Chapter 4

Plant Response and Crop Selection for Saline and Alkali Soils

Significance of Indicator Plants for Saline Soils

Hilgard (1906) was among the first to recognize the significance of certain native plants as indicators of the characteristics of soils, and to make use of them in determining the availability of saline and alkali soils to agriculture. More recently, Sampson (1939, *p. 200*) has stated:

> In the future a broader use of indicator communities and species is likely, but such use is sure to be backed by sounder evidences than it has at this time. Preceding this possible broadened use there must first be more critical study of the growth requirements of both the indicator plant and the economic species; only then will the indicator concept reach its maximum reliance.

Some progress has been made in developing quantitative methods for the study of the indicator plant concept; and, in some areas, data have been obtained that relate the growth performance of indicator plants and their ability to survive to the physical and chemical measurements of the soils in which they grow. Kearney and associates (1914) made a quantitative study of plant communities as indicators of salinity and soil moisture in the Tooele Valley, Utah, and determined the moisture equivalent, wilting coefficient, and salt content for six characteristic plant communities. For example, they concluded that land characterized by a sagebrush association is capable of crop production with irrigation, and that a greasewood-shadscale type of vegetation indicates land that is suitable for crop production under irrigation only after the excess salts are removed by leaching. Harris and coworkers (1924, *p. 922*), working in the same valley, found "a close parallelism between physiochemical properties of tissue fluids of native species on the one hand and the characteristics of the soil and the capacity of the land for crop production on the other."

In connection with investigations of grazing in western Utah, Stewart, Cottam, and Hutchings (1940) investigated the root penetration of several desert plants as influenced by soil salinity and the nature of the root system of the plant. They found that roots of shadscale readily penetrated soil having 1,000 to 10,000 p. p. m. salt, but those of sagebrush did not. Billings (1945) studied the soil characteristics of several plant communities in western Nevada, including greasewood and greasewood-shadscale associations, and reported data on soil type, texture, pH, and electrical conductivity of the soil solution. He found rather high alkalinity (pH 8.5 to 9.5) throughout the profile in the greasewood association, and conductances of 1:5 soil:water extracts ranging from 1.6 to 8.4 mmhos/cm. in the 2- to 50-cm. depths.

Roberts (1950) has investigated the chemical effects of salt-tolerant shrubs on soils in the semiarid regions of western United States, and found that such shrubs as greasewood and shadscale were responsible for significant changes in some of the chemical characteristics of the soil profile. Data from several hundred field pH tests and some laboratory analyses showed striking differences among the pH, exchangeable sodium, and total salt content of soils under some species of shrubs as compared to those under other species and to the soils in intervening barren areas. Soils in a mixed shadscale-greasewood association in the Antelope Springs silty clay loam in southwestern Utah had a higher pH value under greasewood than under shadscale, and both values were higher than the pH of barren soil. A similar relationship was found with respect to EC_e and sodium status.

Fireman and Hayward (1952) made a quantitative study of several indicator plants growing in mixed and pure associations in the Escalante Desert, Utah, to determine the relation of vigor, age, and distribution of indicator plants to the physical and chemical characteristics of the soils of their habitats, and to compare soils occupied by the root systems of indicator plants and the soils in the adjacent interspaces. The pH values of saturated soil pastes and 1:10 soil: water suspensions, particularly of the surface soil, generally were higher under shadscale and invariably higher under greasewood than under sagebrush or in the adjacent bare areas. The *ESP* of the soil was somewhat higher under shadscale and very much higher under greasewood than under sagebrush or in the barren areas, and the soluble-salt content was appreciably higher under shadscale and greasewood than in adjacent bare soil or under other shrubs.

These and other studies by Flowers (1934), Harris

(1920), and Shantz and Piemeisal (1924) indicate that a vegetational survey can be useful in appraising an area if quantitative data are available regarding the soils and the ecology and physiology of the indicator plants. However, certain precautions should be taken in the use of indicator plants as a basis for the diagnosis of saline and alkali soils. In the first place, it would be unwise to appraise land on the basis of a single species unless it is a reliable indicator. Some species of plants growing in semiarid regions are poor indicators, even though they may tolerate large quantities of salt, because they will also grow very well in the absence of salinity or alkali. Tussockgrass, saltgrass, and shadscale, especially, tolerate an appreciable degree of salinity but will grow well in the absence of salt. Even greasewood is not an infallible indicator, since it has been found making thrifty growth on nonsaline sand dunes.

A second point to emphasize is the need for very careful sampling. The studies by Roberts and by Fireman and Hayward, cited above, indicate that large differences may occur in soil samples from sites only a few feet apart, especially when the plant association is a mixed one. If a vegetational survey and related soil sampling are to serve as a basis for determining the suitability of soils for irrigated agriculture, the analysis of the plant population and the collection of soil samples must take into account the possible effects of the indicator plants on the chemical and physical characteristics of the soil.

A third consideration relates to the purity and density of stand and the vegetative vigor of the various species present in the area to be evaluated. In the following paragraphs, the statements regarding the significance of various indicator plants are based on the assumption that they occur in a relatively pure stand and that they are growing in a normal manner. In the case of mixed associations, the appraisal should take into account the indications of all of the dominant species in the plant community.

Several species of plants native to western United States are regarded as good indicator plants if the precautions noted above are observed. Some of the best known indicator plants are listed below, and pertinent available data are given regarding their ranges, characteristics of the soils on which they grow (texture, soil moisture, salinity, etc.), and the conditions which they may indicate with respect to reclamation or soil-management practices needed for irrigation agriculture. The order in which the indicator plants are listed is based on the approximate level of soil salinity associated with the occurrence of the species in pure stand or as one of the dominant species. The information given was compiled from the data and field observations of the authors cited in this chapter.

Indicator Plants [10]

MESQUITE (*Prosopis juliflora*).—Range: Southern Kansas to southeastern California, Baja California and Sonora, Mexico, to eastern Texas. Occurs on a variety of textural soil classes that are very permeable and well-drained, with a low water table and an intermediate moisture-holding capacity (*SP* 25 to 50).[11] The soils are usually nonsaline throughout the 4-foot profile, but salt may accumulate at the surface under some conditions. Indications: Suitable for agriculture if water is available.

CREOSOTEBUSH (*Larrea tridentata*).—Range: Southern Colorado and southern Utah to west Texas, west to California and Mexico. On dry plains and slopes. Occurs on soils of coarse and moderately coarse texture that are very permeable and well-drained, with low water table and low to intermediate moisture-holding capacity (*SP* 15 to 40). The soils are nonsaline to a depth of 4 feet (<0.03 percent) [12] and nonalkali. Indications: Where stands are good, the soils are nonsaline and of sufficient depth to support a specialized agriculture provided water is available. If stands are poor, the soils may be shallow, underlain with layers of rock or hardpan, and unsuitable for crop production.

SAGEBRUSH (*Artemisia tridentata*).—Range: South Dakota to British Columbia, south to northern New Mexico and northern Arizona; rare in southern California. Occurs on loamy soils (loamy sand, gravelly loam, sandy loam, loams, silt loam, and clay loam) that are more or less permeable and well-drained, and the soil moisture may vary from low to high (*SP* 15 to 70). The soils are nonsaline (<0.05 percent) and nonalkali in the zone occupied by the roots. Indications: The soils are suited for irrigation agriculture or dryland farming, provided they are in an area where precipitation is adequate and the growing season is favorable. No reclamation practices are required. Sagebrush is not a good indicator of soil texture, because it occurs on a wide range of textural classes. It may grow well on soils that are too stony for farming.

WINTERFAT, or WHITESAGE (*Eurotia lanata*).—Range: Saskatchewan, Canada, to Washington, south to Texas, Arizona, and California. May be in pure stands, but frequently occurs in mixed associations with shadscale, rabbitbrush, and greasewood. Occurs on loamy soils that are permeable and well-drained, with a low water table and low to intermediate moisture-holding capacity (*SP* 20 to 45). Soils usually nonsaline in the first foot or two (<0.03 percent), but roots may penetrate soil layers having salt in excess of 1,000 p. p. m. (0.1 to 0.6 percent). Indications: Where winterfat is dominant, the soils are usually nonsaline, but this plant can tolerate some salt; therefore, leaching may be required.

DESERT SALTBUSH (*Atriplex polycarpa*).—Range: Arizona, Nevada, Utah, central California to northwestern Mexico. Occurs on moderately coarse-textured soils (sandy loam, fine sandy loam) that are moist in winter and dry in summer and fall. The water table

[10] The authors acknowledge the assistance of W. G. Harper, Division of Soil Survey, in the preparation of this section.

[11] See Method 3b for estimating saturation percentage (*SP*) in coarse-textured soils.

[12] Values for salinity in this and following statements are given as percent salt (dry-weight basis).

is usually low, and the moisture-holding capacity is intermediate (*SP* 25 to 50). The soils may be nonsaline in the first foot, but they usually contain some salt in the subsoil (0.04 to 0.5 percent). Indications: Where stands are pure and growth is good, the soils are nonsaline or slightly saline and are suitable for irrigation agriculture. Where growth is poor, there may be a limy hardpan or salt in the subsoil. Leaching and drainage may be necessary.

ARROWWEED (*Pluchea sericea*).—Range: Texas, southern Utah, southern California, and northern Mexico. Occurs on loamy soils which are usually permeable, with an intermediate moisture-holding capacity (*SP* 30 to 50). There is usually a high water table or available moisture below the first foot throughout the year. It frequently occurs with the saltbush (*Atriplex lentiformis*), but it is less salt tolerant than that plant. The soils may be strongly saline in the surface foot (0.6 to 2.0 percent), the salinity decreasing with depth (0.1 to 0.5 percent in the fourth foot). Indications: The soils are usually saline or strongly saline; but, where the subsoil is permeable, the land is suitable for agriculture after drainage and leaching.

SHADSCALE (*Atriplex confertifolia*).—Range: North Dakota to Oregon, south to New Mexico, northern Arizona, and California. Plains and valleys in mountainous areas. Usually occurs on medium to moderately fine-textured soils. The soils have an intermediate to high moisture-holding capacity (*SP* 25 to 60), may have restricted permeability, and a high water table may develop, depending upon subsoil conditions. The soils are nonsaline to slightly saline in the first foot (0.02 to 0.1 percent), the salinity increasing with depth (0.3 to 1.0 percent). The soils may contain exchangeable sodium, and the pH of the surface soil may exceed a value of 9.0. Indications: Shadscale is salt and alkali tolerant, but it has a wide range of tolerance and may grow well on soils that are nonsaline or slightly saline. It usually indicates a soil with harmful amounts of salt or exchangeable sodium in the subsoil. The soils may be farmed after leaching, but drainage may be required.

GREENMOLLY (*Kochia americana*).—Range: Wyoming to northeastern California, south to northern Arizona and New Mexico. Occurs on medium- to fine-textured soils that are usually homogeneous to a depth of several feet. They may puddle easily, and the permeability is lower than that on sagebrush lands, which frequently adjoin *Kochia* associations. Soil moisture is intermediate to high (*SP* 40 to 70), and there may be a high water table. The salinity is moderately low in the first foot (0.12 to 0.3 percent), but it increases with depth so that the second to fourth feet may be strongly saline (0.55 to 1.5 percent). Since *Kochia* tends to have a shallow root system which does not penetrate the more saline deeper portions of the profile, it should not be regarded as especially salt tolerant. Indications: Pure stands of *Kochia* occur in soils that are low in salt in the first foot but have a saline subsoil. Leaching and drainage are required, and suitability of such land for irrigation agriculture is doubtful.

ALKALI-HEATH (*Frankenia grandifolia* var. *campestris*).—Range: Central and southern California and Nevada. On low-lying lands and alkali flats. Occurs on soils of various textures (sandy loams to fine-textured loams) with soil-moisture conditions which vary from well-drained to wet with a high water table. The salinity is also variable, ranging from low to very high (0.02 to 2.0 percent), and exchangeable sodium is frequently present. Indications: Where alkali-heath is growing luxuriantly in a uniform stand, the soils are generally highly saline and the lands are unsuitable for agriculture unless they are drained and leached. Where growth is sparse, the soil may be much less saline and easier to reclaim.

GREASEWOOD (*Sarcobatus vermiculatus*).—Range: North Dakota to Alberta, Canada, south to California, Arizona, and northern Mexico; rare in California and southern Arizona. Usually occurs on fine-textured soils (clay, clay loam) but occasionally on soils of coarser texture. The moisture content of the soil is intermediate to high (*SP* 45 to 70), especially below the second foot, permeability may be restricted, and frequently the water table is high. The soils are generally saline-alkali; the range of salinity is wide (0.05 to 1.6 percent) and varies with depth; exchangeable sodium is present in most areas and the values are moderate to high. Indications: Greasewood is very salt and alkali tolerant, and usually indicates a fine-textured, relatively impervious soil with high salinity and exchangeable sodium. Drainage and leaching are required, and amendments may be necessary.

CRESSA (*Cressa truxillensis*).—Range: Texas to southern Utah and southern California and Mexico. Occurs on saline flats where the soils are fine-textured, usually moist, with restricted permeability. The salinity is very high (1.0 to 2.0 percent). Indications: Cressa is a good indicator of saline soil and is more reliable than alkali-heath, because the range of salinity under which it grows is less variable. The soils require drainage and leaching.

SALTGRASS (*Distichlis stricta*).—Range: Saskatchewan to Washington, south to Texas, Arizona, and California. On salt flats and wet meadows. Occurs on soils of various textures, but it is most commonly found on loamy soils. The moisture-holding capacity is usually high (*SP* 45 to 90), and the soils are moist or wet throughout much of the year with a high water table. The salt content of the 4-foot profile is usually high (0.8 to 2.0 percent), with the highest content in the first foot. However, good stands may occur on soils containing very small amounts of salt (0.05 percent). Exchangeable sodium may or may not be present. Indications: Usually indicates wet, strongly saline soils with high water tables, but the plant may occur in areas low in salinity. Drainage and leaching are essential.

SALTWORT, or SEEPWEED (*Suaeda* spp.).—Range: Alberta to Oregon, south to northern Mexico. Salt flats and marshes. Occurs on loamy soils of varying

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textures which may be puddled and underlain with hardpan. Usually found on moist seep lands with high water tables but may occur on better drained land. Moisture-holding capacity is intermediate to high (*SP* 30 to 60). The soils are saline or saline-alkali, with high concentrations of salt in the first foot (0.6 to 3.2 percent) and decreasing amounts with depth, but the average salinity for a 4-foot profile may exceed 1 percent where the growth is luxuriant. The soils may contain exchangeable sodium. Indications: Where virgin growth is vigorous, seepweed is a good indicator of highly saline or saline-alkali soil. Drainage and leaching are essential, and amendments may be required.

ALKALI SACATON, OR TUSSOCKGRASS (*Sporobolus airoides*).—Range: South Dakota to Washington, south to Texas, Arizona, and southern California. In low, wet areas, and river valleys. Occurs on loamy and clayey soils that have an intermediate to high moisture-holding capacity (*SP* 45 to 75). The soil surface is moist a great part of the year, and the water table is usually high. The salinity of the soil may vary within wide limits (0.3 to $>$3.0 percent), the higher values being in the first foot; but the plant grows best in the lower range (0.3 to 0.5 percent). Exchangeable sodium may be present, and this grass is very tolerant to it. Indications: In pure, vigorous stands, this plant is a good indicator of wet, very saline or saline-alkali soils, with a high water table. It may occur on soils without a high moisture content in the subsoil on sites receiving runoff water. The land requires drainage and leaching, and soil amendments may be needed unless gypsum is present.

SAMPHIRE, OR GLASSWORT (*Salicornia* spp.).—Range: Saskatchewan to British Columbia, south through Colorado and Nevada. On salt flats and along shores of saline ponds and lakes. Occurs on fine-textured clayey soils that are very wet throughout the profile, with high water tables. The salinity is very high, and this plant grows well where salt may average 1 to 4 percent in the 4-foot profile. Exchangeable sodium may be present in varying amounts. Indications: Soils are usually very wet, with excessive salinity. Useless for agriculture without drainage and prolonged leaching.

PICKLEWEED, OR IODINEBUSH (*Allenrolfea occidentalis*).—Range: Oregon to Baja California, Mexico, east through Arizona and New Mexico to western Texas. On saline flats. Occurs on a wide range of soil textures (loamy and clayey soils), but usually on fine-textured soils. The soils are moist or wet throughout the year, with high water tables that may be close to the surface. The soils are excessively saline in the first foot (1.0 to $>$2.5 percent) and are very saline throughout the 4-foot profile (average 1.0 to 1.5 percent), but the salinity decreases somewhat with depth. Exchangeable sodium may be present in varying amounts. Indications: Soils are usually fine-textured, very wet, and excessively saline. If the stand is good, the land is not suited for agriculture without drainage and prolonged leaching.

Crop Response on Saline Soils

A field of crop plants growing on saline soil usually has barren spots, stunted growth of the plants with considerable variability in size, and a deep blue-green foliage; but these features are not invariable indications of salinity. For example, barren spots may occur in nonsaline fields because of faulty leveling and the resultant inadequacy of irrigation; and retarded growth and abnormal color may result from nutrient deficiencies.

The extent and frequency of bare spots in many areas may be taken as an index of the concentration of salt in the soil. Inasmuch as most plants are more sensitive to salinity during germination than in later stages of growth, barren spots are more indicative of salinity around the seed during germination than they are of the general salinity status of the soil profile. Frequently, cultural practices contribute to an accumulation of salt around the germinating seed with resultant failure in germination. The vigor of the plants adjacent to barren spots may indicate the distribution of salt in the soil. Full-sized vigorous plants immediately adjacent to a bare spot suggest a local concentration of salt, while stunted plants in this position indicate a more general distribution of salinity in the area. If the level of salinity is not sufficiently high to result in barren spots, the major characteristic in the appearance of the crop may be a marked irregularity in vegetative vigor.

Caution should be exercised to avoid confusion between effects of low soil fertility and those caused by salinity. Plants that are stunted because of low fertility are usually yellowish green, whereas those stunted owing to salinity are characteristically blue green. The bluish appearance is the result of an unusually heavy waxy coating on the surface of the leaves, and the darker color to an increase in the chlorophyll content on a surface-area or fresh-weight basis. Sugar beets, crucifers (cabbage, mustards, and related species), alfalfa, some clovers, grasses, and other crops generally develop a noticeable blue-green coloration when grown on saline soils.

There are many regions where plants may develop an intense chlorosis because of certain soil conditions. The causes of chlorosis are not fully understood, but this condition is frequently associated with calcareous soils or, in some cases, with the use of irrigation waters of high bicarbonate content (Harley and Lindner, 1945). Although calcium carbonate is relatively insoluble, much crop injury is associated with its presence. Since this soil condition frequently occurs in the absence of an accumulation of soluble salts, chlorosis cannot be regarded as a definite symptom of salinity.

Some species of plants develop characteristic necrotic areas, tipburn, and firing of the margins of the leaves when grown on saline soil. Many stone fruits, avocado, grapefruit, and some of the less salt-tolerant varieties of cotton belong in this category.

The cupping or rolling of leaves is a common manifestation of moisture deficiency in plants, but these symptoms may be indicative of salinity when they occur in the presence of apparently adequate soil moisture; however, other factors that cause malfunction of the root system, such as root diseases and high water tables, may produce similar leaf symptoms. While the appearance of the crop may, therefore, be indicative of saline conditions, a reliable diagnosis of salinity usually requires additional evidence derived from appropriate soil and plant tests.

Salinity and Water Availability

Numerous laboratory experiments with sand and water cultures have demonstrated the close relationship between plant growth and the osmotic pressure of the culture solution. On a weight or equivalent basis, chloride salts are generally more inhibitory to the growth of plants than sulfate salts, but this difference tends to disappear when concentrations are expressed on an osmotic basis. These relationships indicate that it is the total concentration of solute particles in the solution rather than their chemical nature which is mainly responsible for the inhibitory effects of saline solutions on the growth of crop plants. Direct experimental evidence of the influence of osmotic concentration on water uptake by plant roots has been reported by Hayward and Spurr (1944). In addition to the osmotic pressure of the solution, the nature of the salts present may exert an important influence on plant growth. Such specific ion effects are discussed in a subsequent section.

There is much evidence to indicate that an increase in the osmotic pressure of the soil solution may result in a decrease in the water uptake by plant roots, but an additional factor must be taken into account in dealing with the soil system; that is, soil-moisture tension, or the molecular attraction of the surface of the soil particles for water. Soil-moisture tension increases as the soil becomes drier and the water films around the soil particles become thinner. This equivalent negative pressure is apparently additive to the osmotic pressure of the soil solution in limiting the availability of water to plant roots. The sum of soil-moisture tension and the osmotic pressure of the soil solution is termed "total soil-moisture stress." Studies on the effects on growth of several moisture treatments and

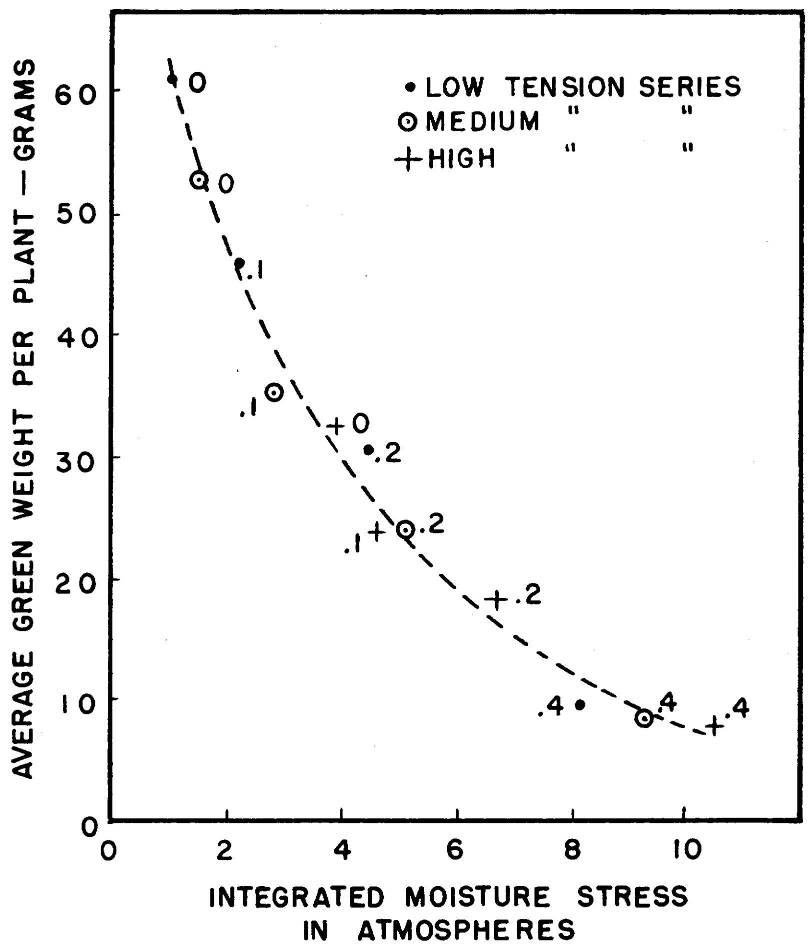

FIGURE 17.—Growth of bean plants as influenced by total soil-moisture stress. The salinity level for each treatment is indicated as percentage on a dry-soil basis (Wadleigh and Ayers, 1945).

salinity levels indicate that plant growth is a function of total soil-moisture stress, regardless of whether this stress arises primarily from salinity or moisture tension (fig. 17).

It is possible to extract the soil solution and determine its osmotic pressure, but this procedure is seldom used because it is simpler to estimate salt concentration by determining the electrical conductivity of the saturation extract (EC_e). Since saturation percentage is related to the field-moisture range, EC_e bears a close relationship to the EC of the soil solution. The relationship between EC and the osmotic pressure of saturation extracts is given in figure 6. The EC_e, therefore, provides information on the concentration of salt in the soil solution and its osmotic properties. The yield of orchardgrass when grown on soil to which various single salts had been added indicated that growth was simply related to salinity, expressed in terms of EC_e for various neutral salts (fig. 18). The response to sodium bicarbonate was, however, exceptional. In this case, calcium and magnesium ions from the soil exchange complex were precipitated as carbonates, thereby greatly increasing the exchangeable-sodium-percentage and producing an alkali soil.

The Scofield scale, in which crop response to salinity under average conditions is expressed in terms of the conductivity of the saturation extract, was discussed in chapter 2. This salinity scale has been widely used for a number of years and has been found to be satisfactory for salinity appraisal. To facilitate the discussion of plant response on saline soils, this salinity scale in its latest modified form is given again.

Salinity effects mostly negligible	Yields of very sensitive crops may be restricted	Yields of many crops restricted	Only tolerant crops yield satisfactorily	Only a few very tolerant crops yield satisfactorily

0 2 4 8 16

Scale of conductivity (millimhos per centimeter at 25° C.)

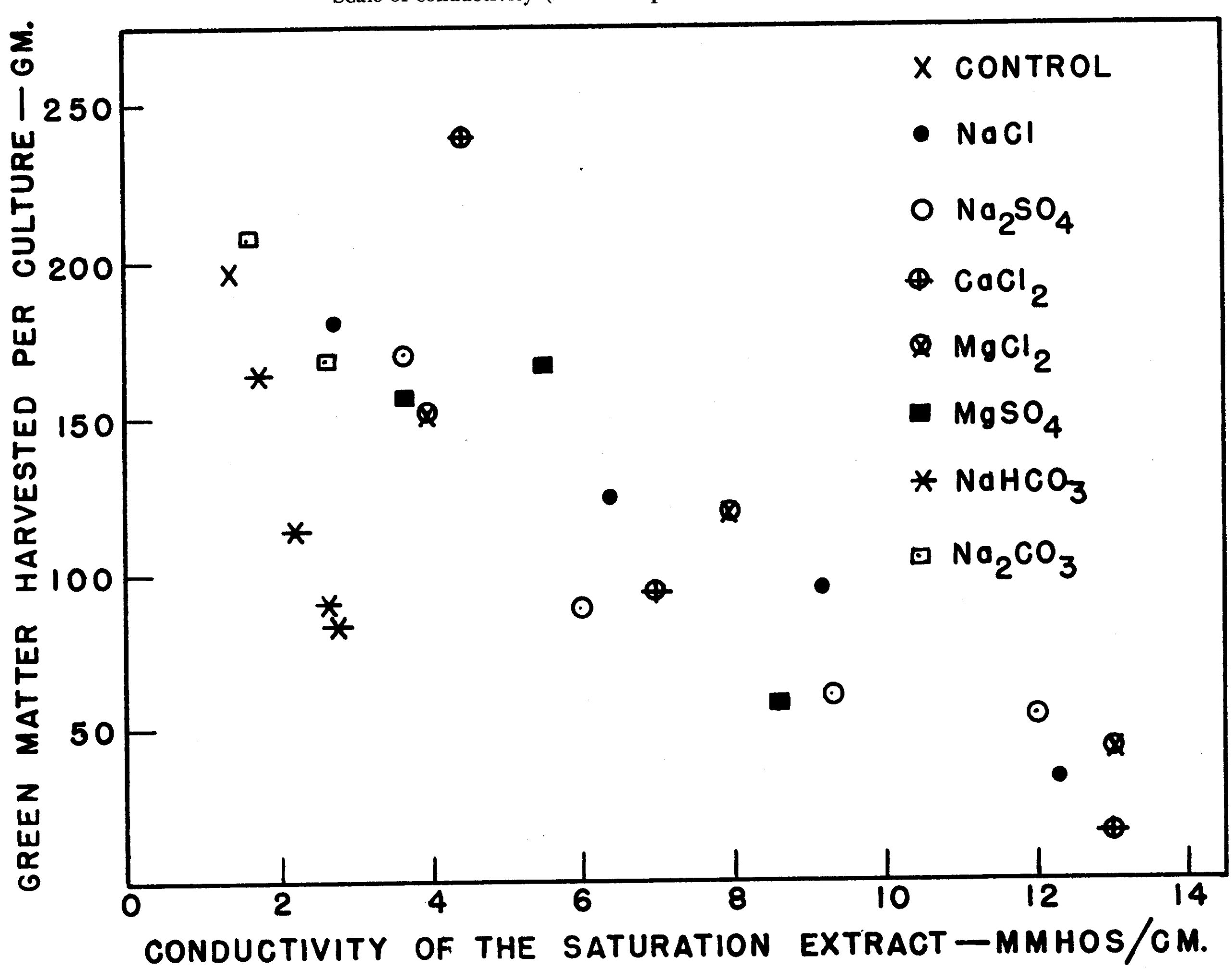

FIGURE 18.—Growth of orchardgrass, as influenced by various salts added to a sandy loam soil (Wadleigh and others, 1951).

It should be emphasized that this classification of plant growth in relation to various salinity levels refers to the salt status of the soil in the active root zone. It is possible to obtain samples from the surface soil around the base of row crops that may contain 5 percent salt or more with EC_e values of 50 mmhos/cm. or higher. This high concentration of salt represents an accumulation in the bed during the growth of the plants and not the salt concentration in the active root zone. Therefore, in correlating crop growth with salinity, care should be exercised to take soil samples from the active root zone that are uncontaminated by surface incrustations of salt. With row crops, the mass of soil making up the bed is frequently more saline than the soil below the furrow, and studies of root distribution and water uptake by plants indicate that under such conditions the major root activity occurs in the less saline parts of the soil, as shown in figure 14. These considerations should be borne in mind in determining the salt status of a soil with reference to plant response.

A technique for measuring the freezing point of soil moisture has been developed that provides a rapid, useful method for obtaining, by a single determination, the total moisture stress in a soil sample at field-moisture conditions (Method 6b). This eliminates errors caused by dilution of the soil solution and the resultant dissolving of moderately soluble salts, such as gypsum. Total soil-moisture-stress values obtained by freezing-point measurements are in good agreement with previously used methods involving determination of EC_e and moisture tension for the soil studied (Wadleigh, 1946, and Ayers and Campbell, 1951).

The experimental evidence cited above supports the concept that decreased growth on saline substrates is related to decreased water availability, but certain relationships between plant and substrate are still not fully understood. Despite marked decreases in growth with increasing concentration of the substrate, osmotic gradients between tops of plants and substrate are sometimes unaffected by increased osmotic pressure or total soil-moisture stress of the substrate. This is caused by increases in osmotic pressure of aerial parts of the plant that parallel increases in osmotic pressure of the substrate (Eaton, 1942). In addition, the osmotic pressure of expressed tissue fluids from the tops of plants does not appear to be correlated with the salt tolerance of some species. It is possible, however, that such measurements of osmotic gradient between plant tops and substrate may not represent the effective osmotic force which limits water absorption by the roots.

Specific Ion Effects

The previous discussion has dealt primarily with the effect of soluble salts in limiting the availability of moisture to plants. Other effects of salt may be equally important in restricting the growth of certain species. Injury or growth depression of plants, which cannot be accounted for on the basis of the osmotic pressure of the solution, will be referred to as a toxic effect of the salt in question. It should be recognized that toxicity so defined need not involve a direct effect of the salt or ions, either on surface membranes of plant roots or in the plant tissues. Frequently, toxicity may be caused, in part, at least, through effects on the uptake or metabolism of essential nutrients. As it is not always possible to distinguish clearly the mechanism underlying specific ion effects, it is convenient to refer to such phenomena as toxicities in contrast to the general osmotic effect of salt on plant growth.

The influence of excessive concentrations of specific salts on plant growth is an extremely complex subject involving many fundamental principles of plant nutrition. It is beyond the scope of this handbook to review the voluminous and diversified literature bearing on this subject. Much of the pertinent literature is cited in a review by Hayward and Wadleigh (1949). Literature citations in the following discussion are restricted mainly to papers of special significance in connection with certain topics not considered in the review cited above.

Ions that are frequently found in excess in saline soils include chloride, sulfate, bicarbonate, sodium, calcium, and magnesium. Less frequently encountered in excessive amounts are potassium and nitrate. The effects of all these ions on plant growth are being investigated by comparing plant response to isosmotic solutions of different salts. Species and even varietal differences among plants make it difficult to generalize regarding the toxicity of various salts or ions. It appears, however, that differences in plant tolerance to excessive concentrations of ions in the substrate are related, in some degree, to specific selectivity in ion absorption and nutrient requirements of the plants. In addition to these factors, there is also a marked difference among species in the amounts of such ions as sodium and chloride that can be accumulated without toxic effects.

Before considering specific toxic effects caused by excessive concentrations of soluble salts, other effects of certain ions deserve some mention. Although not considered essential plant nutrients, sodium and chloride, when present in relatively small concentrations, may stimulate the productivity of certain crops. Thus, Harmer and Benne (1941) have attributed increased yields of beets, celery, Swiss chard, and turnips to sodium. These authors consider sodium to be "nearly as much needed as a nutrient for these crops as is the potassium ion." Other investigators believe the effect of sodium to be more indirect, either substituting to some degree where potassium is deficient (Lehr, 1949; Dorph-Petersen and Steenbjerg, 1950) or limiting excessive accumulation of calcium, which with beets results in the development of a "calcium-type plant" characterized by a blue-green color and stunted growth (Lehr, 1942). Chloride, like sodium, has been observed to increase yields of some crops, notably beets, spinach, and tomato (Hayward and Wadleigh, 1949). On the other hand, chloride salts have long been known to affect adversely the quality of such crops as potatoes and tobacco. However, on saline soils, chloride and sodium ions occur in much higher concentrations than customarily employed in fertilizer studies. Under such conditions the high osmotic pressure of the soil solution tends to obscure specific effects of sodium or chloride on crop yields and quality (Bernstein and others, 1951).

Sodium

Plant species vary greatly in the amounts of sodium that they may accumulate, and many species tend to exclude sodium from their leaves, although they may accumulate it in their stems or roots. Notwithstanding this extreme selectivity in accumulation of sodium by plants, few well-defined instances of sodium toxicity have been reported. Lilleland and coworkers (1945) described a tipburn of almond leaves that is related to sodium content, and Ayers and associates (1951) have described a sodium-scorch of avocado leaves. In both studies, the soils on which affected trees grew were sufficiently low in soluble salts and exchangeable sodium to be regarded as nonsaline and nonalkali. Although sodium salts in water cultures rarely cause toxic plant reactions, stone-fruit trees (Brown and others, 1953) and avocados (Ayers, 1950) evidenced the same types of leaf injury in sand or water cultures containing added sodium salts as were observed in the field, thus confirming the relationship of sodium to leaf injury in these species. Unpublished data by Wadleigh and Gauch indicate that leaf burn in salt-sensitive cotton varieties is closely correlated with the sodium content of leaves.

Sodium in the soil may exert important secondary effects on plant growth through adverse structural modifications of the soil. Thus, if the exchange complex contains appreciable amounts of sodium, the soil may become dispersed and puddled, thereby causing poor aeration and low water availability (McGeorge and Breazeale, 1938). This is especially true in fine-textured soils. Also, if the exchange complex becomes more than 40 to 50 percent saturated with sodium, nutritional disturbances may result (Ratner, 1935; Thorne, 1945). Ratner (1944) stated that under such conditions the exchange complex actually removes calcium from the root tissues of the plant and that death may ensue because of calcium deficiency. Laboratory experiments have shown that the addition of calcium, and sometimes magnesium, to alkali soils can improve plant growth very markedly with an associated increase in the uptake of these added elements by the plants (Bower and Turk, 1946).

Bower and Wadleigh (1949), using amberlite resins, determined the effects of various levels of exchangeable sodium on cationic accumulation and growth of four species of plants. The effect of increasing levels of exchangeable sodium on cationic accumulation varied among the species and between tops and roots of a given species and was related to inherent specificity of the species in accumulating the several cations. In general, increasing the exchangeable-sodium-percentage of the substrate resulted in a decreased accumulation of calcium, magnesium, and potassium in the plants.

Calcium

The effect of high concentrations of calcium ions in saline soil solutions varies with the species. Some species, such as guayule, are more tolerant of added calcium salts than of other neutral salts (Wadleigh and Gauch, 1944). Masaewa (1936), however, found added calcium chloride to be more toxic to soil cultures of flax than added sodium chloride. Wadleigh and coworkers (1951) have reported specific toxicity of calcium salts added to soil cultures of orchardgrass, and unpublished data by Ayers indicate a similar relation for tall fescue. Both the calcium and chloride contents of the grasses from the calcium chloride treatments increased markedly; but since calcium nitrate produced a toxic effect similar to that of calcium chloride, the toxicity was attributed to calcium accumulation rather than to chloride (Wadleigh and coworkers, 1951). Moderate concentrations of calcium chloride are highly toxic to stone fruits in sand culture, and it appears that this toxicity is associated with an accumulation of chloride in the leaves. This chloride accumulation is more pronounced in the presence of excess calcium ions than when sodium occurs in excess (Brown and others, 1953).

Magnesium

High concentrations of magnesium in the substrate are frequently more toxic to plants than isosmotic concentrations of other neutral salts. This toxicity of magnesium may be alleviated by the presence of relatively high concentrations of calcium ions in the substrate.

Potassium

Although the occurrence of high concentrations of potassium in the soil solution is rare, toxic effects of high potassium have been reported. There is evidence to indicate that toxicity of high potassium, like that of high magnesium, may be lessened when balanced by high calcium concentrations. High concentrations of potassium may also induce magnesium deficiency (Boynton and Burrell, 1944) and iron chlorosis (Walsh and Clarke, 1942).

Chloride

As indicated under the discussion of calcium toxicity, the accumulation of chloride ion in plant tissues manifesting toxic symptoms is not an infallible indication of the specific toxicity of chloride. Many plant species are no more sensitive to chloride salts than they are to isosmotic concentrations of sulfate salts. There is good evidence, however, for the specific toxicity of chloride to some tree and vine crops. Hayward and associates (1946) and Brown and coworkers (1953) have found chloride salts to be toxic to peaches and other stone fruits, and Harper (1946) has reported chloride burn of pecan and native tree species of Oklahoma. Chloride burn has also been reported for citrus (Reed and Haas, 1924; Cooper and Gorton, 1951), avocados (Ayers, 1950; Ayers and others, 1951; Cooper, 1951), and grapevines (Thomas, 1934; Ravikovitch and Bidner, 1937).

Reference has been made in the discussion on toxic effects of high concentrations of potassium and magnesium to the ameliorative effects of increased concentrations of calcium. In such cases, high concentrations of potassium or magnesium result in increased absorption of these ions and decreased absorption of calcium; hence, the beneficial effect of increasing the calcium concentration in the substrate. It is pertinent, at this point, to consider whether such effects occur in the anion nutrition of plants; specifically, whether high levels of chloride (or sulfate) may interfere with nitrogen, phosphorus, or sulfur nutrition. Available evidence indicates that such interference in absorption of essential anions from saline substrates is of relatively minor importance and that decreased growth on saline media is not related in any appreciable degree to decreased availability of essential anions. However, Breazeale and McGeorge (1932) have emphasized the importance of decreased availability of phosphorus and nitrogen in calcareous alkali soils.

Sulfate

Specific sensitivity of plants to high sulfate concentrations has been noted for a number of crops, and it appears that such sensitivity is related to the tendency of high sulfate concentrations to limit the uptake of calcium by plants. Associated with this decrease in calcium are increases in the absorption of sodium and potassium, so that harmful effects of high sulfate in the substrate may be related to a disturbance of optimum cationic balance within the plant.

Bicarbonate

Plant species differ markedly in their tolerance to the bicarbonate ion, which sometimes exerts specific toxic effects, resulting in serious injury even at low osmotic concentrations. Beans and Dallis grass are very sensitive, while Rhodes grass and beets are relatively tolerant (Wadleigh and Brown, 1952; Gauch and Wadleigh, 1951). Studies in sand culture indicate that the bicarbonate ion affects the uptake and metabolism of nutrients by plants and that the nature of these effects varies with the plant species. For example, bean plants in the presence of the bicarbonate ion contain less calcium and more potassium than control plants, while the main effects in beets are a decrease in magnesium and an increase in sodium content. The pattern of effects is obviously related to the inherent selectivity of species in relation to mineral nutrition.

The studies by Wadleigh and coworkers cited above are of interest in connection with the problem of lime-induced chlorosis. Chlorotic symptoms and associated divergences in metabolism, involving contents of active iron, organic acid fractions, and essential cations, are very similar for typical cases of lime-induced chlorosis (Iljin, 1951, 1952; McGeorge, 1949) and bicarbonate-induced chlorosis. Since the basic causes of these chloroses are not understood, it would be speculative to suggest any closer relationship of the two disorders than the common features indicate. Thorne and others (1951) have shown that chloroses owing to such diverse causes as development in darkness, zinc deficiency, virus infection, and lime-induced chlorosis may be accompanied by very similar changes in potassium accumulation, water-soluble nitrogen fraction, and other features frequently considered characteristic of lime-induced chlorosis.

Boron

In addition to the elements that frequently occur in relatively high concentrations, boron may cause injury to plants even when present in very low concentrations in the soil solution. Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirements and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirements may be toxic for plants sensitive to boron.

Symptoms of boron injury may include characteristic burning, chlorosis, and necrosis, although some boron-sensitive species do not develop perceptible symptoms. Citrus, avocados, persimmons, and many other species develop a tipburn or marginal burn of mature leaves, accompanied by chlorosis of interveinal tissue. Boron injury to walnut leaves is characterized by marginal burn and brown necrotic areas between the veins. Stone-fruit trees, apples, and pears are sensitive to boron, but they do not accumulate it in high concentration in their leaves nor do they develop typical leaf symptoms. Cotton, grapes, potatoes, beans, peas, and several other plants show marginal burning and a cupping of the leaf that results from a restriction of the growth of the margin.

Boron toxicity occurs in limited, scattered areas in arid or semiarid regions. While its incidence is not restricted to saline or alkali soils, excess boron is frequently present in saline soils.

Plant Analysis

The normal mineral composition of plant parts is frequently altered under saline- or alkali-soil conditions, and analysis of appropriate plant organs may serve for diagnosing mineral excesses as well as for mineral deficiencies of soils. In addition, plant analysis may indicate salt injury in cases where the soil is regarded as nonsaline. This condition may occur with plants that are very sensitive to salt, such as beans and stone fruits, or in cases where the soil salinity is transitory.

Under some conditions, as in the presence of the bicarbonate ion, the entire complex of factors in the mineral composition of plants may be altered, and caution should be exercised in relating malfunction of these plants to a specific ion. Frequently, excessive accumulation of an ion in the plant may be the result of conditions other than high concentration of that ion in the soil solution. Any factors that inhibit plant growth, such as mineral deficiencies and high moisture stress, may result in abnormal accumulation of ions in plant tissues. For example, plants deficient in potassium will often show greater accumulation of calcium, magnesium, or sodium than normal plants (Cooil, 1948). Owing to the high degree of variability in the composition of "normal" plants under diverse growing conditions, the chemical composition of plant parts should usually be considered as only one line of evidence in the diagnosis of crop injury on saline or alkali soils. Appropriate soil tests, as described elsewhere in this handbook, may be used to furnish corroborative evidence.

Eaton (1942) has pointed out that no particular range of salt concentration in the substrate is critical in retarding plant growth. Growth depression is usually progressive as salt concentration increases. This type of relationship is to be expected in cases characterized by a predominance of the osmotic factor in limiting growth on saline substrates. Correspondingly, there is usually a progressive increase in salt concentration in the plant tissues as salinity in the substrate increases, although frequently the curve relating concentration of a specific ion in the leaves to that in the substrate may be exponential rather than linear. Considering the progressive nature of growth depression and ionic accumulation, it becomes apparent that for such cases no critical level of salt concentration in the tissues can be established with reference to the onset of "salt injury." In some instances, however, specific toxic effects of an ion may be of predominant importance in limiting plant growth. In extreme cases, death may ensue, whereas isosmotic concentrations of salts not specifically toxic to the species may cause only minor growth depression. Under such conditions, fairly definite limits of accumulation of ions, such as sodium or chloride, have been observed to be associated with the development of toxic symptoms in certain plant species.

Foliar analysis is commonly used in studying salt accumulation. The relationships between foliar composition and the principal ions that occur in excess in saline soils can be summarized as follows: (1) Chloride concentration in leaves usually bears a close relationship to the chloride concentration of the substrate; (2) excessive sulfate in the substrate causes small relative increases in total sulfur of the leaf tissue; (3) increases in calcium concentration in leaves are frequently associated with excess calcium in the substrate; (4) excess soluble sodium may or may not be reflected in the sodium content of leaf tissues. The influence of high exchangeable-sodium-percentage in depressing the calcium concentration of plant tissues has been mentioned in an earlier section.

Recent studies have furnished information on levels of chloride and sodium accumulation in leaf tissues associated with leaf injury. Rootstock studies by Cooper and Gorton (1951) and Cooper and associates (1951 and 1952) indicate that grapefruit and Valencia orange may develop leaf burn when chloride accumulation reaches about 1.0 to 1.5 percent on a dry-weight basis, whereas bronzing may occur with even lower chloride accumulation. Avocados appear to be more sensitive than citrus, since leaf tipburn symptoms were reported at chloride concentrations of 0.5 to 0.9 percent (Ayers, 1950; Haas, 1950; Ayers and coworkers, 1951; Cooper, 1951). Cooper and Gorton (1951) have observed tipburn symptoms when chloride was only 0.2 percent. Burning of peach leaves has been noted when chloride content reached 1.0 percent (Hayward and others, 1946); and, in a study of six varieties of stone fruits, leaf burn was not observed until chloride levels reached values of 0.6 to 1.8 percent of the dry weight of the leaves, depending on the variety (Brown and others, 1953). Plum and prune showed leaf-burn symptoms with about 0.6 percent chloride in the leaves, while burning occurred in peach and apricot at 1.0 percent chloride. The leaves of the two almond varieties, Nonpareil and Texas, developed burn at 1.2 and 1.8 percent, respectively. In a study of salt injury to pecans and native trees of Oklahoma, Harper (1946) found approximately 0.6 percent chloride to be associated with the development of leaf-burn symptoms. Thomas (1934) observed leaf burn of grapes having a chloride content of 0.5 percent, and Ravikovitch and Bidner (1937) found 1.2 percent. The latter reported that the variety Chasselas accumulated as much as 3.0 percent chloride in severely burned leaves, while the variety Muscat Hamburg accumulated a maximum of 1.5 percent. Such varietal differences in levels of chloride accumulation doubtless will be found for other crops.

Other factors that may affect the level of accumulated chloride include age of leaf, season, and climatic conditions. Brown and coworkers (1953) and Thomas (1934) reported increasing levels of chloride in leaves of stone fruits and grapes, respectively, as the season progressed. Hot, windy weather may result in very rapid chloride accumulation in leaves in a very short time (Thomas, 1934); and, under such conditions, higher chloride levels may appear to be critical in the development of leaf injury. Although chloride contents of 0.5 to 1.0 percent may be associated with foliar injury of some crops, it should be pointed out that many species of plants, including some possessing no outstanding salt tolerance, such as potatoes, may accumulate as much as 5.0 percent chloride on a dry-weight basis without showing foliar symptoms (Bernstein and associates, 1951).

While the causal relationship between chloride accumulation and leaf symptoms has been demonstrated by means of carefully controlled experiments for some of the crops mentioned in the above discussion, such as avocado and stone fruits, the data for other crops are based only on a close concomitance between chloride accumulation and observed leaf injury.

Few instances of injury related to excessive sodium accumulation have been noted. With some crops sodium injury may be obscured by simultaneous chloride injury, as Ayers and others (1951) have pointed out for avocado. In a water-culture study, Ayers (1950) observed leaf burn of avocado when leaves contained 0.5 percent sodium on a dry-weight basis. Lilleland and associates (1945) have indicated that sodium accumulation of 0.3 percent in almond leaves is associated with incipient leaf-burn symptoms. In sand cultures, Brown and coworkers (1953) have observed tipburn of Texas almond leaves containing 0.4 percent sodium and of plum leaves containing 0.3 percent. Unpublished data by Wadleigh and Gauch have indicated that leaf burn of salt-sensitive cotton varieties may occur in leaves containing 0.2 percent sodium.

Chapman (1949) has indicated that chloride or sodium accumulations of 0.25 percent or higher in citrus leaves should be regarded as excessive. While these values are lower than those at which definite foliar injury may appear, they do emphasize the fact that under some conditions even lower values than those cited in the above discussion may indicate a definite tendency toward excessive accumulations of harmful ions in the plant.

Foliar analysis is useful in the diagnosis of boron injury of many plant species. The boron content of normal, mature leaves of such plants as citrus, avocados, walnuts, figs, grapes, cotton, and of alfalfa tops is about 50 p. p. m. Boron contents of 20 p. p. m. or less indicate deficiency, while values above 250 p. p. m. are usually associated with boron toxicity. Stone-fruit trees, apples, and pears do not accumulate high concentrations of boron in their leaves, although these species are sensitive to excess boron. If due allowance is made for varietal specificity in boron accumulation, foliar analysis may provide a readier basis for diagnosis than analysis of soil or water.

Crop Selection for Saline Soils

Because of saline irrigation water, high water table, or low permeability of the soil, it may not be economically feasible to maintain low salinity. In such instances, the judicious selection of crops that can produce satisfactory yields under saline conditions and the use of special management practices to minimize salinity may make the difference between success or failure.

As has already been pointed out, the availability of water to plants is always a factor under saline conditions. For example, suppose alfalfa is being grown on a loam having a salt content of 0.2 percent sodium chloride and a wilting percentage of 6 when the latter is determined on a nonsaline sample. Under such conditions, because the osmotic effect is additive with soil-moisture tension, alfalfa will stop growing when the soil dries to a moisture content of only 13 percent. In other words, if the soil contains 0.2 percent salt, the alfalfa plant cannot use a large part of the soil moisture that is normally available under nonsaline conditions. The presence of even smaller quantities of salt in this soil would cause a fraction of the soil moisture above the wilting percentage to be unavailable to the plant. More frequent irrigation would be required to decrease the inhibitory effect of the salt on the growth of alfalfa.

Although it has been shown that crop growth on saline soils is definitely benefited by more frequent irrigation, the need for this irrigation may not be indicated by the appearance of the crop (Richards and Wadleigh, 1952). In nonsaline soils, there is usually a relatively abrupt transition from low moisture stress to high moisture stress conditions, and the wilting of the plant indicates the need for irrigation. In saline soils, changes in moisture stress are more gradual and, although the plants may be subjected to high stress, there is no abrupt transition in the turgor condition of the plant and, hence, no sign of the need for irrigation. Nevertheless, experiments have shown that crop growth is greatly improved by more frequent irrigation under such conditions. Careful leveling of the fields to insure more uniform moisture distribution during irrigation will also improve chances for successful crops on saline soils.

Germination

In selecting crops for saline soils, particular attention should be given to the salt tolerance of the crop during germination because poor crops frequently result from a failure to obtain a satisfactory stand. This problem is complicated by the fact that some crop species which are very salt tolerant during later stages of growth may be quite sensitive to salinity during germination (fig. 19). Sugar beets, for example, which are very salt tolerant during later stages of growth, are extremely sensitive during germination. On the other hand, barley has very good salt tolerance during all stages of growth, although it is more sensitive during germination than at later stages (Ayers and others, 1952). Under field conditions, it is possible by modification of planting practices to minimize the tendency for salt to accumulate around the seed and to improve the stand of crops that are sensitive to salt during germination (Heald and coworkers, 1950).

Relative Salt Tolerance of Crop Plants

The salt tolerance of many species and varieties of crop plants has been investigated at the Laboratory. Previously published lists (Magistad and Christiansen, 1944, and Hayward and Magistad, 1946) have been modified on the basis of recent findings and are presented in table 8.

The salt tolerance of a crop may be appraised according to three criteria: (1) The ability of the crop to survive on saline soils, (2) the yield of the crop on saline soils, and (3) the relative yield of the crop on a saline soil as compared with its yield on a nonsaline soil under similar growing conditions. Many previous observations on salt tolerance have been based mainly on the first criterion, ability to survive; but this method of appraisal has very limited practical significance in irrigation agriculture. Although it is recognized that the second criterion is perhaps of greater agronomic importance, the third criterion was used in compiling the present salt-tolerance lists because it provides a better basis of comparison among diverse crops.

The salt-tolerance lists are arranged according to major crop divisions; and, in each division, crops are

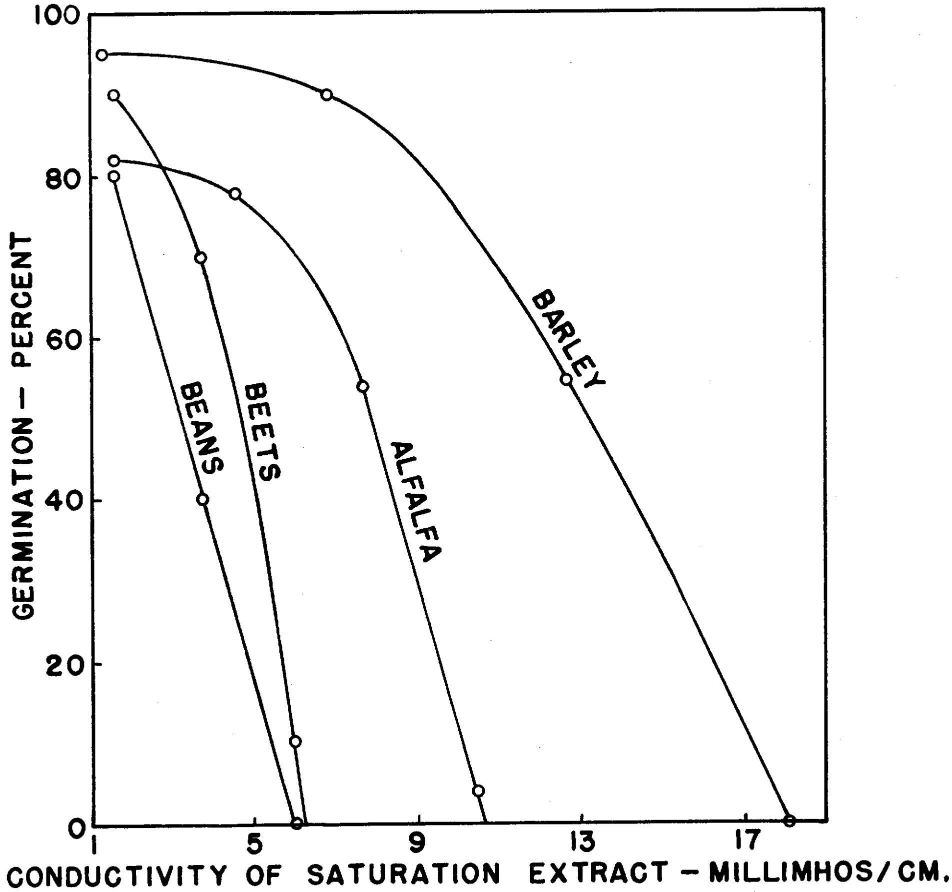

FIGURE 19.—Percent germination of four crops, as related to the conductivity of the saturation extract of the soil, under laboratory conditions (Ayers and Hayward, 1949).

listed in three groups. Within each group, the crops are listed in the order of decreasing salt tolerance, but a difference of 2 or 3 places in a column may not be significant. EC_e values given at the top of a column represent the salinity level at which a 50-percent decrease in yield may be expected as compared to yields on nonsaline soil under comparable growing conditions. For example, for crops with high salt tolerance in the division of field crops, EC_e values of 16 mmhos/cm. occur at the top of the column and 10 mmhos/cm. at the bottom. This indicates that crops near the top of this column will produce about 50 percent as well on a soil having an EC_e of 16 mmhos/cm. as on a nonsaline soil under similar conditions, and crops near the bottom of this column will produce about 50 percent as well on soils having an EC_e of 10 mmhos/cm. as on a nonsaline soil. EC_e values having similar significance have been shown for each group of plants for which such data are available.

In most instances, these data are based on a field-plot technique in which crops are grown on soils that are artificially adjusted to various salinity levels after the seedlings are established. By this method, crop yields were related to EC_e values for comparable saline and nonsaline soils, and the salinity level associated with a 50-percent decrement of yield was determined graphically. In many of these studies, a number of varieties of a given crop were compared. Significant varietal differences were found for cotton, barley, and smooth brome, while for truck crops such as green beans, lettuce, onions, and carrots varietal differences were not of practical significance.

In applying the information in the following table, it is important to remember that climatic conditions may influence profoundly the reaction of plants to salinity. The choice of suitable salt-tolerant varieties and strains will depend on local climatic factors; and, consequently, information on salt-tolerant varieties should be evaluated with reference to the conditions under which the crops are to be grown. The position of each crop in this table reflects its relative salt tolerance under management practices that are customarily employed when this crop is grown under irrigation agriculture and not the inherent physiological ability of the crop to withstand salinity under some given set of conditions that is uniform for all crops.

A salt-tolerance list for some important crops of Holland has recently been prepared by Van den Berg

TABLE 8.—*Relative tolerance of crop plants to salt* [1]

FRUIT CROPS

High salt tolerance	Medium salt tolerance	Low salt tolerance
Date palm	Pomegranate	Pear
	Fig	Apple
	Olive	Orange
	Grape	Grapefruit
	Cantaloup	Prune
		Plum
		Almond
		Apricot
		Peach
		Strawberry
		Lemon
		Avocado

VEGETABLE CROPS

$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Garden beets	Tomato	Radish
Kale	Broccoli	Celery
Asparagus	Cabbage	Green beans
Spinach	Bell pepper	
	Cauliflower	
	Lettuce	
	Sweet corn	
	Potatoes (White Rose)	
	Carrot	
	Onion	
	Peas	
	Squash	
	Cucumber	
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 3$

FORAGE CROPS

$EC_e \times 10^3 = 18$	$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$
Alkali sacaton	White sweetclover	White Dutch clover
Saltgrass	Yellow sweetclover	Meadow foxtail
Nuttall alkaligrass	Perennial ryegrass	Alsike clover
Bermuda grass	Mountain brome	Red clover
Rhodes grass	Strawberry clover	Ladino clover
Rescue grass	Dallis grass	Burnet
Canada wildrye	Sudan grass	
Western wheat-grass	Hubam clover	
Barley (hay)	Alfalfa (California common)	
Bridsfoot trefoil	Tall fescue	
	Rye (hay)	
	Wheat (hay)	
	Oats (hay)	
	Orchardgrass	
	Blue grama	
	Meadow fescue	
	Reed canary	
	Big trefoil	
	Smooth brome	
	Tall meadow oat-grass	
	Cicer milkvetch	
	Sourclover	
	Sickle milkvetch	
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 2$

FIELD CROPS

$EC_e \times 10^3 = 16$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton	Rice	
	Sorghum (grain)	
	Corn (field)	
	Flax	
	Sunflower	
	Castorbeans	
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 6$	

[1] The numbers following $EC_e \times 10^3$ are the electrical conductivity values of the saturation extract in millimhos per centimeter at 25° C. associated with 50-percent decrease in yield.

(1950). Based on field-plot studies in areas which had been inundated by salt or brackish water in 1944–45, the salinity values ("salt index," expressed as grams NaCl per liter of soil water) associated with 75 percent of normal yields for 14 crops were determined. Despite obvious differences in climate and cultural practices, Van den Berg's results for relative salt tolerance are in good agreement with those in table 8.

Relative Boron Tolerance of Crop Plants

Plant species differ markedly in their tolerance to excessive concentrations of boron. In sections where boron tends to occur in excess in the soil or irrigation water, the boron-tolerant crops may grow satisfactorily, whereas sensitive crops may fail. The relative boron tolerance of a number of crops was determined by Eaton (1935), and his results are reported in table 9 with

TABLE 9.—*Relative tolerance of plants to boron*

[In each group, the plants first named are considered as being more tolerant and the last named more sensitive]

Tolerant	Semitolerant	Sensitive
Athel (*Tamarix aphylla*)	Sunflower (native)	Pecan
Asparagus	Potato	Black walnut
Palm (*Phoenix canariensis*)	Acala cotton	Persian (English) walnut
Date palm (*P. dactylifera*)	Pima cotton	Jerusalem artichoke
Sugar beet	Tomato	Navy bean
Mangel	Sweetpea	American elm
Garden beet	Radish	Plum
Alfalfa	Field pea	Pear
Gladiolus	Ragged Robin rose	Apple
Broadbean	Olive	Grape (Sultanina and Malaga)
Onion	Barley	Kadota fig
Turnip	Wheat	Persimmon
Cabbage	Corn	Cherry
Lettuce	Milo	Peach
Carrot	Oat	Apricot
	Zinnia	Thornless blackberry
	Pumpkin	Orange
	Bell pepper	Avocado
	Sweetpotato	Grapefruit
	Lima bean	Lemon

minor modifications based on field observations. The boron-tolerance lists are analogous to the salt-tolerance lists and subject to much the same limitations in interpretation. Differences in position of a few places may or may not be significant, and there is no sharp division between successive classes. Climate and variety may also be factors in altering the indicated tolerance of a given species under specific conditions.

Available information on boron tolerance does not permit the establishment of definite permissible limits of boron concentration in the soil solution. Irrigation waters are classified on the basis of boron content in table 14, chapter 5, with reference to sensitive, semitolerant, and tolerant crops. The effect of a given concentration of boron in the irrigation water on the boron content of the soil solution will be conditioned by soil characteristics and management practices that influence the degree of boron accumulation in the soil. In the discussion of saturation extracts of soils (ch. 2), 0.7 p. p. m. boron in the saturation extract was indicated as the approximate safe limit for sensitive crops.