not runoff control measures are necessary. Pesticides should always be used strictly in accordance with instructions on their labels; to do otherwise is illegal. The chemicals should be stored so as to minimize the hazard of possible leakage, and containers should be disposed of after use in accordance with procedures

Table 18. Practices for the control of pesticide loss from agricultural applications and their highlights.

No.	Pesticide Control Practice	Practice Highlights
	Broadly Applicable Practices	
P 1	Using alternative pesticides	Applicable to all field crops; can lower aquatic residue levels; can hinder development of target species resistance.
P 2	Optimizing pesticide placement with respect to loss	Applicable where effectiveness is maintained; may involve moderate cost.
P 3	Using crop rotation	Universally applicable; can reduce pesticide loss significantly; some indirect cost if less profitable crop is planted.
P 4	Using resistant crop varieties	Applicable to a number of crops; can sometimes eliminate need for insecticide and fungicide use; only slight usefulness for weed control.
P 5	Optimizing crop planting time	Applicable to many crops; can reduce need for pesticides; moderate cost possibly involved.
P 6	Optimizing pesticide formulation	Some commercially available alternatives; can reduce necessary rates of pesticide application.
P 7	Using mechanical control methods	Applicable to weed control; will reduce need for chemicals substantially; not economically favorable.
P 8	Reducing excessive treatment	Applicable to insect control; refined predictive techniques required.
P 9	Optimizing time of day for pesticide application	Universally applicable; can reduce necessary rates of pesticide application.
	Practices Having Limited Applicability	
P 10	Optimizing date of pesticide application	Applicable only when pest control is not adversely affected; little or no cost involved.
P 11	Using integrated control programs	Effective pest control with reduction in amount of pesticide used; program development difficult.
P 12	Using biological control methods	Very successful in a few cases; can reduce insecticide and herbicide use appreciably.
P 13	Using lower pesticide application rates	Can be used only where authorized; some monetary savings.
P 14	Managing aerial applications	Can reduce contamination of non-target areas.
P 15	Planting between rows in minimum tillage	Applicable only to row crops in non-plow based tillage; may reduce amounts of pesticides necessary.

approved under the provisions of the Federal Environmental Pesticide Control Act of 1972 (Public Law No. 92-516). The best disposal method at present involves burying the containers in an approved landfill. Containers should be triple-rinsed and punctured before burying, and the rinsings should be added to the spray tank if possible. Otherwise, the rinsings should be treated as excess pesticide and buried along with the container. If adequate pesticide application equipment is not available or if the farm operator is untrained and uncertain of proper application procedures, consideration should be given to the employment of certified commercial applicators. When feasible, farm operators should seek training and certification themselves.

In addition to the practices listed below, other measures can be taken to reduce runoff contamination by pesticide residues, but they are not listed directly because they are either in the exploratory stage with more research required, or they have deficiencies that cancel their environmental advantages. Among these are the use of controlled-release pesticides, the use of synergistic pesticide combinations, the use of foams, the destruction of plant residues after harvest, and the practice of increasing the pest damage threshold before pesticides are applied.

Broadly Applicable Practices

P 1. Using Alternative Pesticides

When more than one chemical of comparable cost and efficacy is available to control a specific pest, one should use those compounds that are least likely to cause water pollution. Pesticides that have low toxicity, are not persistent, and do not build up through food chains should be given preference. In an area of appreciable surface runoff but with little erosion, pesticides that move primarily with sediment should be favored over those that are readily dissolved in and move with the water. Table 11 lists the chemicals that are used on the major field crops and Tables 8, 9, and 10 and Figure 29 give specific information bearing on water pollution. Not all of the chemicals listed in Table 11 for a particular crop are interchangeable, only those groups among them that are effective against the same pest. Direct alternatives are noted in the pesticide recommendations of the Cooperative Extension Service of the individual states and the United States Department of Agriculture.

The use of different chemicals in successive years that are equally effective against the same insects or weeds is also beneficial. This acts against the buildup of resistance in the target species and will also result in lower residue levels of those compounds that are relatively stable in the aquatic environment.

P 2. Optimizing Pesticide Placement with Respect to Loss

The manner of placement of a herbicide or insecticide in or on the soil can significantly affect the potential for contamination of runoff. To minimize the hazard, the pesticide is best placed in a narrow band well below the soil surface; broadcast applications on the surface are the least desirable. Pesticidal effectiveness must obviously be maintained and, consequently, soil incorporation is often not practicable. On the other hand, it is more effective in certain situations, such as with volatile or photosensitive herbicides, and is widely used. Other favorable practices include the application of insecticides directly into the seed furrow in row crops and the placement of herbicides in narrow rather than wide bands. The first of these is as effective as band application over the row, provided that the chemical is not toxic to the plants. Only a few chemicals, notably carbofuran and diazinon, can be used in this way. When herbicides are placed in narrow bands centered over the planted row, a supplemental cultivation is necessary to control the weeds between the treated bands. Bands must be wide enough to ensure that weeds do not compete with the crop and to permit cultivation to the edge of the band without injury to the crop. Subsurface sweep applicators that allow precision band placement of herbicides at a predetermined depth are being used with persistent, nonleachable herbicides. Despite the increased power requirements, this equipment is very much needed because precision placement of granules can cut herbicide requirements by as much as 50%.

Fuel shortages could restrict the use of the environmentally desirable band applications. It has been suggested that, to economize on both fuel and labor, farmers might gradually have to replace band application with broadcast methods, with a resultant large increase in pesticide applied per acre. The trend among soybean growers is already toward increased broadcast application of herbicides. Broadcasting is also the only feasible treatment in closely drilled crops.

P 3. Using Crop Rotation

Crop rotation, a practice that is used primarily when crops complement each other economically, can lessen

the pesticide contamination of runoff. Sometimes, crop rotation will suppress insects, weeds, or plant diseases, so that less chemical pesticide is required, and it can also reduce soil erosion. Therefore, the advantage of the technique should be explored and exploited wherever possible. Crop rotation has lost favor recently because of the development of new, efficient pesticides that permit continuous cropping of economically advantageous crops. However, the present energy shortage and increased costs of chemicals may well reawaken interest in rotation.

Evidence for the environmental benefits of crop rotation is abundant. For example, a potato-oats-sod rotation reduced runoff losses of organochlorine insecticides as much as 40% in comparison with losses from continuous potatoes. In insect control, rotations suppress the buildup of resistance to insecticides and break the life cycle of certain insects that require specific host plants to survive. The favorable action of rotations in insect control is typified in Illinois, where almost 70% of the fields in continuous corn were treated with soil insecticides in 1972, whereas only 42% of the fields in first-year corn were treated. Rotations also help to control weeds because some weeds are harder to control in some crops than in other crops. On the other hand, control of a few weeds, such as Johnsongrass in cotton, is simplified if a single crop is planted in successive years.

P 4. Using Resistant Crop Varieties

The use of crop varieties resistant to attack by diseases or insects will obviously reduce the need for chemical treatment. Some crop varieties are more competitive with weeds than others, but generally such differences are only moderate and other weed control practices are required. Two examples of resistance against insects are hybrid corn varieties resistant to first-generation corn borers and potato varieties resistant to the golden nematode. Crop resistance is generally insufficient in itself to control insects and supplemental chemicals may have to be used, but fewer treatments are needed. There are exceptions, however: certain wheat varieties are practically immune to Hessian-fly attack and require no chemical treatment. A minimum-hazard pest control program should include the use of resistant varieties.

P 5. Optimizing Crop Planting Time

Agronomically, the recommended time of planting many crops in any given area covers a range of several weeks. For certain insects, the precise time of planting within this period can strongly influence infestation of the crop and can thus affect the eventual need for insecticides. With corn, for example, early planting is preferable with respect to infestations of the European corn borer. First-generation borers, to which many hybrid corn varieties are resistant, lay most of their eggs in early-planted fields; eggs of second- and third-generation borers, which must be controlled by insecticides, are usually concentrated in late-planted fields. Early-planted corn is subject to less attack by the corn earworm in northern states than later corn, but the reverse is true in southern states because crops that are more attractive to the insects than corn are not available until later. Late planting also helps to combat damage by white grubs and seed maggots in corn, because of the early active life of the insects. However, an inherent disadvantage of late planting is that rain delays could greatly reduce yields. With wheat, an effective way to avoid infestation by the Hessian fly is to seed late in the fall after the fly has disappeared. Damage by white grubs and wireworms is also prevented. Early planting of sugarcane (August) produces less injury by sugarcane beetles and by wireworms than late plantings (September-October). A break of several weeks between early and late planting of sorghum in an area can help reduce populations of the sorghum midge.

P 6. Optimizing Pesticide Formulation

The formulation in which a pesticide is applied can affect the runoff contamination potential. For example, the addition of surfactants or nonphytotoxic petroleum or linseed oils to the spray mix of foliar-applied herbicides can increase the penetration and translocation of the chemicals within the target plants, so that the efficiency of action is increased and less active ingredient is needed.

Some formulations are a greater hazard than others having the same active ingredient because other components in a pesticide formulation—solvents, additives, or diluents—may be more toxic to fish and other aquatic organisms than the herbicide itself. Newer formulations, such as controlled-release products and foams, may increase effectiveness and reduce treatment rates, but are still largely experimental. Granular formulations, particularly if incorporated in the soil to avoid losses by erosion, are environmentally preferable to liquids because application losses are lower. It has been predicted that the trend in the pesticide industry will be away from solvents and emulsifiable formulations and toward wettable powders and more concentrated formulations because of impending shortages in petrochemical feedstocks.

P 7. Using Mechanical Control Methods

Sound management of cropland requires a careful balancing of the various interacting agronomic, economic, and environmental factors; nowhere is this more evident than in the choice of chemical or mechanical control of weeds or a combination of the two, which is a common practice. Mechanical weed control includes hand pulling, mowing or cutting, flooding, covering with mulch, oiling, and burning, but the most important method by far is tillage. Preplant tillage is useful not only for controlling weeds but also for proper seedbed preparation. If rainfall is not very heavy or intense, it may reduce soil loss in runoff by breaking up the surface layer of soil so that infiltration is increased. It obviously reduces the necessity for herbicide application and disperses phytotoxic residues from any herbicide applied in the previous year.

There are, however, drawbacks to tillage that counterbalance its benefits. Erosion may be substantial if heavy rain falls while the soil is bare. Repeated manipulation of soil may deteriorate soil structure, especially with moist soils. Moreover, frequent use of heavy machinery can compact the soil so that air and water movement is restricted and crop yield is reduced. The most severe shortcoming of tillage, and the one factor that seems to be causing a current trend away from mechanical cultivation, is the economic consideration. Tillage requires manpower, machinery, and fuel. It has been estimated that, if herbicides were unavailable, an additional 100 million gallons of fuel would be needed annually in this country to control weeds by mechanical cultivation. In view of the presently sharply rising costs not only of fuel but also of labor and equipment, it is no surprise that herbicides are finding increasing favor among our farmers.

P 8. Eliminating Excessive Treatment

A common practice in insect control is to apply an insurance treatment of a chemical to guard against a possible outbreak of a particularly destructive pest. For soil insects, this is often the only safe policy to follow, because it cannot generally be predicted where populations will be of economic proportion and the insects may otherwise destroy the crop. As a result, high percentages of the soil insecticides are applied needlessly. Where predictive techniques have not been developed, cultural or biological controls should be instituted whenever possible to reduce unnecessary applications.

Control of aboveground insects should always be based on plant damage and actual pest counts and should be used only where potential economic losses justify the pesticide application. For larger fields, careful treatment of infested areas only should be considered rather than spraying entire fields. Often, the decision to apply pesticides is now made in the field by insufficiently trained personnel; clearly, additional educational efforts are needed. Use of the "scout" system, in which professional entomologists are employed by responsible agencies to survey crop areas and determine when insecticide application is needed, will reduce unnecessary treatments and is strongly recommended.

There is also a tendency to use unnecessarily widespread treatments for weed control. It is important to identify specific weed problems so that judicious controls may be instituted. Fall weed surveys, as well as follow-up surveys during the subsequent growing season, which might be done in conjunction with insect or disease scouting, could improve efficiency through application of chemicals only where needed.

P 9. Optimizing Time of Day for Pesticide Application

If pesticide spraying is confined to the early morning or evening hours when the air is relatively still, better on-target deposits will be obtained and the rate of application could well be reduced. This is particularly important with aerial sprays. Evening spraying of chemicals that are toxic to beneficial honeybees, such as the methylcarbamate insecticides, is preferable because the bees generally stop seeking pollen in the late afternoon. Irrespective of the time of day, spraying should be postponed under windy conditions, when a temperature inversion (warm air overlying cool air) exists, or in the face of forecasts of impending heavy rain.

Practices Having Limited Applicability

P 10. Optimizing Date of Pesticide Application

Pesticides usually must be applied within a relatively brief time period to be effective against the target organisms, so few options are open with respect to reducing runoff contamination by changing the application date. Unfortunately, the best time for applying many pesticides, early spring, coincides with the time that high rainfall and accompanying high runoff and sediment transport often occur. Because losses of pesticide in runoff are relatively large only when rainfall occurs shortly after application, any action taken to move the pesticide treatment away from peak runoff periods while maintaining pesticidal effectiveness is

advantageous. Thus, where runoff is high in the spring and where the options are practicable, postemergence treatments are preferable to preemergence treatments, treatments late in the season when the crop canopy has closed are potentially less hazardous than earlier treatments, and fall treatments are more desirable than spring treatments. Due regard must, of course, be given to the nonenvironmental disadvantages of the practices, and judgments must be made after weighing the offsetting factors. For example, postemergence herbicide applications are disadvantageous in that they allow early competition of weeds with crops; require labor at a critical time on many farms; often are not as effective as preemergence treatments; and allow no later options, as do preemergence applications, if weather interferes with the treatment.

The timing of preplant soil-incorporated chemicals is less critical than that of preemergence types, so very early preplant applications can be considered for some chemicals, particularly insecticides, having sufficient persistence in the soil. Some insecticides are equally effective whether applied in early spring at planting or in late spring. The later treatment is preferable not only because the runoff hazard is less but because shorter-lived chemicals can be used effectively.

P 11. Using Integrated Control Programs

An effective integrated control program—defined as any combination of chemical, biological, cultural, or mechanical control techniques—to eradicate a pest or to decrease its population to acceptable damage levels and maintain it there is the ideal in pest management. Some outstanding successes have been achieved with integrated programs, one example being the control of the spotted alfalfa aphid in western U.S. fields during the 1950's, in which resistant alfalfa varieties, parasites, predators, pathogens, and pesticides were effectively combined. Other experimental programs hold promise for overcoming very important pests, such as the boll weevil and bollworm in cotton. Another attribute of integrated control is that it can be far more economical than pesticide use alone; the amount of pesticide needed can often be reduced substantially.

The building of an integrated control program by design, however, is a complex task that requires lengthy research and many different talents. The dynamics of pest populations must be studied and the most effective combination of available control techniques identified. On the other hand, present-day economic and environmental pressures are not expected to ease, so that integrated control will continue to be actively developed in the coming years.

P 12. Using Biological Control Methods

Biological methods hold promise for control of damaging insects and weeds, but the achievements to date, although significant, are still relatively small compared to the great number of pests. In insect control, biological methods appear to be most effective against pest populations that had been reduced by preliminary treatment with insecticides. Other inherent problems in using biological methods include the control of selectivity, parasites of the biological agents, and the fact that insects cannot be introduced to control plants, such as cactus, that are serious weeds in agricultural situations but desirable in others (cactus is used for feed or food in some locations). Although results have been dramatic and advantageous in a number of cases, biological control of insects and weeds has not been used widely on agronomic crops.

The methods include the use of sex attractants, warning or aggregating chemicals that influence the behavior of insect colonies, insect growth regulators, sterilized male insects, insect pathogens (disease-causing agents), antifeeding compounds, and parasitic or predatory insects. Research on each of these is being pursued and there have been a number of successful applications. One insect pathogen, *Bacillus thuringiensis*, is now commercially produced. It is, however, useful only against insects whose gut is alkaline (moth larvae, caterpillars, butterflies), it must be ingested, and it is rapidly destroyed by sunlight. Biological methods are most useful against insects and mites, but there have been a few cases of successful control of weeds, notably Klamath weed (St. Johnswort), alligator weed and cactus (in foreign locations), by introduction of insect predators.

P 13. Using Lower Pesticide Application Rates

Federal pesticide registrations, including recommended rates of application that appear on pesticide labels, are issued on a nationwide basis. Because of the very large number of formulations and the broad areas involved, it is not possible to test rigorously each pesticide in each local situation. Consequently, there may be situations in which climatic and geographic conditions are such that doses below the minimum recommended rates will control a pest. Several such cases have in fact been noted by the Environmental Protection Agency. Furthermore, doses lower than recommended rates may be adequate for use in integrated pest management programs. Since rates below label recommendations are now permitted for agricul-

tural uses provided that they are authorized by appropriate agencies such as the Cooperative State Extension Service, State agricultural experiment stations, or offices of County Agricultural Commissioners, it is recommended that such authorized rates be used whenever possible, to save pesticide costs and to lower the potential environmental hazard.

Reduced-spray techniques can also be used effectively in some instances, with accompanying reduction in total pesticide applied. On fruits, for instance, reduced or half-sprays with extended intervals between spraying or alternate middle-row treatments have provided adequate control. Similarly, spraying with low-volume concentrated sprays rather than with dilute sprays at high volume can reduce insecticide use as much as 20% while maintaining the same level of pest control.

P 14. Managing Aerial Applications

Aerial applications of pesticides are not environmentally favorable and special precautions should, therefore, be taken when such treatment is necessary. Aerial treatment can only be applied broadcast, increases the likelihood of uneven distribution of pesticide on the crop, and increases spray volatilization and drift that may injure susceptible crops in adjoining areas and directly contaminate nearby surface waters. A smaller amount of chemical reaches the target and, therefore, somewhat higher treatment rates may be needed to achieve the same degree of pest control. Because of the drift hazard, aerial spraying should be limited to periods of low wind and when the wind is blowing away from susceptible crops. Spraying should not be conducted when there is a temperature inversion, because such conditions favor horizontal transport of airborne pesticides. Where contamination of areas adjacent to the treated area must particularly be avoided, special pesticide formulations, special nozzles, and/or low pressures should be used.

Despite these problems, aerial treatment is the only practical means of spraying in some agricultural situations (close-growing crops, rangeland) and its use on field crops is increasing. It can be used in areas of excessive rainfall where ground equipment would fail, eliminates wheel track compaction that can reduce crop yields, and is the only effective means to combat sudden, widespread pest infestations.

P 15. Planting Between Rows in Minimum Tillage

Planting between last year's rows rather than on them in continuous minimum tillage systems helps somewhat to reduce populations of soil insects and may lessen the need for heavy insecticide applications. The practice does, however, have disadvantages. Planting would be more difficult in the areas that had been compacted by wheeled equipment travel of the previous year, and row fertilizer placed for the previous crop would not be used by the new planting.

SECTION 5

ECONOMIC CONSIDERATIONS

The definition of pollution implies that one group in society creates and deposits in the environment certain materials that degrade the aesthetic environment or raise costs for others. The imposition of pollution controls is designed to prevent environmental degradation through the encouragement of production methods that will not cause off-site pollution.

The purpose of this manual, as already stated, is to provide information to individuals or agencies charged with developing plans for the control or reduction of pollution from nonpoint agricultural sources. The information presented in preceding sections dealt with the technical aspects of nonpoint pollution control. However, responsible officials also must consider the various positive and negative economic impacts that pollution and pollution control plans have upon agricultural producers and the economy as a whole.

The assessment of these economic impacts involves first the decision-making process of individual farmers faced with new pollution tolerances or recommended runoff control practices, since all efforts to manage pollution alter the decision-making options of the farmer. Pollution control agencies may forbid selected methods of production or prescribe certain activities that are deemed desirable for the environment. The individual farmer is concerned with adjusting his farm cropping plan and production activities to the new standards in a manner to ensure that his operation is profitable. This problem is addressed in Sec. 5.1.

The sum of independent decisions of individual farmers caused by the imposition of pollution standards has positive and negative effects on society. These social impacts may include: increases in food prices; changes in demand for and prices of inputs such as energy, pesticides, and labor that are used in all sectors of the economy; and changes in the availability and quality of some agricultural products. Additionally, there may be secondary effects such as the changed volume of business for suppliers of affected inputs, adjustments in land value, and changed employment requirements in agriculture where cropping intensities are changed. The social benefits may include cleaner water, longer lasting reservoirs, reduced water purification costs, more fish, and less eutrophication of lakes. These issues will be discussed in Sec. 5.2.

This overview of economic considerations can estimate neither the social costs and returns nor farmers' reactions in specific cases. It tries only to set a framework and to alert drafters of pollution regulations to potential local and national economic impacts of their actions. These impacts will have to be quantified on a case-by-case basis for specific pollution regulations. This is not easy and may require a substantial research effort. This effort can be aided by conceptualizing the impacts in large-scale models, such as interregional linear programming or simulation models or by use of input-output multipliers and similar tools. The policy maker may wish to seek specialized assistance from economists with state or national agencies, universities, and private firms in the process of formulating the most socially responsible pollution control program.

5.1 Effects on Individual Producers

If a pollution control board promulgates a new environmental standard, some individual farmers must adjust their production methods to satisfy the restrictions, while others may find that the new standards place no restriction on their practices. The actions of any one farmer will have no measurable influence on the regional-national markets. The farmer's attention is thus logically focused on the maximization of his average net returns over time. To aid in his decision-making process, he could use a partial budget framework. He would select, from the physically feasible set of production methods permitted under the standards, those alternatives that yield the highest average annual net return for his resources. Table 19 lists variables that should be considered in the budgeting framework. Use of the procedure is demonstrated in the farm example in Sec. 6.2.

Expected gross revenue is expected crop yield times expected selling prices. Alternative production methods may reduce or increase expected yields. Examples of

Table 19. Factors that should be considered in budgeting alternative nonpoint pollution control practices

A. GROSS REVENUE:

1. Expected prices
2. Expected production

Gross Revenue = (1 X 2)

B. PRODUCTION COSTS BY OPERATION:

1. Land Charge

2. Tillage
   - Labor
   - Equipment
   - Fuel
   - Interest
   - Scheduling

3. Fertilization
   - Labor
   - Equipment
   - Fuel
   - Fertilizer
   - Interest
   - Scheduling

4. Pest Control
   - Labor
   - Equipment
   - Fuel
   - Pesticides
   - Interest
   - Scheduling

5. Planting
   - Labor
   - Equipment
   - Fuel
   - Seed
   - Interest
   - Scheduling

6. Harvesting
   - Labor
   - Equipment
   - Fuel
   - Interest
   - Scheduling

7. Storage and Transport
   - Labor
   - Equipment and Facilities
   - Fuel
   - Interest
   - Scheduling

8. Pollution Control Practice Design, Construction, Installation, Operation and Maintenance
   - Labor
   - Equipment
   - Fuel
   - Interest
   - Scheduling

TOTAL PRODUCTION COSTS = 1+2+3+4+5+6+7+8

NET REVENUE = (Gross Revenue - Total Production Costs)

C. OTHER FACTORS (Risk, Uncertainty, Attitudes, Preferences, etc.)

such yield differences are increased yields on terraced acres (in some cases) because of improved moisture retention or decreased yields for no-till fields as a result of the requirements for more precise management and timeliness compared with conventional tillage.

Tillage, fertilization, pest control, planting, harvesting, storage and transportation may change independently with the imposition of pollution standards. All changes should be carefully considered for both cost and yield effects.

The cost of equipment and facilities used currently should be amortized over their expected life, and their annual operating and maintenance cost budgeted according to their level of use. Adoption of new production practices may make some equipment obsolete. Any such capital loss should be charged to the new practice in the budget, amounting to current depreciated value less salvage value of the obsolete equipment. One method of including such capital loss is to amortize it over the life of the new equipment. Thus, the new practice is charged with both the new capital costs plus the capital loss which would result from its adoption.

Both inputs and products should be included in budgeting storage and transportation costs. A given alternative practice may change the requirements for storing fertilizer, fuel, product, or equipment.

The cost for the control (Item 8, Table 19) refers to the cost of land structures such as terraces, ponds and drainage ditches. This cost includes the prorated annual opportunity costs [1] of the capital investment plus any annual operation and maintenance costs.

All production costs should include a charge for interest. This charge refers to either the opportunity cost of capital involved in the operation, such as implements, or to interest charges for loans to purchase fertilizer, seed, etc. The opportunity cost for capital should be prorated over the economic life of the capital item, whereas short-term interest costs are charged only for the period for which money is working.

No management decision is made exclusively on the basis of monetary costs and returns. Other variables (Item C, Table 19) such as risk, uncertainty, grower attitudes, preferences, education, size of operation, work scheduling problems, alternative investment opportunities, tax structures, and tenure status, will also influence the individual's decision. The final choice must be left to the producer, but the profit maximizing farm plan is a good indicator of what farmers may do as a result of a new regulation.

If the user wishes more detail on partial budgeting techniques and related information than is presented in this chapter, the example in Section 6.2 or in Volume II, Appendix C, other works are available. Such references as the following could be consulted: Emery N. Castle, Manning Becker and Fredrick Smith *Farm Business Management*, second edition, The Macmillan Company, New York, 1972; J. H. Herbst, *Farm Management: Principles, Budgets, Plans*, third revised edition, Stipes Publishing Company, Champaign, Illinois, 1974; Sydney C. James and Everett Stoneberg, *Farm Accounting and Business Analysis*, Iowa State University Press, Ames, Iowa, 1974.

5.2 Aggregate Economic and Social Effects

A pollution control board should recognize that any action it takes may cause large numbers of farmers to change their production practices. These changes would be expected to improve the environment and thus benefit society. However, the net effect of many changes in production decisions may reflect costs to society. For example, total production may be reduced, food prices raised, and regional specialization and the general level of business activity and employment may be changed.

[1] Opportunity cost is defined as the return which the capital would have been expected to earn if it had been invested elsewhere.

Of course, a lack of adequate environmental standards also may have pervasive economic and social effects. For example, high rates of soil erosion reduce the future yield capability by removing the surface layers of large tracts of soil.[2] The eroded soil enters waterways, causing complex problems involving water purification for down-stream users, out-of-bank flows, and accelerated siltation of reservoirs and shipping lanes. The pollution boards, acting on behalf of society, will have to compare the social costs and benefits of nonaction to those of imposing alternative types and levels of environmental standards.

To evaluate the social costs and benefits of imposing an environmental standard, one must first assess and aggregate the adjustments individual farmers will make in their production plans. Previous sections of this manual will help users identify the type and scope of pollution problems to be expected in broad areas of the country. By the method outlined in Section 5.1, users may obtain a general idea of the type and size of the adjustments that will be required from farmers in local areas as a result of specific pollution tolerances and practice restrictions.

The environmental standards will necessitate changes in production methods of those farmers whose previous production practices would cause pollution in excess of the standards. Once the cumulative changes have been estimated, a series of direct and indirect impacts must be considered. These impacts include changes in production costs, aggregate farm income, crop prices, acreage of cropland, location of production, land values, foreign exchange earnings, economic viability of rural businesses, the tax base of rural communities, and social and cultural values of rural people[3].

These impacts are highly interrelated. Assuming impacted farmers had already utilized their resources to maximize net income, their net income after making necessary changes is likely to be reduced both because of changes to lower valued crops and the likelihood of increased production costs. For farmers not directly impacted, the situation is more difficult to estimate. The situation is affected by the cumulative decisions of impacted producers including the effect these decisions

[2] Part of this yield decline may be offset by increases in fertilizer use. In this case, there are also social costs to consider. First, the increased fertilizer demand may raise the price of fertilizer, increasing production costs for all agricultural producers. Second, the higher-price fertilizer may cause a subsequent increase in the production of fertilizer, drawing raw materials away from other uses. Third, in the case of fertilizer materials that are imported from foreign sources, there will be a direct effect upon the foreign trade balance of the United States.

have on aggregate output and demand for inputs. The interaction between actions taken by affected and nonaffected producers creates implications for land values, total acreage used for cropland and relocation of production. For example, if producers with highly erodible land have to produce lower valued crops as a result of a pollution control regulation, the agricultural value of their land would be expected to decrease. Similarly, less erodible lands could increase in value, bringing windfall gains to owners. Additionally, it could be expected that shifts in location of production would occur if a regulation changed the competitive production aspects among regions. The final effect of an aggregate change in output on crop prices and on gross revenues of farmers will depend upon the nature of the demand and the structure of the market for outputs, i.e., the ability of farmers to pass cost increases to consumers.

Changes in variables mentioned above, in turn, have implications for rural businesses such as fertilizer dealers, grain elevators, and banks. Additionally, rural communities are potentially affected through changes in the tax base, demand for services, employment opportunities, etc. Also, social and cultural values, quality of life and related issues enter into a complex set of impacts and interactions. For example, in certain situations, production cost increases resulting from the imposition of an environmental standard can be passed on to consumers in the form of higher food prices. In such cases, relatively more of the impact of the standard will be borne by those members of society who spend relatively large portions of their income on food. Detailed analyses are required to sort out these interactions. Various analytical techniques, as mentioned previously, have to be employed. This brief chapter cannot include a discussion of these analytical methods.

For a more complete discussion of some of the concepts introduced here, the user may wish to consult works such as Joseph J. Seneca and Michael K. Taussig, *Environmental Economics,* Prentice Hall Incorporated, Englewood Cliffs, New Jersey, 1974. Application of these concepts to environmental problems is described in many works, including Allen V. Kneese and Blair T. Bower, *Managing Water Quality: Economics, Technology, Institutions,* Johns Hopkins University Press, Baltimore, Maryland, 1968; and Earl O. Heady and Uma K. Srivastava, *Spatial Sector Programming Models in Agriculture,* Iowa State University Press, Ames, Iowa, 1975. If a basic treatment of analytical methods is desired, such works as the following may be helpful: William H. Miernyk *The Elements of Input-Output Analysis,* Random House, New York, New York, 1965; J.B. Dent and J. R. Anderson, editors, *Systems Analysis and Agricultural Management,* John Wiley and Sons, Sydney, Australia, 1971; and Fredrick Hillier and Gerald Lieberman, *Introduction to Operations Research,* Holden-Day Incorporated, San Francisco, 1967.

Of equal importance in setting priorities on pollution control is a recognition of the private and social benefits to be derived from such control. To the extent feasible, these benefits should be assessed. Typically, the costs of pollution control have some effect on different groups in society and different geographical areas than those groups or areas receiving benefits. This makes an assessment difficult. Also, many of the benefits are more difficult to quantify relative to costs. Regardless of these quantification difficulties, a decision on nonpoint pollution control regulation will be made and should be based on a comparison of the total benefits received relative to the total costs to society. Obviously, benefits should exceed costs.

Benefits potentially can occur at various levels. There may be on-farm, local-area, regional and national benefits. On-farm benefits can be in the form of reduced gully and sheet erosion, more efficient use of plant nutrients and pesticides, increased organic matter in the soil, and increased water retention in fields resulting in decreased production costs, higher yields and more cultivatible area within given fields. Local-area benefits may include better drinking water; more recreation; less stream, channel and bridge repair; less in-stream dredg-

[3] Some attempts have been made to evaluate a few of these potential impacts. For example, a recent Iowa State University Study; Nicol, K. J., Madsen, H.C. and Heady, E.O. "The Impact of a National Soil Conservancy Law", Journal of Soil and Water Conservation, Sept-Oct. 1974, Vol 20, No. 5; indicated shifts in location of production would occur if a national soil loss restriction of 5 tons per acre per year were imposed. The acreage used for cropland would be reduced by more than 14 million acres from the 1969-71 level. Changes varied by region of the country with decreases in 4 major regions and increases in other regions. Associated with these changes would be reductions in row crop acreage and shifts to close-grown cover crops. This study also predicted that prices at the farm level would generally rise.

Another study; Rosenberry, P. and Alt, K. "Gross Soil Erosion and Crop Production in Iowa-Cedar River Basin", Economic Research Service, USDA Draft Report; indicates that restricting soil loss to 3 tons per acre per year in the Iowa-Cedar River Basin increased variable costs of production more than 5 percent. Preliminary results show a major portion of this cost impact falls on producers in land areas with highly erodible soils. The study also concludes there would be significant shifts in location of production from more to less erodible soils, changes in crop rotations, and a general shift from conventional to minimum tillage.

ing; and general aesthetic improvement. Regional and national benefits are similar to potential benefits to local areas, although they may be more extensive and less easily attributed to specific pollution control regulations or practices. Benefits could include less flooding potential, better use of natural resources, maintaining productivity of agriculture, better health conditions and lower fuel consumption.

An approach to assess benefits is to cost out alternatives. This approach has several advantages. In a partial budget analysis some of the on-farm benefits, particularly costs of production and yield effects, would be included. Consequently, these benefits would be known. The same is not true for area, regional and national benefits. However, it must be recognized that pollution control is being demanded by many groups in society. These demands are based upon their perception of pollution problems and environmental quality. If a decisionmaker can present to society the private and social costs associated with alternative standards and regulations, then both the decisionmaker and society, in general, should be in a better position to judge the desirability of and need for alternative levels of control.

In the final assessment, if the total benefits greatly exceed the private and social costs and if severely disadvantaged social groups could be compensated appropriately, then a special pollution standard or practice should be imposed. Unless there is compensation in some form (such as cost sharing or tax write-offs), the burden of the regulation may fall relatively heavily upon the region that imposes the standard. There may, therefore, be some income transfer from this area to other areas as a result of the regulation.

The agency charged with setting pollution tolerances and developing control programs may be urged to consider more strongly the local costs and benefits than the regional-national costs and benefits. However, to the extent feasible, boards should also consider the national and regional implications of their actions.

Hopefully, actions to control pollution from nonpoint sources would address those problems offering the greatest benefits to society, i.e., benefits per person times number of people benefited. Regulations or recommended practices selected should be those with the least negative economic and social impacts on individuals and society.

SECTION 6

DECISION FLOW CHARTS AND EXAMPLES

6.1 FLOW CHARTS

Determining whether a nonpoint pollution problem may exist and, if so, what measures may be taken to alleviate it most effectively involves a logical sequence of decisions. This sequence can be illustrated schematically by flow charts. Flow charts for assessing erosion problems and selecting physically feasible control practices are shown for large and field-sized areas in Figures 36 and 37, respectively. Similar flow charts are shown for nutrients and pesticides in Figures 38 and 39, respectively. Then, examples are given showing how the flow charts can be applied to both large and small areas.

Quantitative information is available to permit development of definitive answers for most of the questions posed in the flow charts. The figures and tables referenced within the charts give the needed data for relatively large areas, and similar information can be easily obtained for individual fields or other small areas. *Certain of the questions, however, require more detailed analysis before an adequate answer can be obtained.* One such question, "IS TRANSPORT OF PLANT NUTRIENTS ON SEDIMENT A HAZARD?," is posed in Figure 38. Here, it is desirable to refer first to Figure 9 for relative erosion potential, but this in itself will not provide the needed answer. Reference to a soil-loss tolerance goal as in Figure 37 is not much help and can even be misleading. This is because tolerances are selected for reduction of soil loss to maintain the productivity of the land; transport of sediment itself is of concern, not transport of plant nutrients attached to the sediment. Thus, the recommended use of a 3- or 4-year crop rotation to reduce soil loss to an acceptable average annual loss over the period of the rotation would not necessarily eliminate the nutrient hazard, because nutrient movement could be quite high during the worst year of the rotation. To answer the question properly, one must consider not only the long-term erosion potential but also the potential for gross sediment loss in any given year in which fertilizers are applied. Similarly, to answer the question in Figure 39, "IS TRANSPORT OF THESE PESTICIDES ON SEDIMENT A HAZARD?," one must consider not only the relative erosion potential (Figure 9) but also whether persistent and/or toxic chemicals can be moved on eroded material to an unacceptable extent even when gross sediment movement is low. Thus, the user of the flow charts must occasionally obtain additional information pertaining to the land areas under consideration to supplement the information in the figures and tables.

6.2 EXAMPLE FOR A FIELD-SIZED AREA

Consider a field in Western Iowa on a 6% slope of Monona silt loam with organic-matter content above 3%. The slope length is about 350 feet and the topography is suitable for contour farming. The farmer wishes to produce as much corn as is feasible. What are his alternatives?

Proceed as outlined in the Master Flow Chart, Figure 1, to the Erosion Flow Chart for field-sized areas, Figure 37.

1. R = 160 (Figure 10a); K = 0.37 (SCS, or Table 2a); LS = 1.3 (Table 3); I = 160 x 0.37 x 1.3 = 77 T/A.
2. For this example, we will assume a tolerance goal, T, of 5 T/A. It is not the intent here, however, to recommend this as an overall goal.
3. $\lambda = T/I = 5/77 = 0.065$.
4. λ is less than 1.0; therefore, erosion is a potential hazard.
5. Enter Table 4 with the threshold value $\lambda = 0.065$. Lines 20 through 26 have C values less than λ and would meet the soil-loss tolerance goal of 5 T/A. However, only No. 20 allows corn on the field more than half the years, and it requires no-till planting in a wheat winter cover that is chemically killed at corn planting time. The example location is in an area of moderate annual rainfall that receives only 8 inches from November 1 though April 30, and water use by the winter cover may significantly reduce corn yields. Use of supporting practices will make options available that do not involve this risk. Consequently, none of these options are selected.

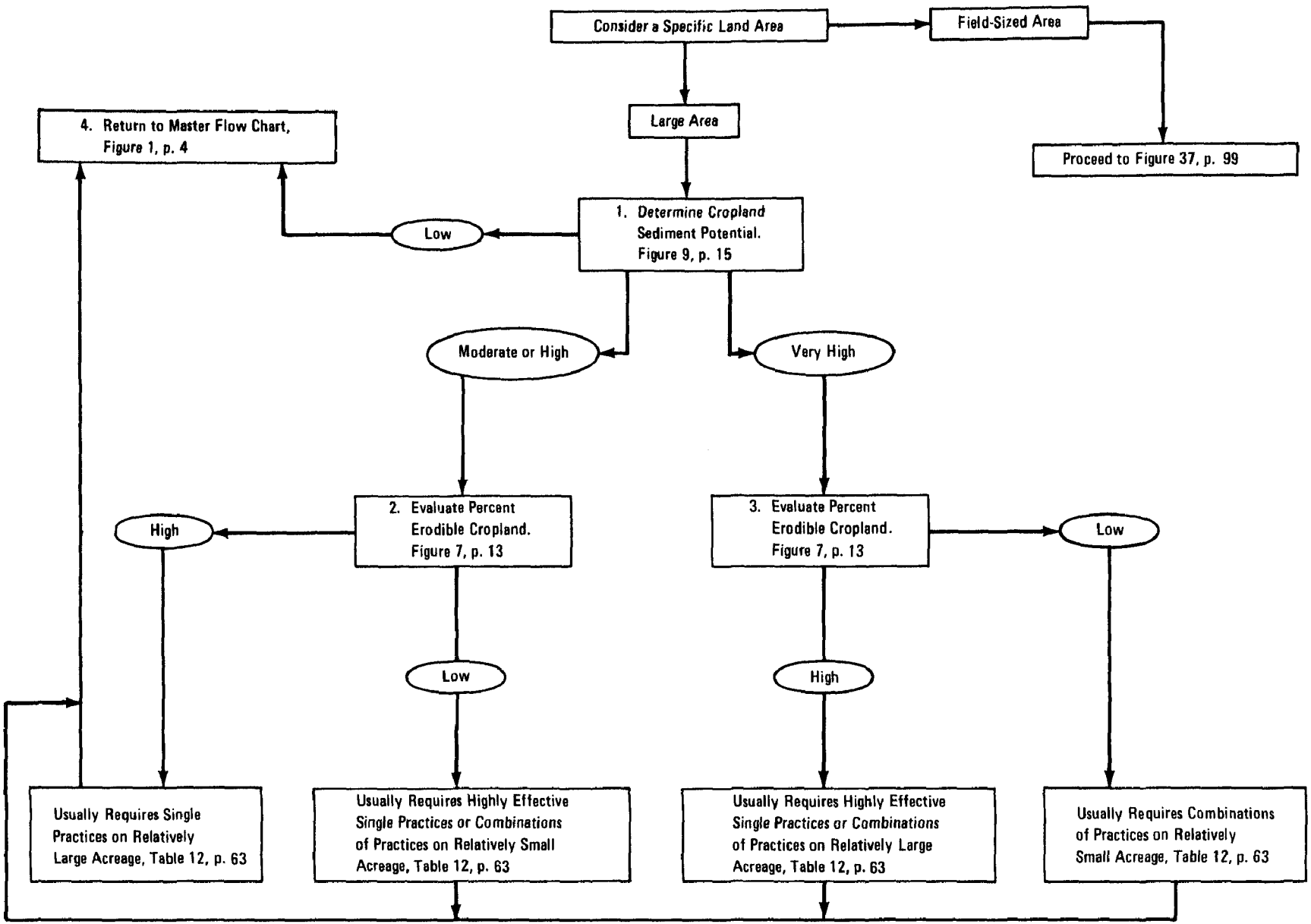


Figure 36.–Flow chart for assessing erosion problems and selecting physically feasible control practices for large areas.

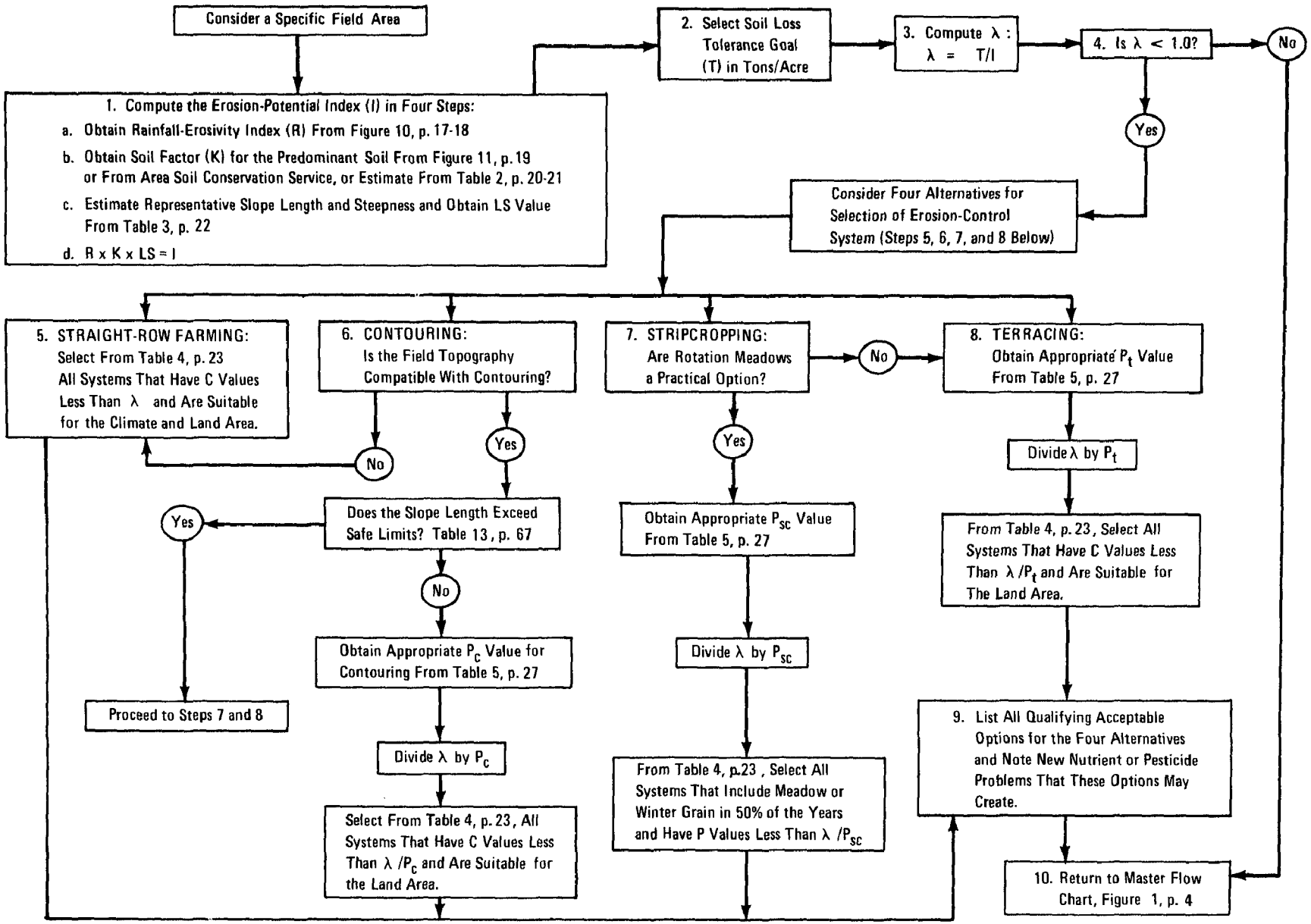


Figure 37.–Flow chart for assessing erosion problems and selecting physically feasible control practices for field-sized areas.

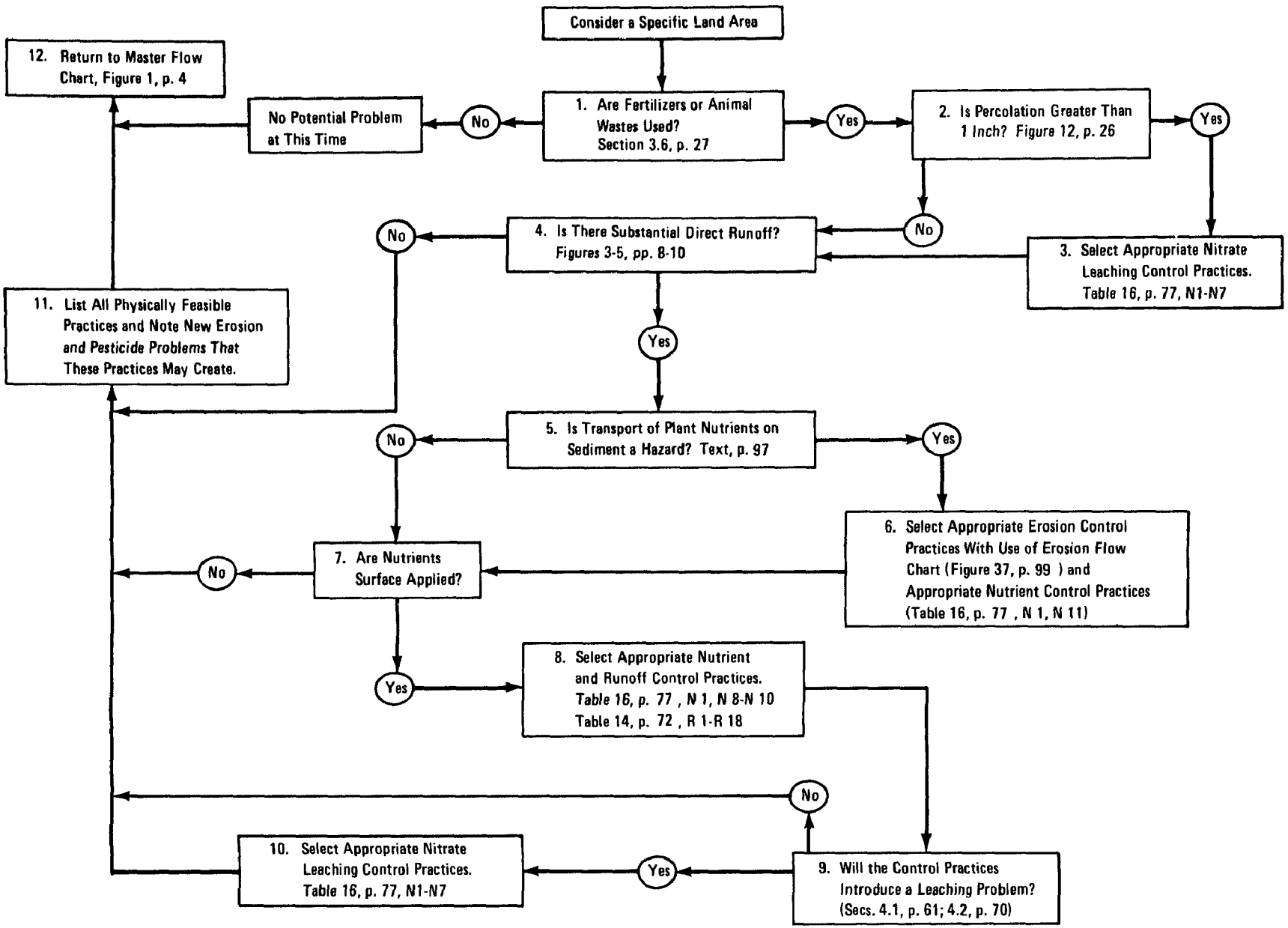


Figure 38.–Flow chart for assessing potential nutrient problems and selecting physically feasible control practices.

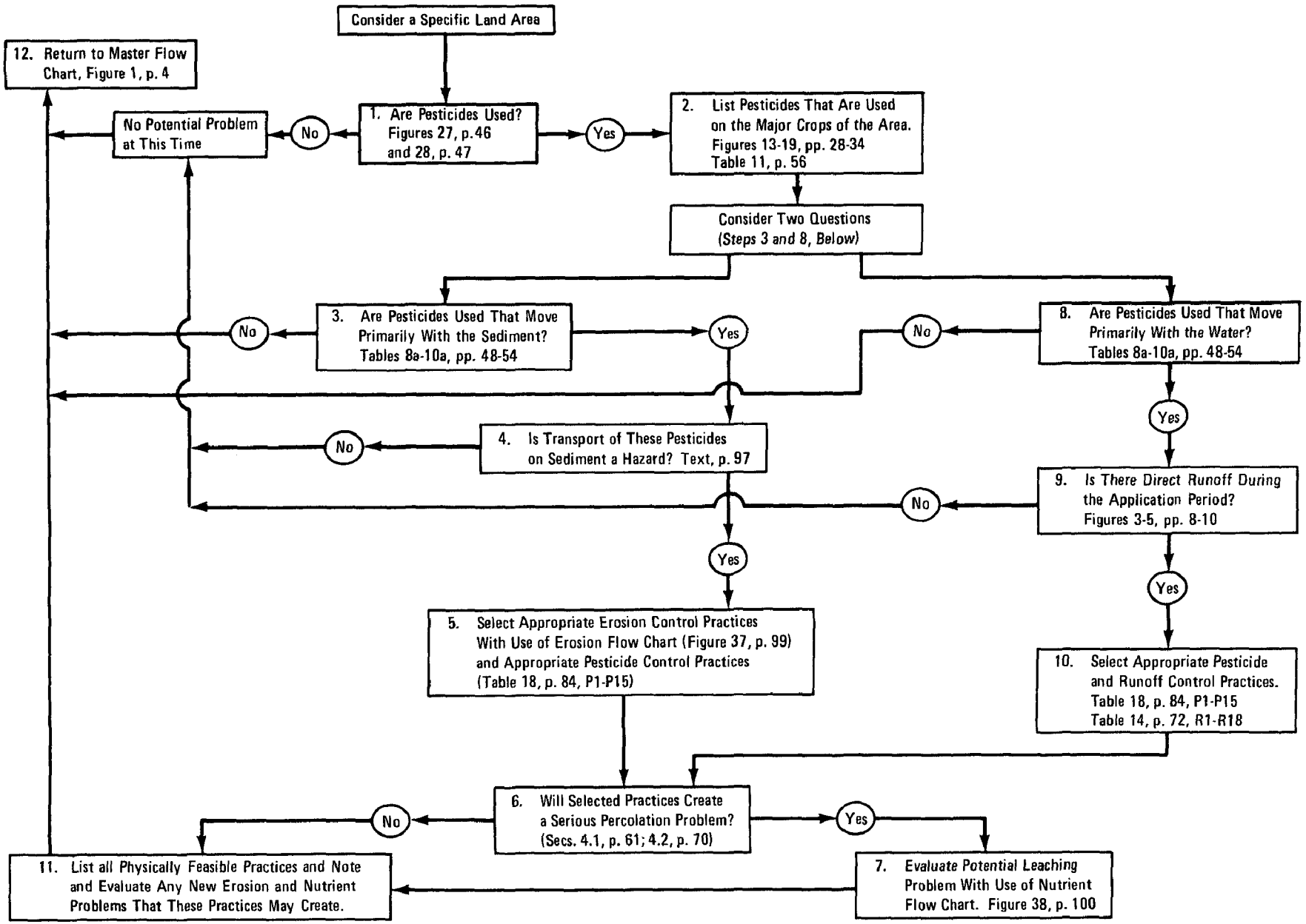


Figure 39.–Flow chart for assessing potential pesticide problems and selecting physically feasible control practices.

6. The field topography is suitable for contouring. The slope length of 350 feet does not exceed the limit given in Table 13 for effective contouring on 6% slope if the system provides at least 50% surface cover by residue mulch when canopy cover is absent or poor. Therefore, contouring is an important option.

For contouring on 6% slope, $P_c = 0.5$ (Table 5) and $\lambda/P_c = 0.065/0.5 = 0.13$. With this larger threshold value, lines 15 through 19 of Table 4 would also meet the 5-ton tolerance goal. With contouring, the farmer could no-till plant corn annually in 70% residue cover (No. 16) or could produce corn 3 years in 5 (No. 18) by moldboard plowing for first-year corn and no-till planting the second and third years of corn. In some years the harvest of corn may be too late for planting wheat and a spring-seeded small grain would be used. For convenience, only the wheat system will be considered in this example.

7. For contour stripcropping with alternate strips in meadow, $P_{sc} = 0.25$, and $\lambda/P_{sc} = 0.065/0.25 = 0.26$. This higher threshold value would qualify additional lines of Table 4, but the requirement of having only half the field in corn would not be compatible with the farmer's cropping goals.
8. Two terraces could divide the 350-foot slope length into three 117-foot slopes. If the 5-ton tolerance is for the purpose of maintaining the productivity level of the field, it is applied to the amount of soil moved to the terrace channels. For this purpose, $P_t = 0.5/\sqrt{3} = 0.29$ (Table 5), and $\lambda/P_t = 0.22$. The farmer then has the additional options of continuous corn using conservation tillage practices that are less restrictive than no-till (Nos. 11 and 13), a no-till planted corn-soybean rotation (No. 37), or corn 3 years in 5 using the conventional plow system (No. 12).

If the tolerance limit were established solely for pollution control, it is much less restrictive on the terraced field than indicated in the preceding paragraph. Because of deposition in the terrace channels and outlet, not more than 20% of the soil eroded to the channels is likely to leave the field. With the 117-foot terrace spacing on 6% slope, the annual contribution to off-field sediment would probably average only about 2 T/A if he doubled the computed 0.22 threshold value. Therefore, conventional plow systems for continuous corn or a corn-soybean rotation would also be acceptable for pollution control.

9. For this illustration, we will assume that the goal is to hold average annual soil movement to the channels within the 5-ton limit. The farmer then has at least five options for comparative evaluation on the basis of chemical pollution and economic return. Although each of the five satisfies the tolerance goal, some provide more control than others, as shown by Table 20.
10. Master Flow Chart says to evaluate potential nutrient problems, Figure 38.

Table 20. Cropping options selected in example for erosion control and their estimated annual soil loss.

Supporting practice	Table 4 line no.	System	Estimated soil loss[1]
			T/A.
Contoured	16	Corn annually, no-till plant in 70% residue cover	4.2
Contoured	18	C-C-C-W-M rotation with turnplowing for first year corn; no-till second and third corn	2.9
Terraced (2 terraces)	13	Corn annually, tillage in row zones only	3.6
Terraced	11	Corn annually, chisel plant	4.2
Terraced	37	Corn-soybean rotation, no-till	4.0
(None	[2] 5	For comparison, not an option	29.0)

[1] Estimated soil loss is equal to the product of the erosion potential index (I), the cropping and management factor, C, and the support-practice factor, P.

[2] Line 5 represents continuous corn with crop residues plowed under in spring, planting in smoothed seedbed, and post-emergence cultivation.

1. Yes, fertilizers are needed in this area for economic yields of row crops in the five options for erosion control under consideration (Table 20).
2. Yes, the Monona silt loam is classed in hydrologic group B (Table 7.1, Hydrology, SCS National Engineering Handbook), which is the same as the predominant hydrologic group used for LRA 107 in Figure 12. The average annual percolation is estimated to be 1 to 3 inches.
3. N1. Prevent Excessive Application of Nutrients

Suppose soil samples had been sent to the Iowa State University Soil Testing Laboratory and the phosphorus level was found to be in the medium class. Their fertilizer recommendations would probably be:

Corn – 170 lbs. N and 13 lbs. P per acre (30 lbs. P_2O_5).

Small Grain – 60 lbs. N and 11 lbs. P per acre (25 lbs. P_2O_5).

Soybeans – 0 lbs. N and 15 lbs. P per acre (35 lbs. P_2O_5).

Grass-legume pasture – No N or P.

Following these recommendations will provide adequate but not excessive amount of fertilizer except under unusual conditions such as drought.

N 2. Timing Nitrogen Applications

Figures 34 and 35 indicate leaching potential is low for nitrogen applied either in the fall or spring in this area.

N 3. Using Crop Rotations

The use of the corn-soybean rotation reduces the long-term nitrogen fertilizer requirement by more than half, since soybeans are legumes.

The use of wheat and a meadow in 2 of 5 years reduces the total N applied in 5 years from 850 to 570 lbs/A.

N 5. Plowing-Under Green Legume Crops

The meadow contains N which will reduce fertilizer requirements. It is estimated that the total fertilizer requirement during the 5-year rotation is 400 lbs. Practices N 4, N 6, and N 7 are judged to be not applicable on this farm.

4. The average direct runoff is 1 to 3 inches annually. Figure 5 shows that most of this occurs during May and June.
5. Erosion is potentially very severe in this area, and thus nutrient transport by sediment may be a hazard.
6. Five cropping practices have been selected (listed earlier under erosion part of the example) that will provide adequate erosion control. Meeting sediment loss goals does not guarantee the nutrient loss goals will be met, but since there is a lack of quantitative information, it will be assumed that adequate erosion control will provide adequate nutrient loss control. Since only 10 to 20% of the sediment that reaches terraces actually leaves the field, terrace systems may meet more restrictive nutrient loss goals without a reduced sediment goal.
7. Most phosphate fertilizer is applied broadcast.
8. Incorporating surface applications, practice N 8, will be achieved to a limited extent in the options with chisel plant and strip till plant. Controlling surface applications, practice N 9, can be used by applying the broadcast phosphate fertilizer in the fall or early spring. The most erosive period is from May to June (Figure 30) so that plowing in early spring should be acceptable. The fertilizer should not be applied to frozen or snow-covered ground.

The cropping practices selected to control erosion will also reduce the frequency and total amount of runoff. Runoff will be slightly reduced for no-till systems, and moderately reduced for strip tillage and chisel plant systems. Contouring and terracing in addition to the above practices will reduce runoff (Tables 14 and 15).

9. Decreased runoff means increased percolation, but its occurrence in May and June is not expected to cause a problem since plant growth is underway. Any additional nongrowing-season nitrate leaching should be controlled by the practices already recommended, N 1, N 3, and N 5.
11. N 1. Eliminating Excessive Fertilization
    N 3. Using Crop Rotations
    N 5. Plowing-Under Green Legume Crops
    N 8. Incorporating Surface Applications
    N 9. Controlling Surface Applications
    N 10. Using Legumes in Haylands and Pastures
    N 11. Timing Fertilizer Plow-Down
12. The Master Flow Chart indicates we are now ready to evaluate potential pesticide problems, Figure 39.

Pesticide Flow Chart

1. The five crop management options for erosion control that are under consideration (listed earlier in the erosion part of the example), as well as the annual corn with no supporting practice included for comparison, all require the use of both herbicides and insecticides to maintain productivity.
2. In 1973, the Iowa State Cooperative Extension Service recommended 7 herbicides and 18 insecticides for use on corn, as follows:

   Herbicides–alachlor, atrazine, cyanazine, 2,4-D, linuron, propachlor, butylate

   Insecticides–Bux, carbaryl, carbofuran, chlordane, Diazinon, disulfoton, EPN, ethoprop, fensulfothion, fonofos, heptachlor, Landrin, malathion, methyl demeton, naled, phorate, toxaphene, trichlorfon.

   All of the insecticides are compatible with non-till management, as are all of the herbicides except butylate, which must be incorporated perplant and, therefore, cannot be used with no-till.

   For soybeans, the Extension Service recommended 10 herbicides and 4 insecticides:

   Herbicides–alachlor, chloramben, chloroxuron, chlorpropham, dinoseb, fluorodifen, linuron, dinitramine, nitralin, trifluralin

   Insecticides–azinphos methyl, carbaryl, malathion, toxaphene

   All of these insecticides and the first seven herbicides listed are compatible with no-till production. For wheat and meadow, pesticides compatible with no-till can be taken from Extension Service recommendations and listed in the same way.
3. Yes, by reference to the above lists and to Tables 8a and 9a. (The selection of a small number of specific pesticides for use by the farmer may, of course, create a "No" answer.)
4. Biologically significant concentrations of pesticides could be delivered to drainage streams by adsorption on sediment particles.
5. Five feasible erosion control practices have already been selected by following the erosion control flow chart. Accompanying pesticide control practices that should be considered for this farm can be obtained from Table 18. These would appear to be practices P 1, P 2, P 4, P 5, P 6, P 8, P 9, and P 11. Each will be discussed individually in development of recommendations below.
6. The estimated annual percolation of 1 to 3 inches (Figure 12) is insufficient to threaten the quality of ground water during the residence time in the soil of the pesticides being used.
8. Yes by reference to the lists of pesticides and to Tables 8a and 9a. (As in question 3, choice by the farmer of a small number of specific pesticides may result in a "No" answer.)
9. In Iowa corn is usually planted during May, and the period of highest direct runoff is during May and June (Figure 5). Except for later postemergence treatments, herbicides and insecticides are also applied during this period.
10. Pesticide practices will duplicate those selected in Number 5 for sediment-borne pesticides; some runoff control will be achieved by options selected for erosion control. Additional runoff control practices that are physically feasible for this area are level terraces, discussed in R 12, and farm ponds, R 18. However, these practices are more expensive to install and will not be considered in this example.
11. The eight pesticide control practices noted above that can be recommended to minimize pesticide movement off the farm have attributes that sometimes vary with the crop management option chosen for erosion control, as follows:

P 1. Using Alternative Pesticides

Use of less-toxic (Tables 8a and 9a) and less-persistent (Figure 29) pesticides is recommended on this farm when alternatives are available, as is use of different pesticides in succeeding years. For example, seven different insecticides-carbaryl, carbofuran, Diazinon, EPN, phorate, toxaphene, trichlorfon–are suggested by the Iowa Cooperative Extension Service for control of the corn borer. Reference to the cited tables and figures will provide a rational basis for selection. With the no-till practice options, pesticides that move primarily with the sediment (Tables 8a and 9a) are preferred over those that move primarily with the water, because no-till reduces erosion more than runoff.

P 2. Optimizing Pesticide Placement

Whenever possible, pesticides should be incorporated into the soil. In no-till practice, the insecticide should be placed in the seed furrow at corn planting time and covered with untreated soil. Only one of the insecticides recommended by the Extension Service for use against soil insects in corn, carbofuran, is not toxic to the seed and can be used in this way.

P 4. Using Resistant Crop Varieties

Use of resistant corn hybrids is already accepted practice in Iowa.

P 5. Optimizing Crop Planting Time

Corn can be planted in Iowa as early as April 20, although most planting is done in May. The earliest possible planting is recommended to minimize corn borer attack and to avoid the peak direct runoff period.

P 6. Optimizing Pesticide Formulation

Granular pesticides should be used in preference to liquid or dust formulations.

P 8. Eliminating Excessive Treatment

Elimination of insurance treatments with soil insecticides is not recommended for continuous corn. For aboveground insects, treatment should not be begun until the economic threshold is reached, preferably as determined by a professional entomologist.

P 9. Optimizing Time of Day for Pesticide Application

If liquid formulations of pesticides must be used, early morning or evening spraying is recommended to increase on-target deposits and to minimize potential damage to honeybees.

P 11. Optimizing Date of Pesticide Application

The preplant herbicides–on corn: alachlor and atrazine in no-till plus butylate in tillage practices; on soybeans: alachlor in no-till plus dinitramine, nitralin, and trifluralin in tillage practices–should be applied as early in the spring as possible, to avoid peak runoff periods (Figure 5). Post-emergence insecticides should be applied as late as possible while maintaining good pest control.

12. The Master Flow Chart, Figure 1, shows that we are now ready to estimate costs of applying practices.

Economic Evaluation

The following discussion uses the methodology presented in Section 5.1 to evaluate the options. This example is clearly site-specific and cannot hope to show the full gamut of variables which may potentially be of significance in other situations. The size of the farm is 250 acres and the costs and returns are for the whole farm for a single (average) year.

Only a summary of the calculations is presented here (Table 21). Detailed tables and sources of information are given in Appendix C, Volume II. It was assumed that none of the macroeffects described in Section 5.2 influence any of the decision variables of this example. It is implicitly assumed that any machinery that might become obsolete because of a change in cropping practices could be sold at a cost close to its depreciated value.

The terracing options require 62,250 feet of terraces costing $0.60 per foot to construct and $0.06 per foot per year to maintain. The construction cost is prorated over a 20-year economic life, discounted at 8% p.a. interest.

Each of the options requires a specific set of field operations and implements. Tractor costs and fuel and lubrication costs are listed separately. Depreciation was calculated by the straight-line method. Interest charges (at 8%) were included in the tractor and implement cost.

The no-till options were assumed to have a higher seed mortality rate due to higher crop residue levels. Nitrogen was applied as anhydrous ammonia and the phosphate and potassium were applied in granular bulk form.

The herbicide costs for the no-till options were higher because both greater amounts and more expensive herbicides were assumed to be used. The insecticide cost for the corn years of the rotation including meadow was greater, due to the expected incidence of the first-year corn insect complex. The average per-year cost for all years in the rotation, however, was reduced by the inclusion of wheat and meadow since these crops are assumed to require no insecticides. No insecticide cost was included for soybeans, since soybeans are seldom treated in this area. Therefore, the insecticide costs for the corn-soybean rotation were 50% of the insecticide costs for continuous corn.

The labor requirement per acre was estimated as 130% of the tractor-hour requirement to account for overhead. The cost per hour was $2.50.

Cost of corn drying was $0.12 per bushel and 8% interest costs for operating expenses (excludes land, tractors, and implements). These costs are shown as "other" expenses.

The costs and returns for continuous corn (residue left, with turn plow, straight row) are shown for comparison purposes only. This system does not meet the erosion limitation and is not an available option.

Yields were 110 bushels per acre for corn except for the no-till options, which were estimated at 105 bushels per acre. The yields for wheat, soybeans, and meadow

Table 21. Costs and returns for selected options.

Item	Straight-row	Contour		Terraced		
	C conv.	C no-till	C-C-C-W-M no-till	C chisel	C strip	CB no-till
Gross revenue	$75,625.00	$72,187.50	$61,312.50	$75,625.00	$75,625.00	$66,093.75
Costs						
Tractor (excl. fuel)	3,430.25	3,066.46	3,426.24	3,238.69	3,066.70	2,887.79
Implements (excl. fuel)	5,940.23	4,973.11	8,038.98	4,961.73	5,077.54	5,179.43
Fuel	1,432.85	1,113.92	1,427.16	1,267.69	1,113.92	937.36
Seed	1,712.50	1,937.50	2,947.50	1,787.50	1,787.50	2,155.00
Fertilizer	7,912.50	7,912.50	4,452.50	7,912.50	7,912.50	4,782.50
Pesticides	4,500.00	5,750.00	3,750.00	4,500.00	4,500.00	4,500.00
Labor	1,803.75	1,178.12	1,659.12	1,568.12	1,348.75	885.62
Terracing	0	0	0	3,450.00	3,450.00	3,450.00
Other	4,195.00	4,088.09	2,691.01	4,190.96	4,183.51	2,246.64
Land charge (see text)	18,020.00	18,020.00	18,020.00	18,020.00	18,020.00	18,020.00
Total costs	48,947.08	48,039.70	46,412.51	50,897.19	50,460.42	45,044.34
Net return	26,677.92	24,147.80	14,899.99	24,727.81	25,164.58	21,049.41

were 45 bushels per acre, 40 bushels per acre, and 4 tons per acre, respectively.

Table 21 summarizes all of the preceding computations and shows the gross revenue and net return for each of the six systems. A land cost was included based on an assumed land value of $974.00 per acre and a cash rent of $7.40 per $100 value. Since this land charge applied equally to all six production methods, any error in this land charge will change only the absolute levels and not the differences in net returns among the six alternatives.

The (unavailable) alternative of continuous corn with conventional turn plow tillage has a significantly higher net revenue than any of the available options. There is only a small variation in net return of the top three available options with a major net return drop to the corn-soybeans alternative. The corn-corn-corn-wheat-meadow rotation has by far the lowest net return, indicating that the savings in fertilizer cost generated by the nitrogen nutrient credit from the legume meadow are not sufficient to offset the loss of gross revenue.

An important consideration is that the yield variations under no-till are higher than for options utilizing tillage. This higher variation for no-till may be partly due to the growers' lack of familiarity with this method. In this example, the no-till options were assumed to have a lower yield than the others to account for this potential yield impact. A farmer who is a risk-averter or who is unfamiliar with no-till planting may be willing to accept a lower net return with a higher degree of certainty if that option excludes no-till planting.

One additional consideration is related to the cost of terracing. The present example assumes that the farmer bears the full cost of terracing. Historically, society has reimbursed terracing costs through various government programs so that the farmer usually paid half the cost or even less. Under any such cost-sharing program the relative differences in net revenue will change. In the present example, a cost-sharing program with a 50-50 split would give two of the terraced alternatives a net revenue practically identical to the conventional tillage, continuous corn activity.

In conclusion, the final decision has to remain with the farm operator. His decision will depend on the value he places on minimizing risk, his expectation of risk for each alternative, his familiarity with the alternative production method, his reluctance to try a method with which he is unfamiliar, and, as shown above, which cost-sharing program he can enter to help pay for his terrace construction costs. He may place no value on these intangibles, in which case he would probably choose the alternative with the highest net return.

Summary

Five options were selected that limit annual soil loss to less than 5 T/A. These options and their estimated soil losses are contoured no-till corn, 4.2 T/A.; contoured C-C-C-W-M rotation, 2.9 T/A.; terraced corn tilled in row zones only, 3.6 T/A.; terraced corn, chisel plant, 4.2 T/A.; and terraced corn-soybean rotation, no-till, 4.0 T/A. Estimated soil loss for continuous corn without erosion control is 29 T/A. Nutrient use was similar for all options except for the rotation options, which use substantially less fertilizer nitrogen. Nitrate leaching is not a major problem in this location. Loss of nitrogen and phosphorus with sediment is not anticipated to be a problem when soil loss is controlled by the selected options. Surface-applied phosphate should be incorporated soon after application to prevent losses in runoff.

The control of sediment will probably reduce pesticide losses substantially. However, eight other practices were selected and listed in the pesticide portion of the example that could provide additional reduction. Pesticide use is lower for some options and may result in reduced pesticide loss. For example, insecticide usage was 50% lower for the corn-soybean rotation and 25% lower for the corn-wheat-meadow rotation, as compared to the other options. Herbicide usage was highest for the no-till options, but herbicides generally have less impact on the environment than insecticides.

The economic analysis indicates that the rotation options, particularly the one containing meadow, produce significantly lower net returns. The other options also reduce net return by about 6 to 9% as compared to continuous corn without erosion control. However, the example assumed the farmer bore the full cost of erosion control. Incentives, such as a 50-50 cost sharing for terracing, would make the net revenue from the terraced options similar to that from the conventional corn system.

6.3 EXAMPLE FOR A LARGE AREA

Suppose that a commission responsible for planning the resource development of the Suwannee River Basin is charged with identifying potential nonpoint pollution problems and selecting appropriate control measures. A map of the Suwannee River Basin is shown in Figure 40. From Figure 2 the Land Resource Areas to be considered are: 133, Southern Coastal Plain; 38, North Central Florida Ridge; 152, Gulf Coast Flatwoods; and 153, the Atlantic Coast Flatwoods. To illustrate the procedures developed in this manual we will consider that part of Land Resource Area 133 in the Suwannee Basin. Now that a specific land area has been selected, the first step is to obtain localized information. Rather detailed reports have been prepared for major river basins of the United States and are a good source of additional information. The Suwannee Basin is included in the Report of the United States Study Commission—Southeast River Basins.[1]

A brief description of important characteristics of Land Resource Area 133, quoted from USDA Agriculture Handbook No. 296, follows:

133—SOUTHERN COASTAL PLAIN
Georgia, Alabama, Mississippi, Louisiana, Texas, Arkansas, Tennessee, North Carolina, South Carolina, Virginia, and Florida
145,300 square miles

LAND USE: Nearly all the area is in farms. A small acreage is owned by the Federal Government, and additional small areas are urban or in other uses. Between one-half and three-fourths is woodland, nearly all in small holdings but some in large tracts. The proportion of woodland is greatest in the west. Lumber, pulpwood, and naval stores are the major forest products. Between one-tenth and one-third is cropland; the largest acreage is in the east. Less than one-tenth is in pasture. This is a cash-crop area, and cotton is a major crop. Peanuts, tobacco, melons, various vegetable crops, and corn are important also. The trend recently is to more pasture and woodland and less cropland.

ELEVATION AND TOPOGRAPHY: 100 to 600 feet, increasing gradually from the lower Coastal

[1] U. S. Study Commission. 1963. Plan for development of the land and water resources of the southeast river basins. Appendix 5, Suwannee Basin.

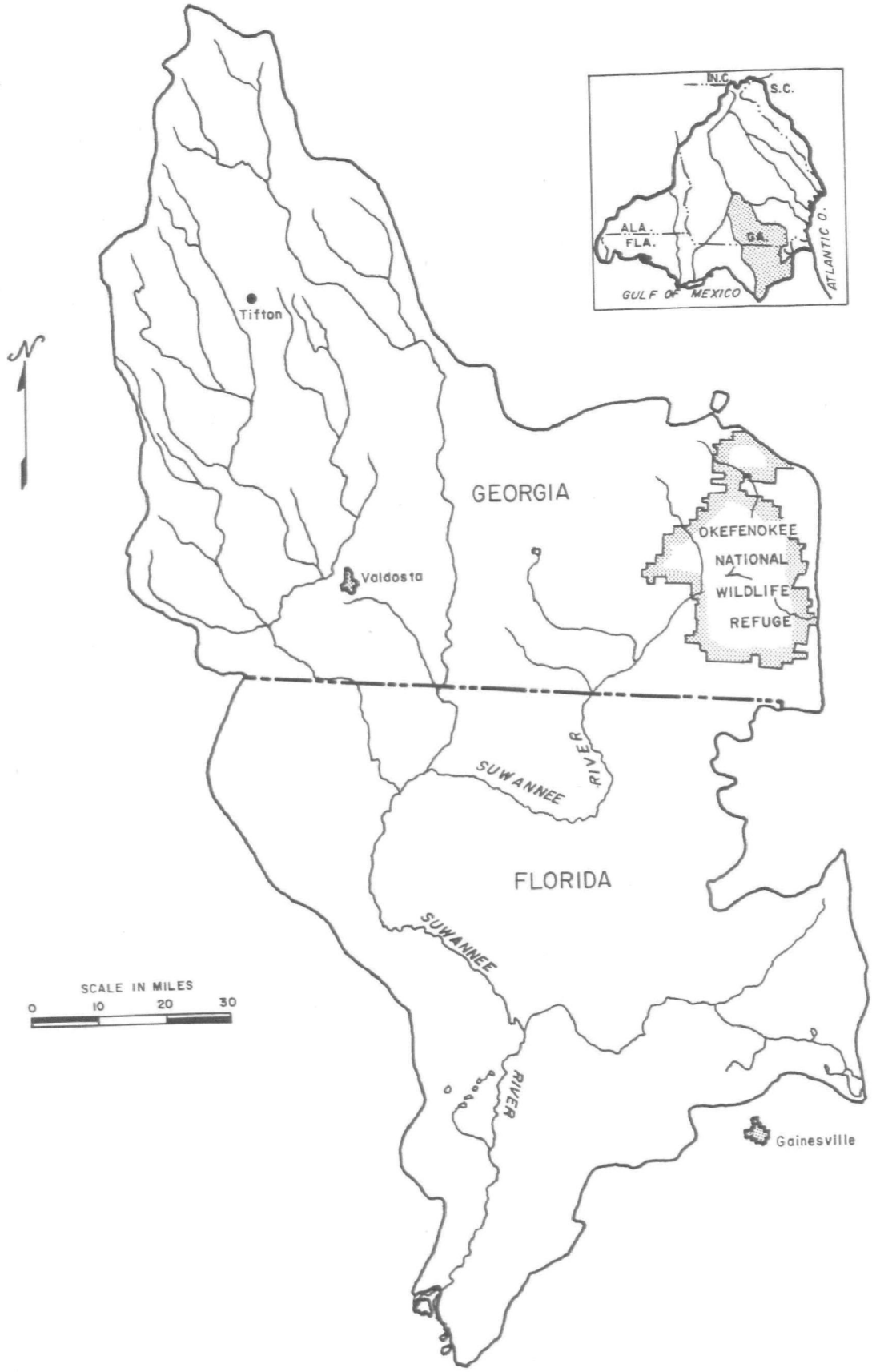


Figure 40.–The Suwannee Basin.

Plain to the Piedmont. The gently to strongly sloping dissected coastal plain is underlain by unconsolidated sands, silts, and clays. In their upper reaches stream valleys are narrow, but the lower parts of the valleys are broad and have widely meandering stream channels. Local relief is mainly in a few tens of feet, but some of the more deeply dissected parts have relief of 100 to 200 feet.

CLIMATE: Average annual precipitation–40 to 60 inches; lowest in autumn throughout the area and highest in midsummer in the east and in winter and spring in the west. *Average annual temperatures*–60° to 68° F., increasing from north to south. *Average freeze-free period*–200 to 280 days, increasing from north to south.

WATER: Rainfall, many perennial streams, and ground water provide an abundance of water. Even though summer rainfall is fairly high, droughts are common and then good returns are obtained from irrigation on all but the wettest soils. Drainage is necessary before the wet lowlands can be used for crops. Domestic water supplies are obtained mainly from shallow wells and water for livestock from perennial streams and small farm ponds. The many perennial streams are potential water sources that have been little used in most of the area.

SOIL: Red-Yellow Podzolic soils are dominant throughout (Ruston, Norfolk, Orangeburg. Saffell, and Lexington from sandy or gravelly materials; Marlboro, Bowie, Savannah, Shubuta, Kirvin, and Silerton from medium to moderately fine textured materials; and Boswell, Susquehanna, Sawyer, and Cuthbert in fine-textured materials). Associated with them on wet lowlands are *Low-Humic Gley soils* (Plummer, Bladen, Bibb, Falaya, and Coxville) and *Humic Gley soils* (Portsmouth, Bayboro, Weeksville, and Johnston). *Reddish-Brown Lateritic soils* (Greenville, Red Bay, and Nacogdoches) are important locally, mainly in the south, but are of small total extent. *Regosols* (Eustis, Lakeland, and Kershaw) are on gently rolling to steeply sloping areas underlain by sands. *Alluvial soils* (Mantachie and Iuka) on narrow bottom lands are important to agriculture locally. In Texas and Louisiana, where the alluvium contains a large amount of material from red rocks, Miller and Yahola are important soils. (In current terminology, these soils are called Ultisols and Entisols).

From the U. S. Study Commission Report we find that the Suwannee Basin comprises 7 million acres. Approximately 4 million acres could be cropped but only 1.6 million acres were cropped in 1961. Most of the cropland in the basin is in LRA's 133 and 138. Additional information could be obtained from reports from USDA, the Georgia Coastal Plain Experiment Station, Tifton, and the Florida Experiment Station, Gainesville.

Identifying potential nonpoint pollution problems and appropriate control measures for LRA 133–Following the Master Flow Chart, Figure 1, the first step is to evaluate the erosion potential using the flow chart in Figure 36.

1. The cropland sediment potential is moderate.
2. Erosion is the dominant limitation on less than 10% of the cropland. Since this can be classed as low, fairly severe erosion from limited acreage is indicated. To correct this erosion problem, highly effective single practices or combinations of practices (Table 12, E 1-E 17) will be required on the erodible areas. Specific control practices can be selected only for individual fields.
4. In returning to the Master Flow Chart, Figure 1, the next step is to evaluate runoff pollution problems by the Nutrient Flow Chart, Figure 38.

Nutrient Flow Chart

1. The figures in Section 3.5 show the distribution of major crops. Corn is the predominant crop and requires substantial nitrogen and phosphorus for good production. Acreages of cotton and vegetable crops also are substantial. Additional information from Agriculture Handbook No. 296 and the U. S. Study Commission Report shows a substantial acreage of peanuts. Consequently, commercial fertilizers are applied. In addition, poultry and swine wastes are available for spreading on cropland.
2. The percolation is estimated to be greater than 7 inches in this Land Resource Area.
3. This area is very susceptible to leaching and excessive fertilization should be avoided (N 1). Therefore, correct timing of fertilization is neces-

sary to supply adequate nutrients to crops (N 2). Practices N 3 to N 6 should also be used in this area when applicable to the cropping system.

4. Runoff (greater than 7 inches) is distributed relatively uniformly throughout the year. Growing season runoff is 3 to 7 inches.
5. Transport of nitrogen and phosphorus on sediments may be a hazard because erosion is severe in some portions of the area.
6. Erosion control practices have already been selected. Nutrient control practice N 11, Timing Fertilizer Plow-Down, would further reduce the loss of nitrogen and phosphorus.
7. Manures and some commercial fertilizers are surface-applied.
8. Nutrient control practices N 8, N 9, and N 10 (Table 16) and runoff control measures R 2, R 3, R 5, R 7, R 8, R 9, R 10, R 12, R 13, R 15, and R 16 (Table 14) that offer moderate to substantial runoff reductions should be considered.
9. Any practice which reduces the direct runoff will increase the amount of percolation. However, a severe leaching problem already exists and the increase in percolation will not create any additional problems.
11. Nutrient and runoff control practices that should be used in the area when applicable to the cropping systems are as follows:

N 1. Eliminating Excessive Fertilization
N 2. Timing Nitrogen Application
N 3. Using Crop Rotations
N 4. Using Animal Wastes for Fertilizer
N 5. Plowing-Under Green Legume Crops
N 6. Using Winter Cover Crops
N 8. Incorporating Surface Applications
N 9. Controlling Surface Applications
N 10. Using Legumes in Haylands and Pastures
N 11. Timing Fertilizer Plow-Down
R 2. Conservation Tillage
R 3. Sod-Based Rotations
R 5. Winter Cover Crop
R 7. Timing of Field Operations
R 8. Plow Plant Systems
R 9. Contouring
R 10. Graded Rows
R 12. Terraces
R 13. Grassed Outlets
R 15. Contour Listing
R 16. Change in Land Use

Pesticide usage may vary depending on the individual practices selected. For example, Conservation Tillage usually requires additional pesticides, particularly herbicides.

12. The Master Flow Chart shows that we are now ready to evaluate pesticide problems by the flow chart shown in Figure 39.

Pesticide Flow Chart

1. Figures 27 and 28 indicate that considerable amounts of pesticides are used in the area.
2. Table 11 lists the specific pesticides used on major crops—corn, cotton, vegetables, and peanuts.
3. Yes, by reference to the specific pesticides listed in Tables 8a and 9a.
4. Biologically significant concentrations of pesticides could be delivered to drainage streams by adsorption on sediment particles.
5. Specific erosion control practices will have to be selected for individual fields. Pesticide control practices that are applicable to this area should be selected from Table 18. These would appear to be practices P 1, P 2, P 3, P 4, P 5, P 6, P 8, P 9, P 10, and P 14. However, the other practices might be applicable in specific situations.
6. A serious percolation problem exists. Pesticides usually do not leach because of their adsorption characteristics. The best control is selecting pesticides that are less persistent (Figure 29). Within a given persistence class, those pesticides that move primarily with the sediment should be favored (Tables 8a and 9a).
8. Yes, by reference to the specific pesticides listed in Tables 8a and 9a.
9. Yes, runoff is substantial during the entire year (Figures 3 to 5).
10. Pesticide practices will duplicate those selected in No. 5 for sediment-borne pesticides. Runoff control practices will duplicate those selected earlier for nutrient control.
11. The pesticide practices selected for additional control when applicable to the cropping systems are as follows:

P 1. Using Alternative Pesticides
P 2. Optimizing Pesticide Placement with Respect to Loss
P 3. Using Crop Rotation
P 4. Using Resistant Crop Varieties
P 5. Optimizing Crop Planting Time
P 6. Optimizing Pesticide Formulation

P 8. Reducing Excessive Treatment
P 9. Optimizing Time of Day for Pesticide Application
P 10. Optimizing Date of Pesticide Application
P 14. Managing Aerial Applications

These practices should not create any new or additional pollution problems.

12. The Master Flow Chart directs us now to Economic Considerations.

Economic Considerations

The decision makers will have to determine the level of control desirable. In arriving at a decision, both physical and economic factors should be considered. The physically feasible alternatives have been discussed. Attention can now be turned to the economic feasibility of the alternatives.

In this example, erosion is the dominant limitation on less than 10% of the cropland. Highly effective single practices or combinations of practices will be required. Furthermore, specific control practices can be selected only for individual fields. Given this information, the analytical procedure used in the small area example would be applicable for identifying on-farm costs and benefits in erodible areas.

Since the highly erodible acreage of the land area is relatively small, it does not appear that practices or procedures needed for erosion control would have significant regional or national impacts. However, certain control levels could require large investments for erosion control or shift cropping combinations and the level of production of specific crops for this area. Any significant changes in levels of production could have noticeable impacts upon the agricultural input and processing industries. For example, reductions in the cotton acreage would reduce ginning demands and the effective utilization of ginning capacities. These impacts would, in turn, affect other sectors of the local economy.

The highly erodible land might be better used for other than row crop production. A trend in this area away from cultivated agriculture toward forest production suggests this as a possible alternative land use. The effect of changes on off-farm employment as well as adverse economic impacts on individuals and measures to alleviate these impacts must be considered.

Similarly, benefits should be assessed. Potential benefits could include less sediment in streams, thus benefiting aquatic populations and possibly enhancing recreation potential. The trend toward forest production also could enhance recreational potentials. Other benefits could include: increased soil conservation and agricultural productivity, less flooding, less dredging and channel repairs, and aesthetic improvements.

No attempt is made to estimate costs and benefits in this example because of the complexity of the task and the time required. However, in an actual situation those responsible for making a decision probably would want to draw upon specialized expertise to make an assessment. This expertise would likely use analytical techniques mentioned in Sec. 5., and be concerned with factors such as historical changes in the area and the reason for these changes, sources of revenue, direct and indirect effects of changes in income and employment, overall economic importance of agriculture in the area, degree of off-site damage from erosion, and nonagricultural employment opportunities.

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16. ABSTRACT

Engineering and agronomic techniques to control sediment, nutrient, and pesticide losses from cropland were identified, described, and evaluated. Methodology was developed to enable a user to identify the potential sources of pollutants, select a list of appropriate demonstrated controls, and perform economic analyses for final selection of controls. The information is presented in the form of regional maps, decision flow charts, tables, and brief technical highlights.

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