BY FAR the largest number of failures in irrigation agriculture, according to this author, have been due to unfavorable conditions of soil, water supply, and drainage not realized in advance. Soil formed in a dry climate has peculiar characteristics. It is not enough merely to supply this soil with water; that viewpoint is likely to lead to mistakes. This article gives particular attention to the character of the soil solution, the quality of the irrigation water, and the necessity for continued research on problems that are as yet unsolved.

Soil, Water Supply, and Soil Solution in Irrigation Agriculture

By C. S. Scofield

MANY people have learned through sad experience that not all irrigated land “blooms as the rose” and that the productivity of some of it is relatively short lived. On the other hand, it is true that a great number of such developments are very successful and continue highly productive after many years or even centuries. In Egypt and elsewhere in north Africa, in the south half of China, and in the river basins tributary to the Persian Gulf, agriculture under irrigation has flourished throughout historic times. The causes of failure, where it has occurred, are not always clearly understood or fully agreed upon. Even in this country, where irrigation has been used extensively for less than 100 years, there are numerous instances of failure through declining crop yields as well as many other instances of long-sustained and continuing productivity. It seems clear that long-continued irrigation farming is practicable where conditions are favorable. If the causes of failure are ascertained and clearly understood, methods of avoiding it may be devised and used.

A review of the history of irrigation development in this country shows that, while some failures may be assigned to unfavorable economic or social conditions and a few to ill-advised or inadequate engineering or overoptimistic promotion, by far the larger proportion have been due to unfavorable conditions of soil, water supply, and drainage, which were not realized before development was started. Inadequacy of information concerning these conditions or failure to

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2 See Irrigation in the United States, p. 693.

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use the information available has been the root of the trouble. In many instances, the areas of our irrigable lands are much larger than may be adequately served with our available supplies of irrigation water. The natural tendency has been to use the water on the land to which it could be most easily applied or to spread the water over more land than could be adequately served. Lack of knowledge as to essential soil characteristics that make for success or failure under irrigation has been conspicuous. Not less so has been the lack of information as to the quality of irrigation water, or the appreciation of the need for effective drainage. These are among the more important agronomic factors that lead to declining crop yields.

Irrigation is used as an aid in crop production on soils that are not adequately supplied with natural rainfall. It is not limited to arid regions. Periods of drought occur seasonally in areas having abundant annual rainfall, as for example in Florida during the winter and in the Pacific Northwest during the summer. One of the important functions of the soil is to serve as a reservoir to supply continuously the water required by crop plants. Its capacity as a reservoir is limited, however, and during periods of active crop growth it must be replenished from time to time either by rainfall or by irrigation. Many of the soil problems that arise in connection with irrigation relate directly to this function of the soil as a reservoir for water.

The subject of the soil as a reservoir for water to be used by crop plants has three major aspects: (1) Conditions that relate to the input of water; (2) the volume capacity of the soil as a water reservoir; and (3) the removal of harmful residues that naturally tend to accumulate in the soil reservoir with continued use. People who work with the soil, whether as farmers or as technologists, know it to be essentially dynamic. It is a complex of diverse organic and inorganic materials, continuously reacting physically and chemically, and of equally diverse living organisms whose normal processes of growth and of decomposition play an important part in the changes that occur. These changes affect not only the fertility of the soil but also its physical characteristics, including those that are involved in the absorption, conveyance, and retention of water.

The application of irrigation water in abundance to soils of arid regions may have consequences unsuspected by those engaged in developing projects and by farmers settling on the land. Our crop plants, with a few exceptions, require an aerated root zone. With an abundant water supply from either rainfall or irrigation this requirement can be met only by free subsoil drainage. The lack of such drainage results in swamp conditions to which few crop plants are adapted. Drainage becomes even more important if the irrigation water contains relatively large quantities of dissolved salts. Where proper drainage is lacking these salts accumulate in the soil solution of the root zone to the detriment of growing plants and of the soil itself. Deficient subsoil drainage and resulting swamp conditions are made obvious with abundant rainfall and may thus be avoided or remedied in advance of use, but under arid conditions the drainage deficiency may not become apparent until after the land has been irrigated for some years.

3 See Drainage in Arid Regions, p. 717.
SOILS FOR IRRIGATION

The ideal soil for irrigation is one of medium or fairly fine texture and of deep, mellow, open structure, allowing easy penetration of roots, air, and water, and having free drainage yet good water-holding capacity. This ideal combination of soil characteristics most often exists in the more recently deposited alluvial soils on the flood plains of streams or on alluvial fans. These soils make up large parts of some of our irrigated sections, especially in the Southwest. They are naturally not only highly productive but comparatively smooth or level and they lie in such a position that they may be rather easily supplied with irrigation water. Typical alluvial soils of the arid West are those of the Gila, Hanford, and Yolo series. Another essential feature of a soil for irrigation is that it be relatively free of harmful salts (alkali). This is not always true of alluvial soils, especially after irrigation has been started on adjacent higher lands. Alluvial soils are variously and irregularly stratified and variable in texture and in places contain layers of sand, gravel, or clay. This lack of uniformity of texture and stratification presents difficulties to the soil specialist in classification and mapping of soils. Its importance is now fully recognized, although this has not always been true.

The soils of upland areas are developed from older alluvial, lake-laid, wind-laid, or loessial (fine wind-borne) deposits, or from an underlying bedrock. Large areas of these older soils are under irrigation in places. Soils developed from loess are generally very desirable. Such soils (Portneuf series) cover the greater part of the Twin Falls section in southern Idaho. The upland soils commonly have more definite profiles, greater uniformity of texture, and less variable stratification than alluvial soils. They are likely to have better surface drainage and to be comparatively free from soluble salts. Many areas are coarse-textured, sandy, gravelly, or stony and have lower water-holding capacity, lower content of organic matter and nitrogen, and lower availability of phosphorus than the alluvial soils. Many areas are underlain by claypans, hardpans, or bedrock at shallow depth. All in all, most upland soils are naturally less productive than most alluvial soils, but the former are less subject to damage by water-logging and concentration of salts.

Neither very sandy soils nor heavy clays are generally desirable for development under irrigation. The sandy soils do not hold sufficient water, are relatively infertile, and have a tendency to blow; the clays do not drain well, are hard to plow and cultivate, and are less productive under average farming practices than medium-textured soils. The soils of medium texture—fine sandy loams, very fine sandy loams, loams, silt loams, clay loams, and silty clay loams—are commonly most productive and most desirable for development under irrigation.

The plans for an irrigation enterprise should include the survey of the soils and classification of the lands as well as an investigation of the available irrigation water and the means of conserving it and conveying it to the land. Furthermore, experience has shown that after irrigation has become established, reexaminations of the soil

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4 This subject is more fully discussed in the articles Soil Maps and Their Use, p. 1002, and Irrigation in the United States, p. 693.
should be made from time to time to determine the trend of changes that may occur in the root zone in consequence of inadequate subsoil drainage or the accumulation of soluble salts. Such examinations of the soil of irrigated lands require special methods not only for the field work but also for reporting the findings. While definite progress has been made by soil scientists in the development of such methods, much may still be done to place this work on a sounder and more acceptable basis. The problem, however, is not so much to develop methods as to make practical application of methods already developed. Meanwhile the work of constructing and operating irrigation projects goes on. Avoidable mistakes are made and there are many failures. Questions are raised as to the permanence of irrigation agriculture because of uncertainties as to the causes of trouble. These are the reasons for emphasizing the need of careful, detailed soil surveys and land classification prior to the development of projects and the development and use of acceptable methods for ascertaining and reporting the conditions in irrigated soils.

The characteristics of a soil that have a special bearing on its suitability for agricultural use under irrigation are its water-holding capacity (the water capacity of the root zone), its permeability and natural drainage, and the nature and concentration of the constituents of the soil solution.

**Water Capacity of the Root Zone**

In considering the reservoir capacity of the root zone of the soil it should be kept in mind that there are three forms of soil water. These may be described briefly as follows:

1. **Hygroscopic water**, or water that is held by the soil when in equilibrium with the water vapor in the air, that is, in an air-dry soil.
2. **Capillary water**, or water that is held as liquid films or masses around the soil particles in such a way as to exert no hydrostatic pressure; in other words in equilibrium with the force of gravity, but not in equilibrium with the moisture in the air.
3. **Hydrostatic water**, or water that moves downward in the soil by gravity unless such movement is hindered by some barrier. This often is called free or gravitational water.

From the standpoint of reservoir capacity in relation to crop use it is only the water of the second form, capillary water, that is to be taken into account. Hygroscopic water is not available to crop plants, and hydrostatic water is available only briefly until it passes on, or as it is drawn into the capillary fringe from a lower saturated zone. The effective reservoir capacity of the root zone is therefore limited on the one hand to the quantity of water that may be held there against the force of gravity and on the other hand by the quantity held so firmly by the soil that it is unavailable to crop plants. This quantity in any case is determined by the texture of the soil, its content of organic matter, the nature of its colloidal complexes, and the depth of the root zone. In general, it ranges from 1 to 2 inches of water for each foot of root-zone soil. The depth of the root zone is also variable. In many irrigated soils it is limited by a saturated zone or water table; in some by bedrock, hardpan, or claypan; in others by the depth to which irrigation water penetrates; and in still

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6 See Water Relations of Soils, p. 897.
others that have no such physical limitations by the depth to which roots normally penetrate.

In view of the importance of reservoir capacity as a factor determining the suitability of soils for irrigation, it is manifestly desirable that an acceptable method be devised for determining quantitatively this characteristic of the soil profile. It should be possible to ascertain either by field or laboratory tests the reservoir capacity of representative layers of the soil profile, expressed as inches of water per unit of depth. This information together with the ascertainable facts as to any physical limitations of the depth of the root zone would serve as a most useful aid in classifying and mapping soils. The experienced soil scientist is able to judge the relative water-holding capacity of various soil types with a fair degree of accuracy and uses it as one of the criteria in classifying soils, but actual tests would be very valuable in helping him to form or check his judgments. Such tests would be useful also as a guide for selecting the program of irrigation best adapted to any situation or crop. Much of the misunderstanding and friction currently existing between water users and operation managers might be eliminated were such information available.

**Permeability of the Soil**

The permeability of a soil to water is as important as its reservoir capacity. The essential requirements are that the surface soil shall permit the inflow of water to replenish the root-zone reservoir and that the subsoil and substratum shall permit the escape downward of excess water or excess dissolved salts that might be injurious to crop plants if retained in the root zone. The permeability of soil to the movement of water is measurably influenced by its texture or particle size. That is to say that, other things being the same, a soil composed of large particles like sand is more permeable than one composed of small particles like clay. But this is not the whole story. Soil particles of whatever size may be cemented together to form impermeable layers commonly called hardpan; or the very finely divided or colloidal material in the soil on absorbing water may expand to form an impervious gelatinous mass.

These, rather than texture alone, are the real hazards to soil permeability. Both the cemented layers and the potentially gelatinous condition occur as the result of chemical reactions and are only partly dependent on soil texture. Cemented layers are formed by the deposition of soluble substances carried by percolating ground water. These may have been dissolved from the soil above or may have been carried in from outside sources. Silica, iron, and lime are the chief inorganic substances involved in the formation of cemented strata, but the decomposition products of organic soil constituents also contribute to the formation of impermeable strata, particularly in acid soils. The processes of decomposition, solution, transport, and deposition are the normal and continuing features of the evolution and differentiation of the soil profile. They operate slowly and the results become obvious in older soils, such as the hardpan soils of the Las Vegas and Pinal series. The younger alluvial soils, such as those of the Gila, Hanford, and Yolo series, do not show such differentiation.
The potentially gelatinous condition of the very fine soil material or colloids, sometimes called dispersion, deflocculation, or puddling, is another result of chemical reactions. These are known as reactions of base exchange. They are well known and extensively utilized in industry, particularly in water softening. These reactions take place between the dissolved salts in a solution and certain of the finely divided or colloidal portions of the soil. In irrigated soils the exchange reactions of chief concern as affecting permeability are those of calcium and sodium. Sodium, in the soil colloid, tends to break down the soil particles and impair the permeability of the soil, while calcium tends to granulate the soil and make it permeable.

The trend of the reactions of base exchange is in the direction of an equilibrium between the soil and the dissolved salts in the soil solution in respect to the proportions of the basic constituents in each. Thus, if a change occurs in the ratio of calcium to sodium in the soil solution a change in the same direction occurs in the ratio of these bases in the exchange complex of the soil. It is not to be inferred that a condition of equilibrium implies that the ratios of the two constituents are the same in the soil and in the soil solution. That is to say, if the concentrations of calcium and of sodium were equal in the soil solution, the quantity of exchangeable calcium in the soil would probably be greater than the quantity of exchangeable sodium. This is because calcium has what is described as a greater "energy of replacement" than sodium.

The fact that changes in the permeability of the soil are caused by reactions of base exchange between the soil and its solution has come to be generally accepted only within recent years. This phenomenon of base exchange is currently the subject of much intensive investigation. Its occurrence and its implications are not limited to irrigated soils, nor are such reactions limited to the two elements calcium and sodium. But the exchange reactions of these two elements do affect profoundly the physical condition and the permeability of irrigated soils. The sustained productivity of irrigated land depends upon the maintenance of soil permeability, hence the importance of the subject and of further research work to unravel its complexities.

It is generally accepted as a fact that the dissolved salts carried to the soil in irrigation water become more concentrated in the soil solution as water is evaporated from the soil or absorbed and transpired by crop plants. Also, that the basic constituents of these dissolved salts participate in the reaction of base exchange in the soil and thus affect its physical condition and its permeability. Because the effect of the sodium constituent is to impair soil permeability, its concentration in the soil solution, relative to the concentration of calcium, is a matter of concern. The current investigational need is for convenient and acceptable methods for determining the composition of the dissolved salts in the soil solution and of the replaceable bases in the soil as related to permeability. Such methods would make it possible not only to ascertain existing conditions but also by successive investigations to ascertain the trend and the rate of change of conditions.

6 See General Chemistry of the Soil, p. 911.
THE SOIL SOLUTION

Water that is held by the soil in the root zone available for the use of crop plants is called the soil solution. The nature and concentration of the dissolved substances are matters of the first importance. This is because these dissolved substances are the only source of the mineral elements essential to plant growth, and also because they may include elements injurious to crop plants or the concentration of which in the solution may be such as to hinder the absorption of the water by the plants. Under conditions of copious rainfall and of free root-zone percolation the need may be to maintain in the soil solution adequate concentrations of the constituents that are essential to normal crop growth. With irrigation, however, and particularly with restricted root-zone percolation, there is another danger, namely, that excessive concentrations of dissolved constituents may accumulate in the soil solution. It is possible, of course, that the soil solution may be at the same time deficiently supplied with some essential constituent and contain an excess of others.

In irrigation farming it is important to maintain in the root zone of the soil an adequate quantity of water to supply the continuing needs of the crop plants, on the one hand preventing excessive root-zone leaching and on the other insuring sufficient leaching to prevent the accumulation of excessive concentrations of dissolved salts. In situations where the irrigation water is relatively pure, losses or injuries from excessive leaching may be avoided by restricting the quantities of water applied. But when the irrigation water contains relatively large quantities of dissolved salts it becomes necessary to use it in sufficient quantities to insure root-zone leaching and thus to prevent the accumulation of excessive concentrations in the soil solution. It follows, of course, that there must be effective subsoil drainage, either natural or artificial, to permit the removal of the percolating soil solution with its dissolved salts.

The occurrence of dissolved or of soluble salts in the root zone of irrigated land may be a natural condition existing before the use of irrigation water. In the survey and classification of land to be irrigated this condition of natural salinity is one of the factors to be appraised. Its correct appraisal is one of the important problems of the soil survey of an irrigable area. The investigational work of such a survey should have four objectives: (1) To determine the quantity or concentration of soluble salts in representative areas and their characteristic distribution in the successive layers of the root zone; (2) to ascertain their composition by analyses; (3) to identify, if possible, their source; and (4) to explore the possibilities of their removal by leaching and drainage.

Although it is now possible to determine approximately the total salt content of a soil and its degree of alkalinity by simple tests made in the field, there is need for improvement in methods to promote uniformity and precision. There is great variety among the methods currently in use. This statement applies particularly to the methods for determining the quantity or concentration of the soluble salts, and to the methods for obtaining samples of the soil solution for detailed analysis. For example, some investigators endeavor to determine by one expedient or another the total quantity of soluble material or the
total quantity of one or more of the soluble constituents contained in a unit quantity of soil. Others attempt to ascertain the concentration or the composition of the solution that may be extracted or displaced from a moist soil. The lack of widely acceptable methods for such work and the use of widely different methods by different investigators has made it almost impossible to compare their findings or to draw conclusions as to the essential facts. Because of this confusion there is no agreement on such questions as, What are the concentrations of any salt constituent that will impair crop growth, and, What is the trend or rate of change of salinity conditions in any given area?

The conditions of salinity in the soil solution are seldom static. Each periodic addition of water to it makes it more dilute and the continuing loss of water from it, whether by evaporation or by plant absorption, makes it more concentrated. Furthermore, it is subject to changes in the proportions of its constituents due to reactions with the soil, differential absorption by plants, and the dissolution or decomposition of the components of the soil. Finally, the solution itself is subject to movement within the soil either laterally or vertically in response to hydrostatic forces. These changes and movements add to the difficulty of ascertaining and reporting the facts as to what are the actual conditions of salinity in the field that cause observable plant responses, or as to what are the actual changes in conditions that occur from time to time as the result of irrigation.

Notwithstanding those ever-changing conditions of salinity within the root zone it is possible to ascertain and to report certain quantitative facts that are significant. These facts include: (1) The depth of the root zone; (2) the quantity of water in depth per unit area (e.g., inches of water per acre) held in the root zone (a) when at field capacity and (b) when at wilting point (wilting coefficient); and (3) the quantity of dissolved or soluble salts in the root zone expressed as tons per acre. With these facts available it is possible to estimate the concentration of dissolved salts in the soil solution and the range of concentration to which the crop plants are subjected between irrigations. It is believed that this method of appraising the conditions of salinity is better than the alternative method of reporting the soluble salts in terms of percentage of the dry weight of the soil. There are two reasons for this choice of methods. One is that all of the precise data as to the reactions of crop plants to salt constituents are reported in terms of solution concentration, and the other is that in the absence of information as to the water relations of the soil it is not possible to estimate the concentration of the soil solution from the data of salt percentages with reference to the dry weight of the soil.

**Constituents of the Soil Solution**

It is essential to an understanding of plant and soil reactions to the composition of the soil solution to keep in mind that it is the salt constituents rather than the salts that cause the reactions. A salt such as sodium chloride, when it passes into solution, dissociates or separates into its two components, sodium as a basic or positively charged ion and chloride as an acid or negatively charged ion. This is true for all of the electrolytic salts that are characteristic of soil solutions. It is these constituent ions that are measured in making the analyses of
solutions, and it is also these ions, acting independently, that are absorbed by plants or that participate in reactions between the soil solution and the soil.

In view of these facts it is manifestly of doubtful utility to describe the composition of a soil solution by naming a list of the combinations that might be formed from the identified constituents. Similarly it is of questionable value to characterize a solution or a salt complex as having certain proportions of black alkali and of white alkali. At best these designations imply theoretical concepts that have little significance. The characteristics of a soil solution may be most concisely and accurately described by giving its total concentration, together with either the actual or proportional concentrations of its more important constituents.

The soil-solution constituents ordinarily identified by analysis in irrigated areas are the following: (1) Calcium (Ca), (2) magnesium (Mg), (3) sodium (Na), (4) potassium (K), (5) carbonate and bicarbonate (CO₃ and HCO₃), (6) sulphate (SO₄), (7) chloride (Cl), and (8) nitrate (NO₃). In some situations the elements boron and selenium occur as parts of ions in the soil solution and are also identified. Certain physical characteristics of the solution are also determined, e.g., the specific electrical conductance, and the hydrogen-ion concentration. Of the eight constituents enumerated above, the first four are cations or basic ions while Nos. 5 to 8 are anions or acid ions. Some of these constituents are known to be essential to plant growth. Other elements, such as iron, manganese, and phosphorus, are also essential but rarely if ever do they occur in harmful concentrations in irrigated lands.

While crop growth on irrigated land may be restricted because of the deficiency of certain solution constituents such as nitrate, phosphate, potassium, or iron, the more striking and disastrous losses are caused by excessive concentrations of such constituents as sodium, chloride, and sulphate, with occasional injury from boron or selenium. The carbonate-bicarbonate constituent is not here included in either category because it is seldom if ever deficient and there is little if any valid evidence that it is ever directly injurious. The situation as to calcium and magnesium calls for special comment. These constituents are almost universally present in irrigation waters and in the soil solutions of irrigated land, and their concentrations are seldom below the maximum plant requirements. On the other hand, calcium is seldom if ever found in the soil solution in concentrations high enough to be injurious to crop plants. This is because it is usually associated in the solution with sulphate and bicarbonate, with which it forms salts of such low solubility that it is precipitated from solution before it reaches injurious concentrations. It is theoretically possible to have injurious concentrations of magnesium in the soil solution, but actually this does not occur frequently.

Because both calcium and magnesium participate in reactions of base exchange between the soil solution and the soil, the occurrence of these constituents in the soil solution is more likely to be beneficial than harmful. Exchange reactions by which calcium and magnesium pass from the solution into combination with the soil tend to improve the physical properties of the soil in respect to tilth and permeability.
Consequently the application of irrigation water relatively rich in calcium and magnesium is likely to benefit the soil and is not likely to injure the crop plants.

In the light of our present knowledge and the considerations discussed above it is manifestly not possible to make two lists of soil-solution constituents, one list to include those that are beneficial and the other those that are harmful. It seems highly probable that all of the constituents named above and probably many others are beneficial if not essential to plant growth. The adverse effects of deficiencies of some of them are well-known. With respect to each of them there is probably some optimum concentration below which growth is impaired and above which there is some injury. There is very little precise information or agreement among investigators as to these optimum concentrations for the several constituents. There are differences of opinion among plant physiologists even as to whether some of these constituents are beneficial at all. There are also wide differences of opinion as to what concentration of any given constituent either above or below the optimum may cause appreciable depression of growth with any given species of plant under any given set of conditions. In view of these facts it is manifestly not possible at the present time to state the limits of tolerance of crop plants to excessive concentrations of the dissolved constituents of the soil solution.

THE QUALITY OF IRRIGATION WATER

Any adequate consideration of the soil conditions of irrigated lands must include the quality of the irrigation water. This is because irrigation water, unlike rain water, contains dissolved substances, often in substantial quantities, and these substances accumulate in the irrigated soil and may, in time, cause profound changes in its character. It is not unusual to apply in a single season as much as 2 or 3 feet in depth of irrigation water. Nor is it unusual that an acre-foot of irrigation water may contain as much as a ton of dissolved solids. Thus, the addition annually of 2 to 3 tons of dissolved solids to an acre of irrigated land is not uncommon. By way of comparison it may be remarked that when soluble salts are used as commercial fertilizers the ordinary rate of application is 200 to 300 pounds per acre.

Some of the dissolved constituents in irrigation water, such as potassium and nitrate, may be directly beneficial to crop plants. Others, such as calcium and magnesium, may under some conditions have a beneficial effect on the physical condition of the soil. There remain, however, other constituents—chloride, sulphate, and sodium, for example—that are seldom beneficial to the soil or to the crop plants and in the higher concentrations are definitely injurious. The effects of these dissolved constituents, whether good or ill, are seldom immediately apparent. If the concentrations are low, irrigation water may be used for many years before the evidences of injury become obvious. Unfortunately it is a fact that by the time the effects of injury, particularly to the soil, become apparent, they have progressed so far that remedial measures are likely to be expensive and to require a long time to become effective.

The effects on the soil of the dissolved constituents of irrigation
water may operate in two ways: (1) On the physical properties of the soil mass; (2) on the concentrations of soil solution. These two kinds of effects may occur separately or together. In considering either or both it should be kept in mind that when irrigation water is applied to the land, most of the water is dissipated into the air either by direct evaporation from the soil or by transpiration from plants, while the dissolved constituents are not so dissipated. Some of them may be absorbed by plants to a limited extent, but for the most part they remain in the soil unless removed from it by drainage. Thus it follows as a matter of course that the soil solution is always more concentrated than the irrigation water, except in instances where rainfall or natural flooding have a marked effect in leaching the soil. How much more concentrated the soil solution is will be determined by the quantity and effectiveness of the drainage.

The physical changes that occur in an irrigated soil are chiefly the results of reactions of base exchange. These reactions are induced by changes in the relative concentrations in the soil solution of the basic or cation constituents such as calcium, magnesium, and sodium. Thus if, in the irrigation water and in the resulting soil solution, the proportion of calcium and magnesium to sodium is substantially the same as that of the original soil solution, there should be no change in the physical properties of the soil. But if these proportions are different in the irrigation water, there would follow a corresponding change in the soil. The change to be feared is the one in the direction of a higher proportion of sodium, because the increase of this exchange constituent may lead eventually to dispersion of the soil particles, a tough or rubbery condition of the soil mass, and to impaired conditions of soil tilth and permeability.

In good agricultural land in normal condition the exchangeable constituents are mostly calcium and magnesium. There are, of course, acid soils in humid regions in which exchangeable hydrogen occurs, but in neutral or alkaline soils of good tilth and permeability calcium and magnesium are the dominant exchangeable constituents. The use of irrigation water in which sodium is the chief basic constituent is almost certain to have an adverse effect on such a soil. The effect may be slow to appear unless the concentration is high both relatively and absolutely, but it is inevitable unless some corrective measures such as the artificial application of calcium are used.

The gradual accumulation of dissolved constituents in the soil solution of irrigated land may occur along with or independently of changes in the physical condition of the soil. The two phenomena are seldom wholly unrelated. To some extent the occurrence of high concentrations of such constituents as sulphate and chloride tend to offset or counteract the dispersing effects of sodium. But the chief concern over high solution concentrations in the soil has to do with their direct effect on plants. These dissolved constituents in the soil solution appear to be injurious in two ways. They tend to inhibit the absorption of water by the plant roots, and some if not all of them when present in excessive concentrations are absorbed by the plants and cause internal derangements of growth processes. Much remains unknown as to just how these toxic effects occur. There is much uncertainty also as to the limits of plant tolerance to each of the salt
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constituents. There is no question, however, as to the fact that the dissolved salt constituents of irrigation water do accumulate in the soil and do impair its productivity.

Fortunately these injurious consequences may be prevented in many instances. The accumulation of these soluble salt constituents results from inadequate irrigation or inadequate drainage. If drainage, either natural or artificial, is adequate, the accumulation of salts in the soil may be prevented by the use of enough irrigation water to leach the root zone at least occasionally and thus carry the salts away. In the survey and appraisal of irrigable land it becomes essential, therefore, to give consideration to the conditions of permeability of the soil and subsoil. Unless these conditions are naturally favorable to drainage and to the removal of the soluble residues of irrigation, the danger of impaired productivity from salt accumulation is serious.

IMPORTANCE TO IRRIGATION AGRICULTURE OF CONTINUED RESEARCH

The history of irrigation shows that there have been many successes and many failures. The determining factors are not always easy to identify, but the majority of them may be traced to unfavorable conditions of water supply, soil, and drainage.

Irrigation agriculture is beset with most of the hazards that plague ordinary farming, such as weeds, insect pests and plant diseases, and the uncertainty of continued soil fertility. It is not even wholly free from the fear of drought. Its operation costs are relatively high because of water-service charges and the labor of irrigation. To meet these higher costs the crop yields must be relatively large, and there should be a reasonable prospect of long-continued productivity. Such a prospect appears to depend upon the wider utilization of the fruits of experience now available, together with the extension of knowledge concerning some of the fundamental conditions of the soil, its reactions to the constituents of irrigation water, and the effects of these constituents on crop plants.

The more important causes of declining crop yields peculiar to irrigated land lie in the conditions of the soil solution and could be prevented if they were better understood. The conditions of the soil solution are, in turn, largely due to the characteristics of the irrigation water. Thus the general problem of the permanence of irrigation agriculture insofar as it depends upon the sustained productivity of irrigated land is directly related to the quality of the irrigation water. The dissolved constituents of the irrigation water may react with the soil to cause changes in its character or they may accumulate in the soil solution and thus directly injure the crop plants. Where the potentialities of injury of either kind exist and are known in advance, remedial measures may be taken, often at small expense. It is much easier to prevent injury than to deal with it after it has developed.

In view of the fact that the extent of the irrigable land in this country greatly exceeds the area for which there is available irrigation water, the first objective should be to select the best land for irrigation development. To do this wisely there is need for wider appreciation and clear understanding of those factors of soil, of topography, and of
drainage conditions that are important in determining the continuity of successful irrigation. Even with the best available land there is further need for information as to the trend of changes that follow irrigation to serve as a guide to proper irrigation and drainage management. The program of management must be adapted to local conditions.

The continued development and extension of irrigation is one of the important causes of changing conditions in respect to the quality of the irrigation water. Along any given stream the diversion and use of water not only diminishes the quantity available below it but affects the quality also. The drainage water returned to the stream from irrigated land carries most of the dissolved salts in the water originally diverted, but the volume of returned water is much less. Thus as the complete utilization of water resources is approached, the problem of dealing with the dissolved salts becomes increasingly acute. This is one of the more fundamental problems of maintaining a permanent irrigation agriculture. To deal with it efficiently and successfully calls for continuing investigation in the field of soil science and the practical application of the findings of such investigation.