Saline and Alkali Soils

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Saline and alkali conditions lower the productivity and value of large areas of agricultural land in the United States—an estimated one-fourth of our 29 million acres of irrigated land and less extensive acreages of nonirrigated crop and pasture lands.

Saline and alkali soils are soils that have been harmed by soluble salts, consisting mainly of sodium, calcium, magnesium, chloride, and sulfate and secondarily of potassium, bicarbonate, carbonate, nitrate, and boron.

Salt-affected soils are problem soils that require special remedial measures and management practices.

Soluble salts may harm soils by increasing the salt concentration of the soil solution and by increasing the percentage saturation of the soil adsorption complex with sodium.

The second effect occurs when sodium salts predominate. It is more permanent than the first because adsorbed sodium usually persists after most of the soluble salts are removed.

Saline soils contain excessive amounts of soluble salts only. Alkali soils contain excessive adsorbed sodium. Because leaching may have occurred previously, alkali soils do not always contain excess soluble salt. They are designated as nonsaline-alkali or saline-alkali soils according to their content of salts.

Salt-affected soils occur mostly in regions of an arid or a semiarid climate.

Under humid conditions, the soluble salts originally present in soil materials and those formed by the weathering of minerals generally are carried downward into the ground water and are transported ultimately by streams to the oceans.

In arid regions, leaching and transportation of salts to the oceans is not so complete as in humid regions. Leaching is usually local in nature, and soluble salts may not be transported far. This occurs because there is less rainfall available to leach and transport the salts and because the high evaporation and plant transpiration rates in arid climates tend further to concentrate the salts in soils and surface waters.

Weathering of primary minerals is the indirect source of nearly all soluble salts, but there may be a few instances in which enough salts have accumulated from this source alone to form a saline soil. Saline soils usually occur in places that receive salts from other locations; water is the main carrier.

Restricted drainage usually contributes to the salinization of soils and may involve low permeability of the soil or the presence of a high groundwater table.

High ground-water tables often are related to topographic position. The drainage of waters from the higher lands of valleys and basins may raise the ground-water level near to the soil surface on lower lands. Low permeability of the soil causes poor drainage by impeding the downward movement of water. The impedance may be the result of an unfavorable soil texture or structure or the presence of hardened layers, called hardpan.

Salt-affected soils occur extensively under natural conditions, but the salt problem of greatest importance in agriculture arises when previously productive soil becomes salt-affected as a result of irrigation.

Irrigated lands are often located in valleys near streams; because they can be irrigated easily, the lower and more level soils usually are selected for cultivation. Such soils may be adequately drained and nonsaline under natural conditions, but the drainage facilities may not be adequate under irrigation. Irrigation waters may contain from 200 pounds to as much as 5 tons of salt per acre-foot, and the annual application of water may amount to 5 acre-feet or more an acre. Considerable quantities of soluble salts thus may be added to irrigated soils in a short time.

Farmers who bring new lands under irrigation often have failed to recognize the need for establishing artificial drains to care for the additional water and the leaching required to prevent the accumulation of soluble salts. As a result, the water table may rise from a considerable depth to within a few feet of the soil surface in a few years.

During the early development of irrigation projects, water is frequently plentiful, and there is a tendency to use it in excess. This hastens the rise of the water table. When the water table rises to within 5 or 6 feet of the surface, ground water containing more or less dissolved salt moves upward into the root zone and to the soil surface. Ground water, as well as irrigation water, then causes the soil to become saline.

ALKALI SOILS CONTAIN excessive amounts of adsorbed sodium.

Because of the presence of negative electrical charges at their surfaces, soil particles adsorb and retain cations, such as calcium, magnesium, and sodium. While the adsorbed cations are combined chemically with the soil particles, they may be replaced or exchanged by other cations that are added to the soil solution. Each soil has a reasonably definite capacity to adsorb and exchange cations, and the percentage of this capacity that is taken up by sodium is referred to as the exchangeable-sodium-percentage. The exchangeable-sodium-percentage of alkali soils is usually 15 or more.

As cations adsorbed on soil particles can interchange freely with those in the soil solution, the proportions of the various adsorbed cations are related to their concentrations in the soil solution. Calcium and magnesium are the principal cations in the soil solution and on the particles of normal, productive soils of arid regions. When normal soils come in contact with irrigation or drainage waters containing a high proportion of sodium, this cation becomes the dominant one in the soil solution and replaces part of the original adsorbed calcium and magnesium. As a consequence of the adsorption of sodium, alkali soils are formed.

THE ACCUMULATION of soluble salts and adsorbed sodium by soils impairs their productivity in several ways.

Because of the presence of considerable dissolved salt and the absence of significant amounts of adsorbed sodium, saline soils generally are flocculated. Their tillage properties and permeability to water therefore are equal to or higher than those of similar nonsaline soils. The abnormally high salt concentration of the soil solution of saline soils, however, reduces the rate at which plants absorb water; consequently growth is retarded. The retardation of growth is almost directly related to the total salt concentration of the soil solution and is largely independent of the kind of salts present.

The salinity status of soils is appraised in terms of effects on crop growth by measuring the electrical conductivity of the solution extracted from saturated soil paste. The electrical conductivity of a solution is a good measure of its total salt concentration, and the water content of saturated soil is related to the field-moisture range. Thus the electrical conductivity of the saturation extract is directly related to the total salt concentration of the soil solution under field conditions.

The effects of salinity on growth are largely negligible when the electrical conductivity reading (expressed in millimhos per centimeter) is less than 2.

At readings in excess of about 16, only a few very salt-tolerant crops yield satisfactorily. The yields of very salt-sensitive crops may be restricted at readings as low as 2; moderately salt-tolerant crops grow satisfactorily below readings of 8; only salt-tolerant crops grow satisfactorily when readings range between 8 and 16.

While the primary effect of soil salinity on crops is one of retarding growth by limiting the uptake of water, certain salt constituents are specifically toxic to some crops. Boron, for example, when present in the soil solution at concentrations of only a few parts per million, is highly toxic to many crops.

Alkali soils remain flocculated and their properties usually are similar to those of saline soils as long as considerable amounts of soluble salts are present. If the excess salts are removed by leaching, however, saline-alkali soils generally become nonsaline-alkali soils, and their physical properties deteriorate markedly.

As the concentration of the salts in the soil solution is lowered by leaching, the adsorbed sodium present causes undesirable characteristics to develop. The soil may become strongly alkaline (pH readings above 8.5), the particles may disperse, and the soil may become unfavorable for the entry and movement of water and air and for tillage. Adsorbed sodium also may be toxic and cause various nutritional disturbances in plants.

There are two principal aspects of the salt problem in irrigation agriculture. One is the improvement (reclamation) of soils that are salt-affected under natural conditions or have become salt-affected because of mismanagement. The other aspect is the management of productive or slightly salt-affected soils so as to prevent increases in the soluble salt and adsorbed sodium contents and thus prevent reduction in crop yields.

Saline soils are improved by establishing artificial drains if a high ground-water table exists and by subsequent leaching with irrigation water to remove excess soluble salts. The improvement of alkali soils involves (besides drainage and leaching) the replacement of adsorbed sodium by calcium or magnesium and the use of practices that develop good soil structure.

Adequate drainage is essential for the permanent improvement of saline and alkali soils. Leaching operations and the application of amendments for the replacement of adsorbed sodium will be largely ineffective unless the ground-water table remains deep enough to prevent appreciable upward movement of water.

The permissible depth to the water table in various types of soils under irrigation and drainage requirements and methods are discussed in the chapter on soil drainage, page 378.

Soils can be leached by applying water to the surface and allowing it to pass downward through the root zone. Leaching is most efficient when it is possible to pond water over the entire soil surface.

Water can be ponded on nearly level land in shallow basins formed by the construction of earthen dikes or borders 2 to 4 feet high. The dimensions of individual basins depend on the slope of the land. Normally the difference in elevation at the high and low points of the basin should not exceed 6 inches. It is wise to construct dikes on the contour where possible, especially if the land slopes very much. Overflow gates or spillways placed in dikes between adjacent ponded areas facilitate the control of water and allow a number of basins to be kept full simultaneously.

Either continuous flooding or periodic applications of water may be used for leaching. Periodic drying usually helps maintain infiltration rates. When the topography is such that ponding is not practical, moderately effective leaching can be accomplished through frequent applications of excess irrigation water in furrows, between border strips, or by sprinklers.

Except in climates where the soil

freezes, it is often convenient to conduct leaching operations during the winter, when water may be more plentiful and the water table and drainage conditions may be more favorable than during the regular irrigation season.

If the soil is only moderately saline, crops that withstand flooding, such as rice, sesbania, and Bermuda-grass, may be grown while leaching is in progress. Care must be exercised in hot weather, however, because holding water on some plants too long may cause scalding. The permeability of most soils declines markedly during prolonged leaching with water of very low salt content. The decrease in permeability is not so marked if the leaching water contains a moderate amount of salt and has a calcium plus magnesium to sodium ratio of 1 or more.

THE AMOUNT of water required to leach saline soils depends on the initial salinity level of the soil and the final salinity level desired.

When water is ponded, about 50 percent of the salt in the root zone can be removed by leaching with 6 inches of water for each foot of root zone; about 80 percent can be removed with 1 foot of water per foot of soil; to remove 90 percent of the salt, 2 feet of water must be used for each foot of soil that is to be leached.

For example, if the average salinity reading in a 3-foot depth of soil is 40 millimhos per centimeter and it is desired to reduce this 80 percent, or to about 8 millimhos per centimeter, then 3 feet of water should be applied.

If water is not applied to the entire soil surface, somewhat greater amounts will be needed to accomplish the same degree of leaching. In estimating the amount of water required for leaching, losses of applied water by evaporation and transpiration should be taken into account.

THE REMOVAL of excess soluble salts is not enough to restore alkali soils to productivity. Most of the adsorbed sodium must be replaced with calcium or magnesium and usually soil structure must be improved.

Some alkali soils contain calcium sulfate in the form of the mineral gypsum. When such soils are leached, the gypsum dissolves, and the replacement of adsorbed sodium by calcium takes place concurrently with the removal of excess salts.

When alkali soils do not naturally contain gypsum, soluble calcium or magnesium must be supplied. Some waters, when used for irrigation, supply appreciable amounts of calcium and magnesium, but it is usually necessary to apply a chemical amendment to restore alkali soils to productivity in a reasonable length of time.

CHEMICAL AMENDMENTS for the replacement of adsorbed sodium are of three types: Soluble calcium salts (calcium chloride and gypsum); calcium salts of low solubility (limestone); and acids or acid-formers (sulfuric acid, sulfur, and iron and aluminum sulfate).

The suitability of the various types of amendments is governed primarily by their solubility and by the lime content and pH reading of the soil.

Any of the soluble calcium salts or acids or acid-formers may be used on alkali soils containing lime, but the addition of limestone will be of no value. Acid and acid-forming amendments react with the lime in the soil to form gypsum. The addition of acids and acid-forming amendments to soils containing no lime tends to make them acid. When the amount of acid or acid-forming amendment needed would make the soil excessively acid (pH 6 or less), the choice of amendment is limited to soluble calcium salts, unless limestone also is applied. The application of limestone alone to lime-free alkali soils tends to be beneficial, but its effectiveness is not great unless the pH reading is 7 or less.

The selection of an amendment is influenced generally by cost considerations and the time required for its reaction in the soil. The cheaper amendments are slower to react. Because of its high solubility in water, calcium chloride is probably the most readily available source of soluble calcium, but it is seldom used because of its high cost. Sulfuric acid and iron and aluminum sulfates, which decompose readily in the soil to form sulfuric acid, also act quickly. Sulfuric acid is often cheap enough for field application, but the use of iron and aluminum sulfates is usually too costly. Because of their relatively low cost, gypsum and sulfur are most commonly used.

The rate of reaction of gypsum is limited only by its solubility, which is about 0.25 percent. Under field conditions, the application of 3 to 4 acre-feet of irrigation water is required to dissolve 4 or 5 tons of the high-grade agricultural gypsum. As sulfur must first be oxidized to sulfuric acid by soil micro-organisms before it is available for reaction, it is slow acting.

Limestone is a relatively cheap amendment, but only occasionally is it useful, as most alkali soils already contain lime. Unless the soil is decidedly acid, the reaction of limestone is slow. Particle size is an important factor affecting the rate at which limestone (as well as sulfur and gypsum) reacts in soils. The finer the particle size, the faster the reaction.

Because the application of chemical amendments usually is expensive, chemical tests should be made on soil samples to determine the kind and amount needed. It is worthwhile to get the advice and help of a county farm adviser or Soil Conservation Service technician.

Chemical amendments, such as gypsum, sulfur, and limestone, normally are applied broadcast and then incorporated with the soil by means of a disk or plow. Thorough incorporation is especially important when sulfur is used to insure a satisfactory rate of reaction. Because of hazards in handling, special equipment is used to spray sulfuric acid on the soil surface.

Except where sulfur is employed, alkali soils should be leached immediately following the application of amendments. Leaching dissolves the amendment and carries it downward. Leaching also removes the soluble sodium salts that form as the adsorbed sodium is replaced by calcium.

When sulfur is applied, 2 or 3 months should be allowed before leaching so that the amendment may oxidize and form gypsum. The soil should be kept moist, however, as water is essential for the oxidation of sulfur.

If the structure of saline-alkali soils is good originally, it will tend to remain good during the removal of excess salt and adsorbed sodium if soil disturbance is kept at a minimum and adequate soluble calcium is supplied. In this case tillage should be reduced, and the use of heavy machinery should be avoided during the improvement process.

If the alkali soil is relatively free of salt, its structure usually is poor. Here, the improvement process may be facilitated by loosening the soil to a considerable depth with a subsoiler or deep plow before applying amendments and leaching. The value of subsoiling and deep plowing alkali soils is questionable, however, unless an amendment is applied. Even after the removal of adsorbed sodium, soil structure may remain poor. The rearrangement and aggregation of soil particles, so as to improve structure, is facilitated by alternate wetting and drying, by alternate freezing and thawing, and by the action of growing plant roots and organic matter.

A SATISFACTORY and sustained crop production on nonsaline irrigated land generally requires the use of special soil-management practices to prevent the excessive accumulation of soluble salts and adsorbed sodium.

Often it is not practical to reclaim completely salt-affected soils or even to maintain conditions of very low salinity and adsorbed sodium (alkali) in irrigated soils. The reasons may be high costs of the amendments, difficulty in providing adequate drainage, use of irrigation water of inferior quality, or inherently low permeability of the soil. If the soil cannot be reclaimed completely, farmers can often live with the salinity or alkali by adopting suitable management practices.

MANAGEMENT PRACTICES for the control of salinity and alkali include: Selection of crops or crop varieties that will produce satisfactory yields under moderately saline conditions; use of land-preparation and tillage methods that aid in the control or removal of salinity and alkali; special planting procedures that minimize salt accumulation around the seed; irrigation so as to maintain a relatively high soil-moisture level and at the same time allow for periodic leaching of the soil; maintenance of water conveyance and drainage systems; and special treatments, such as additions of chemical amendments and organic matter, and growing sod crops to improve structure.

The quality of water used for irrigation and the soil texture determines to a large degree the kind and extent of management practices needed. In judging the quality of irrigation waters, primary consideration is ordinarily given to the salinity and sodium hazards involved in their use.

The total salt content of the water, as measured by its electrical conductivity, is a good index of the salinity hazard. Waters whose electrical conductivity is less than 0.25 millimhos per centimeter can be used for the irrigation of most crops on most soils with little likelihood that soil salinity will develop, but in only a few locations can water having an electrical conductivity in excess of 5 millimhos per centimeter be successfully employed. The greater the electrical conductivity of waters, the greater the care that must be taken to prevent the accumulation of salts. Moreover, the salinity of the irrigation water may limit the choice of crops that can be grown.

The alkali or sodium hazard of an irrigation water is an index of its tendency to increase the adsorbed sodium content of soils upon application. The alkali hazard is more difficult to evaluate than the salinity hazard. It is determined largely by the proportion of sodium to calcium plus magnesium present, together with the total salt content. As the salt content of the water increases, the permissible ratio of sodium to calcium plus magnesium decreases. Under some conditions, the bicarbonate content of the water as related to its content of calcium plus magnesium may influence the alkali hazard. It should also be recognized that irrigation waters may contain toxic amounts of boron.

For more detailed information on water quality, publications such as Circular 969, *Classification and Use of Irrigation Waters*, of the Department of Agriculture, should be consulted.

We know of no economically feasible method for reducing the salt content and, thus, the salinity hazard of irrigation waters.

The alkali hazard of waters can be lowered or nearly eliminated by lowering the ratio of sodium to calcium plus magnesium through the addition of gypsum (calcium sulfate). Reducing the alkali hazard of waters is most practical when the total salt content is low because smaller amounts of gypsum are required and the resulting increase in the salinity hazard is less. Special equipment for adding gypsum to water is available. A simple method of application consists of placing a cloth bag of gypsum with the side slit open at a place in the irrigation system where the water has considerable turbulence.

The control of salinity and alkali is accomplished, in general, most easily in coarse-textured soils, which usually are quite permeable and are less susceptible to deterioration of the physical condition upon the accumulation of adsorbed sodium than the soils of finer texture. Medium- and fine-textured soils have the advantage of a greater water-holding capacity and ordinarily present no great problem from the standpoint of salinity control if they have good structure and are underlain by a sand or gravel aquifer which facilitates the removal of drainage water. Prevention of salt accumulation is most difficult in soils consisting of fine-textured, slowly permeable material that extends to a considerable depth.

WHERE SALINITY CANNOT be entirely eliminated, the judicious selection of crops that can produce satisfactory yields under moderately saline conditions may mean the difference between profit and loss.

In selecting crops for saline soils, particular attention should be given to the salt tolerance of the crop during germination, because poor yields frequently result from failure to obtain a satisfactory stand. Some crops that are salt-tolerant during later stages of growth are quite sensitive to salinity during germination.

The tolerances of many crops are listed in Agriculture Handbook No. 60, *Diagnosis and Improvement of Saline and Alkali Soils.*

Among the highly tolerant crops are barley, sugar beets, cotton, Bermudagrass, Rhodesgrass, western wheatgrass, birdsfoot trefoil, table beets, kale, asparagus, spinach, and tomato. Crops having low salt tolerance include radish, celery, beans, and White Dutch, alsike, red, and Ladino clovers, and nearly all fruit trees.

CAREFUL LEVELING of land makes possible a more uniform application of water and better salinity control.

Barren or poor areas in otherwise productive fields often are high spots that do not receive enough water for good crop growth or for leaching purposes. Lands that have been irrigated 1 or 2 years after initial leveling often can be improved by replaning to remove the surface unevenness caused by the settling of fill material. Annual crops should be grown after the first leveling, so that replaning can be performed without disturbing the crops.

Soils containing appreciable amounts of adsorbed sodium are especially subject to puddling and crusting. They should be tilled carefully. They should not be tilled when moist. Heavy machinery should not be moved over them. More frequent irrigation, especially during the germination and seedling stages of plants, tends to soften surface crusts on alkali soils and helps to get a better stand.

FAILURE TO OBTAIN a satisfactory stand of furrow-irrigated row crops on moderately saline soils is a serious problem in many places. The failures usually are due to the tendency of soluble salt to accumulate in raised beds that are moistened by irrigation water moving from the furrow. Modifications in irrigation practice and bed shape may alter considerably the tendency of salts to accumulate near the seed. Preemergence irrigation in special furrows placed close to the seed often is done to reduce the soluble salt concentration around the seeds and thus permit germination. After the seedlings are established, the special furrows may be abandoned and new furrows made between the rows.

The tendency of salts to accumulate near the seed during irrigation is greatest in single-row, flat-topped planting beds. Sufficient salt to prevent germination may move laterally and concentrate in the seed zone, even if the average salt content of the soil is relatively low. With double-row beds also, most of the salt is carried into the center of the bed, but that leaves the shoulders relatively free of salt and satisfactory for planting, especially if the soil is only slightly saline.

Sloping beds are best on saline soils because seed can be safely planted on the slope below the zone of salt accumulation. The salt is carried away from the soil around the seed instead of accumulating in it. Planting in furrows or basins is satisfactory from the standpoint of salinity control but is often unfavorable for the emergence of many row crops because of crusting or poor aeration.

The method and frequency of irrigation and the amount of irrigation water applied are of prime importance in the control of salinity.

The main ways to apply water are flooding, furrow irrigation, sprinkling, and subirrigation.

Flooding, in which water is applied to the entire surface, is preferable from the standpoint of salinity control if the land is sufficiently level and the crop can be flooded.

Furrow irrigation is well adapted to row crops and is also useful if the land is too steep for flooding. This method allows salts to accumulate in the rows, but plowing and mixing the entire surface soil periodically usually will prevent serious increases in the salt content of the soil. If excess salt does accumulate, a rotation of crops and a change to irrigation by flooding is a possible salinity-control measure.

Irrigation by sprinkling allows a close control of the amount and distribution of water. Sprinkling often is used in places where the slope is too great for other methods. One tends to apply too little water by this method, and leaching of salts beyond the root zone is not accomplished without special effort.

Subirrigation, in which the water table is maintained close to the soil surface, is not suitable when salinity is a problem. Even under the most favorable circumstances, this method is not suitable for longtime use unless the water table is lowered periodically and leaching is accomplished by rainfall or by surface applications of water.

As soluble salts retard plant growth in almost direct relation to their total concentration in the soil solution, the moisture content of saline soils should be maintained as high as practicable, especially during the stage of vegetative growth. With a given amount of salt in the soil, the salt concentration in the soil solution drops as the moisture content of the soil increases. A high moisture level is maintained by irrigating oftener than would be the practice for similar nonsaline soils.

BECAUSE ALL IRRIGATION waters contain dissolved salts, some water in addition to that required to replenish losses by plant transpiration and evaporation must be applied occasionally to leach out the salt that has accumulated during previous irrigations.

The additional irrigation water required for leaching is called the leaching requirement and is defined as the fraction of the applied irrigation water that must be leached through the root zone to control salinity at any predetermined level. The leaching requirement therefore depends on the salt content of the irrigation water and on the maximum salt concentration permissible in the soil solution. This maximum concentration in turn depends on the salt tolerance of the crop.

For salt-sensitive crops, the maximum concentration of the soil solution in the root zone should be 3 to 4 millimhos per centimeter. For moderately salt-tolerant crops it should not exceed 8 millimhos per centimeter. For highly salt-tolerant crops, it should not exceed 16 millimhos per centimeter.

If there is no rainfall and no removal of salt by the crop and if drainage is adequate and no salt becomes insoluble in the soil, the leaching requirement is simply the ratio of the electrical conductivity of the irrigation water to the electrical conductivity of the drainage water, expressed as a fraction or as a percentage.

For example, where an electrical conductivity of 8 millimhos per centimeter can be tolerated in the soil solution of the root zone and the irrigation water has a conductivity of 2 millimhos per centimeter, the leaching requirement will be 2 divided by 8, or 25 percent. That means that if crop use and evaporation amount to 30 inches of water during the growing season, 10 extra inches should be added—a total of 40 inches that enter the soil. Because of the assumptions involved, the 10 extra inches are a maximum value. Care must be exercised in estimating the leaching requirement by this method, especially if leaching due to rainfall has taken place. In any event, the method is useful as a concept of

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what must occur in the root zone of the growing crop.

Unless the soil is well drained, the application of irrigation water in considerable excess over that required for the crop and for leaching can be as detrimental from the standpoint of salinity control as underirrigation.

Overirrigation increases the amount of water that the drainage system must convey; if the capacity of the system is exceeded, the water table will rise to an unsafe level. It is apparent therefore that a proper relation between irrigation, leaching, and drainage is of utmost importance in preventing soils from becoming salt affected. The amount of water applied should be sufficient to supply the crop and satisfy the leaching requirement but not enough to overload the system.

EXCESSIVE LOSS of irrigation water from canals constructed in permeable soil is a major cause of high water tables and salt accumulation. Seepage losses can be reduced by lining canals with cement, buried asphalt membranes, or more commonly with earth of low permeability. The maintenance of drainage systems is also important and usually involves nothing more than keeping tile lines in repair or open ditches clean and excavated to grade.

A gradual decrease in soil permeability is a common cause of declining productivity in land under irrigation. Without satisfactory soil permeability, crops cannot be kept adequately supplied with water and the leaching of salts is not accomplished. Soil treatments for the maintenance of permeability are the same as those we discussed for improving soil structure.

To meet the demand for agricultural products, it will be necessary to utilize salt-affected soils and irrigation waters of inferior quality more and more fully. Thus it can be assumed that the improvement of salt-affected soils and the management of productive soils so as to prevent the excessive accumulation of soluble salts and adsorbed sodium will grow in importance.

Erosion on Cultivated Land

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To protect soil from erosion and to hold as much of the rain as possible in a place where crops can use it are a big part of modern soil management.

We cannot avoid all risks of erosion when we lay a soil bare by cultivating it. Neither can we hold all the rain where it falls in humid or subhumid areas. But we need to know the risks and control them the best we can.

Erosion is slow wherever the soils are covered by trees or grass. Near Zanesville, Ohio, scarcely any loss of soil could be measured in 9 years from a woodland watershed of 2 acres. A nearby pasture lost soil during the same period at an average rate of one-tenth ton an acre a year, or about 1 inch in 1,500 years. A similar watershed cropped to a 3-year rotation of corn, wheat, and hay lost an inch of soil in the 9 years.

The rate of erosion in any storm depends on the force with which raindrops stir up soil and the amount and speed of the runoff water. Other factors affecting erosion include kind and amount of cover, kind of soil, and steepness and length of slope.

To judge the erosion hazards in a particular situation, we need to look at more than one rain and consider the pattern of rainfall for a whole year or for several years.

We need to study the location by looking uphill to see how much water is likely to cross the field and by looking downhill to see where the runoff