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An Examination of Sustainable Reclamation and Management Practices for Salt-Affected (Saline, Sodic, And Saline-Sodic) Soils

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Abstract- Soil salinity is one of the most serious agriculture-associated challenges of arid regions. Salt-affected soils are soils that have been adversely modified for growth of most crop plants by the presence of certain types of exchangeable ions or of soluble salts. This work fundamentally examined sustainable practices of reclaiming and managing salt-affected soils. The study revealed that various salts common to arid-region soils often consist of readily water-soluble combinations of Na+, Ca2+, and Mg2+ with the anions Cl- and SO42-. Several compounds found frequently in salt-affected soils are NaCl, Na2SO4, Na2CO3, NaHCO3, MgCl2, MgSO4, MgCO3, CaCl2, CaSO4.2H2O, and CaCO3. The major classes of salt-affected soils based on chemical properties are saline, sodic, saline-sodic soils. Soil salinity is basically estimated by measuring the EC (SI unit = mhos per centimetre) of the soil solution. Excess neutral soluble salts' accumulation in soils principally harm plants by reducing soil water availability for plant use. The accumulation of excess exchangeable Na in soils is harmful to plants principally because it induces undesirable physical and chemical conditions. The reclamation of salt-affected soils consists of the removal/leaching of excess neutral soluble salts or excess exchangeable Na, or both, from such soils to the extent necessary to return the affected soils to a normal productive condition. It also involves estimating the amendment needs for the reclamation of such soils. Probably the most vital aspect of managing saline soils is to avoid excessive concentration of neutral soluble salts in the plants' root zone. For this purpose, frequent irrigations and careful irrigation management are recommended. An additional aid in the utilization of saline soils is to grow salt-tolerant plant species. Generally, several conditions must be met to accomplish satisfactory leaching of excess soluble salts from soils - irrigation water must be available, and if reclamation of salt-affected soils is to be rapid, there should be some means of impounding the water on the soil surface to provide extensive infiltration into the soil; adequate soil drainage; etc. There are very few management tactics available for assuring satisfactory plant growth on sodic soils, including the planting of excess exchangeable Na-tolerant crops, preferably perennials that need not be re-established each year. In due time, the level of exchangeable Na in the soil can be reduced and the soil's physical condition gradually improved if a sodic soil containing free lime is subjected to long periods of leaching without the application of a soil amendment, because soil reclamation is effected by the small quantity of Ca derived from the lime. Sometimes the incorporation of plant residues or organic manures into sodic soils is recommended as a means of improving the physical condition of sodic soils. The use of saline irrigation water can improve a sodic-soil condition, provided soluble Ca, Mg, and Na occur in proper balance and some leaching is possible to prevent the neutral soluble salts from accumulating in the soil. Besides the few treatments considered in this work, however, little short of complete reclamation can be expected to greatly change the productivity of seriously affected sodic soils. Essential considerations in the irrigation management of salt-affected soils include irrigation water quality; water quality and leaching requirements; and drainage of irrigated land/soils. Some of the benefits of soil drainage (SoD) relate to improvement in soil physical, chemical, and biological properties that contribute to plant growth

functions. Usually, however, the change that most favours plants is the increased availability of oxygen to plant roots. SoD also increases soils' infiltration capacity, which, in turn, is of particular importance in flood and soil erosion control. The study, therefore, recommended frequent irrigations, careful irrigation management, adequate soil drainage, growing of salt-tolerant plant species, and satisfactory leaching of excess soluble salts from soils as sustainable practices for reclaiming and managing saline soils. The planting of excess exchangeable Na-tolerant crops (preferably perennials that need not be re-established each year), long periods of leaching without the application of a soil amendment, application of plant residues or organic manures to sodic soils, use of saline irrigation water, and some leaching were recommended as sustainable measures of reclaiming and managing sodic soils.

Indexed Terms- Salt-Affected Soils, Reclamation, Management, Leaching, Soil Irrigation and Drainage.

I. INTRODUCTION

The build-up or accumulation of soluble salts in soils results in one of the most serious problems associated with agriculture of arid (dry) regions. Injurious effects of salts become apparent with poor seed germination and plant growth, responses that reflect one or both of two conditions: (1) a limited availability of water due to a high osmotic concentration of the soil solution, and (2) an unsuitable physical or nutritional condition of the soil caused by a high level of exchangeable sodium (Na). The first of these conditions can be induced by any salt so long as the salt is readily soluble. However, a high level of exchangeable Na results only where the accumulated soluble compounds are principally Na salts. Since soluble salts are more easily removed from soils, the problems they create are normally considered to be less serious than those caused by excess Na in exchangeable form (Hausenbuiller, 1974; Edem, 2008; Kolay, 2013; Havlin, Tisdale, Nelson & Beaton, 2014). In this work basically, efficient and global best practices of managing/reclaiming salt-affected soils have been examined.

II. THE ORIGIN OF SALTS IN SOILS

In the usual pattern, salts accumulate in a soil when they are carried into a soil by water, which is then selectively lost from the soil by evaporation and transpiration. The origin of the salts is variable, but a principal source is the ocean/sea. The ocean or sea contributes soluble materials to coastal soils by tidal action or through spray transported inland by winds. It equally provides salts indirectly where soils have formed or developed in parent materials of marine origin. Although leaching tends to remove (wash or flush out) these soluble salts from soils in humid regions, such salts are more likely to remain a part of the soil parent material, or of the soil forming it, where the climate is arid (Hausenbuiller, 1974).

The accumulation of salts ordinarily takes place in soils troubled with poor drainage, a condition that automatically enhances water loss by evaporation. These poorly drained soils may be located in depressional areas or other low-lying positions that collect drainage water through seepage or surface flow. They may also be alluvial soils, which are subject to seepage or flooding from a neighbouring waterway. In places, a salted soil condition has resulted from the application of salt-laden irrigation water without suitable leaching or; where the water has been applied in excess, by a rise in the level of the ground water, which then serves as a source of salts (Kelley, 1948; Hausenbuiller, 1974: 366).

Variability among the factors influencing or determining salt accumulation in soils normally results in a non-uniform distribution of salts over the landscape. Thus, it is common for salt-affected soils to be interspersed with other soils of relatively low salt content. Inequalities in salt distribution are most often associated with an uneven topography, which causes variation in the entry of surface water into the soil (infiltration), or with changes in soil texture over a continuous landscape, which affects or determines the pattern of water flow and salt redistribution within the soil (Hausenbuiller, 1974: 366).

III. SOME CHEMICAL ASPECTS OF SALT ACCUMULATION IN SOILS

Salts common to arid-region soils vary in both kind and amount. Such salts most often consist of combinations of the cations Na^+, calcium (Ca^{2+}), and magnesium (Mg^{2+}) with the anions chloride (Cl^-) and sulphate (SO_4^{2-}). One reason for this is that, with the exception of gypsum ($CaSO_4.2H_2O$), combinations of these ions are readily soluble in water (Table 1) and can, therefore, be moved in quantity to sites of accumulation. Table 1 shows the approximate solubility of several compounds found frequently in salt-affected soils (Kelley, 1948; Hausenbuiller, 1974: 366; Brady & Weil, 2015).

Table 1: The approximate solubility of several compounds found frequently in salt-affected soils

Compounds	Solubility in Water (Tons/Acre*)
Sodium chloride, NaCl	72
Sodium sulphate, Na_2SO_4	98
Sodium carbonate, Na_2CO_3	14
Sodium bicarbonate, $NaHCO_3$	14
Magnesium chloride, $MgCl_2$	106
Magnesium sulphate, $MgSO_4$	54
Magnesium carbonate, $MgCO_3$	0.02
Calcium chloride, $CaCl_2$	120
Gypsum, $CaSO_4.2H_2O$	0.6
Calcium carbonate, $CaCO_3$	0.002

*The total quantity of a single salt that could be dissolved in water held by two million pounds of soil at a 20-percent moisture content.

Source: Abstracted from R.L. Hausenbuiller (1974, p. 367).

Where the carbonate ion (CO_3^{2-}) is an important constituent of the accumulating salts, Ca and Mg will be in low concentration because of their propensity to precipitate as very slightly soluble carbonates. The bicarbonate ion (HCO_3^-) may also be present in soil salts, but seldom in large quantities due to the ease with which it converts to the CO_3^{2-} ion. The chemical reaction for this conversion is as follows:

$$2HCO_3^- \rightleftarrows CO_3^{2-} + CO_2\uparrow \quad \text{(Equation 1)}$$

Precipitation of the CO_3^{2-} ion, as by Ca and Mg, or the loss of water and dissolved CO_2 by soil drying causes the reaction in Equation 1 to shift to the right. On the other hand, the reaction is reversed if an increase in the CO_2 pressure of the soil air raises the CO_2 concentration of the soil solution.

Accumulating soluble salts in soils tend to increase the soils' content of exchangeable Na if the Na the soils contain can compete favourably with soluble Ca and Mg for exchange sites. Since Na has a low adsorption affinity, it is not particularly competitive unless its concentration exceeds the combined concentration of Ca and Mg; that is, unless the ratio of soluble Na to soluble Ca + Mg is greater than 1/1. This fact is illustrated by the numerical (quantitative) data in Table 2, where it is observed/seen that, at a constant total concentration of 15 milliequivalents (meq.) per litre (that is, a litre of the soil in question would contain a total of 15 meq. Of Na, Ca, and Mg), variation in the Na/Ca + Mg ratio from 1/1 to 14/1 causes the exchangeable sodium percentage (ESP, which defines the percent of exchange sites in the soil filled by Na) to increase from about 4 to 22. It is worthy to note, however, that even when soluble Na occurs in the soil in a concentration 14 times greater than that of Ca + Mg, it still occupies less than one-fourth of the exchange sites in the soil. Nevertheless, this amount of exchangeable Na can have a decidedly (definitely and in an obvious way) adverse effect on soil properties important to plant growth. An ESP of 4, as shown for the first example in Table 2, would not likely have any particular effect on plant growth (Kelley, 1948; Salinity Laboratory Staff, US, 1954).

Table 2: The effect of variation in the ratio of soluble na to ca + mg in the soil solution on the esp. values are averages that apply to a wide range of arid-region soils

Ion Concentration (meq./1)			
Total*	Na	Ca + Mg	ESP
15	7.5	7.5	4.2
15	10.0	5.0	7.4
15	12.0	3.0	11.7
15	14.0	1.0	22.0

[a]Sum of soluble Na + Ca + Mg

Source: Abstracted from R.L. Hausenbuiller (1974, p. 368).

Sodium may be the dominant ion in the soil solution because of the nature of the soluble salts added to the soil or because the Ca and Mg in these salts are eventually precipitated in compounds, such as gypsum or lime. Precipitation is encouraged by the selective removal of soil water through plant absorption and evaporation, which increases the concentration of Ca^{2+}, Mg^{2+}, and other soluble ions involved in the precipitation of lime or gypsum (Bower & Fireman, 1957; Hausenbuiller, 1974: 368).

IV. CHARACTERIZATION AND GROUPING OF SALT-AFFECTED SOILS BASED ON CHEMICAL PROPERTIES

The term *salt-affected soils* refers to soils that have been adversely modified for growth of most crop plants by the presence of certain types of exchangeable ions or of soluble salts. The term includes soils having an excess of salts, specifically soluble salts (*saline soils*), or an excess of exchangeable Na (*sodic soils*), or a combination of both conditions (*saline-sodic soils*). Salt-affected soils are characterized and classified on the basis of chemical properties. For the most part, the following two measurements are involved: (1) an approximation of the content of soluble salts in the soil, and (2) a measurement of the ESP in the soil. On the basis of these determinations, the soil (being tested of salt accumulation) is assigned to one of the following three classes: saline, sodic, and saline-sodic soils. The term *saline soil* denotes the accumulation of excess soluble salts in the soil; the term *sodic soil* indicates that the build-up of excess exchangeable Na is the problem in the soil, while term *saline-sodic soil* recognizes the presence of both saline and sodic conditions in the soil. Thus, a *saline-sodic soil* is a soil that contains sufficient exchangeable Na to interfere with the growth of most crop plants and contains appreciable quantities of soluble salts. The ESP of a *saline-sodic soil* > 15%, the conductivity of the saturation-paste extract of this soil is > 4 mmhos per cm (at 25°C), and the pH is usually 8.5 or less in the saturated soil. (*Note* that, until recently, the term *alkali soils* has been used to designate excess exchangeable Na in soils. Since this term had been misconstrued to signify an alkaline soil reaction, it is now replaced with the term *sodic soils*) (Hagan, Haise & Edminster, 1967; Hausenbuiller, 1974: 368).

V. APPROACHES TO THE ASSESSMENT/MEASUREMENT OF SOIL SALINITY

Soil salinity is estimated by the ability of a water extract of a soil to conduct an electric current. The advantage of this approach is that the electrical conductivity (EC) of the soil solution closely parallels the concentration of a solution irrespective of the kinds of ions present. The soil solution's EC also relates directly to the total effect of soluble ions in reducing the soil water potential. The measurement of the soil solution's conductivity is, therefore, an indirect measure of the osmotic potential (OP) of the soil solution (Hausenbuiller, 1974: 369; Havlin *et al*., 2014; Brady & Weil, 2015).

The two factors that determine the ability of a solution to transmit an electric current are: (1) the *conductance* of the solution, (2) the *distance* through which the measured current must flow when the test is made. The current flow is measured between two electrodes immersed in the solution. The distance referred to here is the distance between the electrodes. The *conductance* of a solution depends directly on the ion concentration. The standard or SI unit of measurement (or expression) of conductance is the *mho* (the reciprocal of an ohm, which is a former unit of electrical conductance; *mho* = siemens). When expressed per unit of distance through the transmitting liquid, the measurement is termed *electrical conductivity.* The standard or SI unit of measurement of EC is *mhos per centimetre (cm).*

In order to minimize the dilution effects when estimating the salt content of soils, soil conductivities are measured on extracts obtained from different soils adjusted to comparable water contents. The accepted standard is an amount of water that produces a thin paste (*saturation paste)* when mixed thoroughly with the soil. The extract for conductivity measurement is then obtained by filtration.

The conductivity of most saturation-paste extracts is only a fraction of a mho per centimeter. For convenience, therefore, conductivities of soil extracts are expressed in *millimhos* (mmhos) *per centimetre*, a millimho being one-thousandth of a mho (Hausenbuiller, 1974, p. 369).

V. CLASSIFICATION AND DEFINITION OF SALINE AND SODIC SOILS

A *saline soil* is a soil that yields a saturation-paste extract with a conductivity of 4 mmhos per cm or more. The term *saline*, when used alone, implies a low ESP (< 15%). Specifically, a *saline soil* is a soil which provides a saturation-paste extract having an EC > 4 mmhos per cm at 25°C. The nature of the salts has no effect on this definition, since the basis of the classification is the relationship between the conductivity of the extract and the ability of plants to remove water from the soil solution. The limit of conductivity defining a saline soil has been arbitrarily selected; it represents a level of salts that adversely affects the growth of a wide range of common agricultural plants (Hausenbuiller, 1974: 369).

Sodic soils are also arbitrarily defined. Sodic soils contain more than 15% exchangeable Na. Specifically, a *sodic soil* refers to a soil that contains sufficient exchangeable Na to interfere with the growth of most crop plants; the ESP of a sodic soil is 15% or more. This value (15%) is computed through the use of the following equation (Hausenbuiller, 1974, p. 369):

Percent (%) Exchangeable Na = (Na_x/CEC) X 100 ………………….. (Equation 2)

Where: Na_x and CEC are the quantity of exchangeable Na and the cation-exchange capacity (CEC), respectively, expressed in milliequivalents (meq.) per 100 g of soil. Multiplying the result (of the division of Na_x by CEC) by 100 converts the ratio of these two quantities to a percentage.

VI. PLANT GROWTH RELATIONSHIPS IN SALT-AFFECTED SOILS

The way in which plants respond to salted-soil conditions is variable. Plants' sensitivity to salt accumulation in soils may be due to the low availability of water in soils, or to toxic effects caused by specific ions, or to adverse physical or nutritional conditions often associated with sodic soils. Plants may respond differently at different stages of their development. Furthermore, some plants may tolerate soil salinity better than a high level of exchangeable Na (Hausenbuiller, 1974: 370; Brady & Weil, 2015). Due to the diverse effects of salt-affected soils on plant growth, only a few of the more general relationships (between salted-soil conditions and plant growth) have been considered in this work.

1. *General Relationship between Soil Salinity and Plant Growth (General Adverse Effects of Saline Soils or Soil Salinity on Plant Growth)*

The principal harm caused by excess neutral soluble salts to plants is a reduction in the availability of water in the soil for plant use. Ion-hydration forces add (combine with) to matric forces in resisting the uptake of soil water by plants. This effect is not necessarily serious where irrigation water is available and can be applied to the land at frequent intervals (Bower & Fireman, 1957; Hausenbuiller, 1974: 370).

Generally, salts of different ionic composition have almost the same effect/influence on soil water availability provided (if) they occur at comparable osmotic concentrations in the soil. At times, however, a growing plant may be intolerant of a single ion species in the accumulating salts and suffers a reduction in its growth due to a toxicity factor rather than a reduction in soil water uptake. Although each of the elements common to soil salts may be toxic to some plants, Cl and Na are among the most frequent offenders. A toxicity is occasionally caused by boron (B), which can reduce plant growth when it occurs in comparatively low concentration in the soil solution. B toxicities in soils are primarily of local importance,

because this element is not an important constituent of soil salts under most circumstances (Salinity Laboratory Staff, US, 1954; Hagan *et al*., 1967; Hausenbuiller, 1974: 370).
Most plants are more sensitive to soil salinity during germination than at any other time/stage of their development or life cycle. A farmer's success in establishing and maintaining a stand of crop plants, therefore, depends strongly on conditions/circumstances that prevail at planting time. The occurrence of barren patches in fields containing salt-affected soils is often the consequence of a localized salinity effect on plant germination. The following examples may suffice to illustrate variation in the sensitivity of germinating seeds to soil salinity. Beans and sugar beets are more sensitive to soil salts at their germination stage (time) than are alfalfa and barley seeds. It is of particular interest that the germination of alfalfa and barley seeds is not significantly affected where the conductivity of the saturation-paste extract is 4 mmhos/cm, which is the point of division between saline and non-saline soil conditions. This fact emphasizes the *arbitrary nature of the definition of saline soils* and indicates the need to always take into account the type of plant when considering the importance of a soil salinity factor on plant growth (Hausenbuiller, 1974: 370-371).

2. *Soil Exchangeable Na as a Plant Growth Factor: General Relationship between Soil Sodicity and Plant Growth (that is, General Adverse Effects of Excess Soil Exchangeable Na on Plant Growth)*

Excess exchangeable Na in soils is harmful to plants principally because it induces undesirable physical and chemical conditions in the soils in which it occurs. One injurious effect of soil sodicity on plants results from the dispersion of clay, which reduces the permeability of the affected soil to air and water. Clay or soil dispersion equally results in the formation of dense, impenetrable soil surface crusts that seriously hinder the emergence of plant seedlings (Kelley, 1948; Hausenbuiller, 1974: 372).

A second devastating effect of the occurrence of excess exchangeable Na soils on plant growth, is on soil pH. Due to the ease with which exchangeable Na hydrolyzes, *sodic* soils, which are low in neutral salts, often have a pH value as high as 10. While strong soil alkalinity causes little direct harm to plants, it frequently results in reducing the availability of some essential plant nutrients in soils. Examples of such nutrients include iron (Fe), manganese (Mn), Ca, and Mg. The limited availability of Fe and Mn relates to their low solubility under conditions of high soil pH. The availability of Ca and Mg (in sodic soils, specifically) may be low provided their positions on soil exchange surfaces have been extensively pre-empted (replaced; taken over) by Na (Hausenbuiller, 1974: 372; Brady & Weil, 2015).

The high pH of sodic soils causes soil organic matter (SOM) to dissolve. If the dissolved SOM is transported upward by the capillary rise of soil water, it may be deposited as a dark incrustation (a hard outer covering or layer) on the soil surface. When (this incrustation on the surface of the soil) present, a dark-coloured surface is usually indicative of a sodic-soil condition. Many *sodic* soils, however, lack this particular feature (dark incrustation), so it isn't a universal diagnostic property for *sodic* soils (Hausenbuiller, 1974: 372).

Unlike the dispersive effect of excess exchangeable Na in soils, salts flocculate colloidal matter (materials) in soils. *Saline-sodic soils,* therefore, tend to appear in a better physical condition/state than do nonsaline-sodic soils. In addition to that, if the salts present in a sodic soil are *neutral,* suppress the hydrolysis of exchangeable Na, thereby preventing the soil from having an excessively high pH. Under some circumstances, the pH of *saline-sodic soils* is not beyond 8.5. However, although *neutral salts* do improve the physical condition and reduce the pH of *sodic soils,* they do not improve overall conditions of sodic soils for plant growth. If these neutral salts are removed from sodic soils, as by leaching, the characteristics (of sodic soils) associated with dispersed clay and a high pH quickly reappear (Hausenbuiller, 1974: 372).

VII. RECLAMATION OF SALT-AFFECTED (SALINE, SODIC, AND SALINE-SODIC) SOILS

The reclamation of salt-affected soils consists of the removal of excess neutral soluble salts or exchangeable Na, or both, from such soils to the extent necessary to return the affected soils to a normal productive condition/state. The discussions that follow deal with some of the requirements fundamental to these reclamation objectives. Readers should bear in mind, however, that the reclamation procedures dealt with in this work have only limited direct application in the reclamation of *saline* and *sodic soils*. Each problem area must be examined individually and the most applicable or suitable reclamation programme developed to cope with the conditions peculiar to the geographical location in question. Reclamation of salt-affected soils is not always practical, but it is almost always expensive; thus, it should not be undertaken unless there is some advance assurance of success of the proposed project (Hausenbuiller, 1974: 372-374).

1. *The Removal of Excess Neutral Soluble Salts from Soils*

Soluble salts are rather easily removed from soils, if they can be leached (flushed) to a depth that will prevent them from returning to the plant root zone. In general, several conditions must be met to accomplish satisfactory leaching. First, irrigation water must be available, and if reclamation of salt-affected soils is to be rapid, there should be some means of impounding the water on the soil surface to provide extensive infiltration into the soil. Ideally, the land should be flat so that it can be diked and flooded. The period of flooding will then depend on the amount of leaching required. While the leaching requirement cannot be stated precisely, a reasonable generalization is a foot of water for each foot of soil depth to be reclaimed (Hausenbuiller, 1974; Havlin *et al*., 2014; Brady & Weil, 2015).

A second requirement for successful leaching is adequate drainage. Leaching will likely be impractical in fine soils of slow permeability, and it will not have a permanent effect should (if) a water table exists so near the soil surface that it can later regenerate a salted condition in the soil above. A satisfactory depth to a water table is 4-5 feet at a minimum, with 6 feet or more being preferred. If a water table occurs at a shallow depth, provisions for improved drainage should be made before leaching is undertaken (Hausenbuiller, 1974; Havlin *et al*., 2014; Brady & Weil, 2015).

Removal of salts (soluble salts, to be specifically) from *saline-sodic soils* presents a more serious challenge than where salinity alone is the problem. Although *sodic soils* may be flocculated and permeable so long as salts are present in them, once the salt concentration is decreased to a low level, dispersion of clay may follow and so reduce their permeability that further leaching becomes all but impossible. Under these circumstances, the alternative is to remove exchangeable Na, which will then allow the soil to return to a flocculated condition (Hausenbuiller, 1974; Brady & Weil, 2015).

2. *The Removal of Exchangeable Na from Soils*

The displacement of exchangeable Na from *sodic soils* is normally achieved by adding an amendment that will supply soluble Ca. Gypsum is the amendment used most widely for this purpose. (*Note:* If a *sodic soil* contains free lime, elemental sulphur (S) or tetraoxosulphate (vi) acid or, simply put, sulphuric acid [H_2SO_4] may be used as the amendment. To be effective, S must first be oxidized to H_2SO_4. The acid, whether added directly or derived from S, reacts with lime to produce gypsum. Thus, the ultimate source of soluble Ca is the same for all three amendments.). Once in solution, the Ca from gypsum undergoes exchange with Na, which then becomes a part of the soil solution and can be removed by leaching. The reaction is as follows (Hausenbuiller, 1974):

■ Na_2 + ■ $CaSO_4$ → ■ Ca + Na_2SO_4 ………. (Equation 3)

Gypsum is not a highly soluble salt. For the rapid removal of exchangeable Na from soils, therefore, provisions must be made to assure maximum release of the Ca supplied by this amendment. One aid is to mix the gypsum thoroughly with the soil so that it will make extensive contact with soil exchange surfaces. The reason for doing this should be clear, because the greater the removal of Ca from the soil solution by exchange adsorption, the greater the potential for gypsum to dissolve. Leaching is also helpful in this respect, because it removes soluble SO_4^{2-} ions that would otherwise limit gypsum solubility (Hausenbuiller, 1974; Havlin *et al*., 2014; Brady & Weil, 2015).

Soluble Na_2CO_3, which is a common component of many *saline-sodic soils*, is capable of precipitating soluble Ca as $CaCO_3$ and therefore increases the amount of amendment required for effective reclamation of these soils. Soluble Ca lost by this means is not available for the displacement of exchangeable Na. If a soil containing soluble Na_2CO_3 were highly permeable, a preliminary leaching treatment could be used to reduce its concentration in the soil solution. Otherwise, to assure complete reclamation, sufficient amendment must be added to such a soil to react with both soluble Na_2CO_3 and exchangeable Na (Hausenbuiller, 1974; Havlin *et al*., 2014; Brady & Weil, 2015).

3. Estimating Amendment Needs for the Reclamation of Salt-Affected Soils

The quantity of amendment to add/apply for the reclamation of a *sodic soil* can be judged by the direct determination of the quantity of exchangeable Na and Na_2CO_3 present in the soil, or indirectly by a rapid *gypsum requirement test.* In the conduct of the latter test, a soil sample is mixed with a saturated solution of gypsum, and after equilibrium, the reduction in the concentration of soluble Ca is measured. The loss of soluble Ca from the test solution results either from its adsorption in place of Na on the exchange complex or its precipitation by Na_2CO_3. When the amount of Ca lost from solution is multiplied by an appropriate factor, it is converted to the need for gypsum in the field. The conversion factor must take into account the depth of soil to be reclaimed. This normally corresponds to the depth to which the amendment will be mixed with the soil (Hausenbuiller, 1974; Havlin *et al*., 2014).

Some *saline-sodic soils* contain gypsum as a natural component. When these soils are leached, Ca from the gypsum replaces exchangeable Na and thus provides for reclamation without the addition of amendment from an external source (Hausenbuiller, 1974; Havlin *et al*., 2014; Brady & Weil, 2015).

VIII. MANAGEMENT OF SALT-AFFECTED (SALINE, SODIC, AND SALINE-SODIC) SOILS

If the reclamation of a salt-affected soil cannot be undertaken, certain practices may be followed that provide a better soil environment for plant growth. Some of the procedures involved may gradually improve soil conditions, or at least prevent them from worsening (Hausenbuiller, 1974: 375).

Probably the most vital aspect of the management of *saline soils* is to avoid excessive concentration of neutral soluble salts in the root zone of plants. For this purpose, frequent irrigations are recommended. When possible, excess water should be applied to flush (leach) salts more deeply into the soil or to counter the tendency for salts from the water to accumulate in the soil (Hausenbuiller, 1974: 375).

Some control over the distribution of salts in soils is possible with careful irrigation management. When water is applied, it dissolves salts as it moves into and through the soil. Where sprinklers are used, salt movement is in a downward direction. Where furrow irrigation is used, movement is both downward and lateral, with the consequence that the soil immediately below and to the sides of the furrow may be flushed or leached relatively free of salts. Advantage is sometimes taken of this by planting seeds very close to an irrigation furrow where the salt concentration is low (Hausenbuiller, 1974; Havlin *et al*., 2014; Brady & Weil, 2015).

An additional aid in the utilization of *saline soils* is to grow salt-tolerant plant species. The salt tolerance of a number of common agricultural plants is shown in Table 3.

Table 3: The relative tolerance of some crop plants to salts in the soil

Fruit Crops	Field Crops	Forages	Vegetables
PLANTS OF HIGH SALT TOLERANCE			
Date Palm	Barley	Alkali sacaton	Garden beets
	Sugar beets	Saltgrass	Kale
	Rape	Nuttal alkali grass	Asparagus
	Cotton	Bermuda grass	Spinach
		Canada wild rye	

		Western wheatgrass	
		Tall wheatgrass	
		Birds foot trefoil	
PLANTS OF MEDIUM SALT TOLERANCE			
Pomegranate	Rye	Sweet Clover	Tomato
Fig	Wheat	Perennial ryegrass	Broccoli
Olive	Oats	Strawberry clover	Cabbage
Grape	Rice	Sudan grass	Cauliflower
Cantaloupe	Sorghum	Dallis grass	Lettuce
	Corn	Alfalfa	Sweet corn
	Flax	Tall fescue	Potato
	Sunflower		Orchard grass
			Carrot
			Onion
			Peas
			Squash
PLANTS OF LOW SALT TOLERANCE			
Pear	Field beans	White Dutch clover	Radish
Apple		Meadow foxtail	Celery
Citrus		Alsike clover	Green beans
Plum		Red clover	
Almond		Ladino clover	
Apricot			
Peach			

Source: Abstr. from R.L. Hausenbuiller (1974: 376). For a more complete listing, refer to the US Salinity Laboratory Staff, USDA Handbook 60, 67, 1954.

There are very few management tactics available for assuring satisfactory plant growth on *sodic soils.* Tolerant crops may be grown, preferably excess exchangeable Na-tolerant perennials that need not be re-established each year. These may include some, though not all, of the crop species also tolerant of excess neutral soluble salts. Great/special care should be exercised in planting these crops, the objective being to prepare a good seed bed and then to plant and secure seedling emergence before the physical condition/state of the soil changes. The application of irrigation water, for example, may cause the soil to seal over and thereby prevent germination (Hausenbuiller, 1974: 375-376).

In due time, the level of exchangeable Na in the soil can be reduced and the physical condition gradually improved if a *sodic soil* containing free lime is subjected to long periods of leaching without the application of a soil amendment. Soil reclamation is effected by the small quantity of Ca derived from the lime. Sometimes the application of plant residues or organic manure(s) to sodic soils is recommended or suggested as a means of improving the physical condition of *sodic soils* (Hausenbuiller, 1974: 376-377).

The use of saline irrigation water can improve a *sodic-soil condition,* provided soluble Ca, Mg, and Na occur in proper balance and some leaching is possible to prevent the neutral soluble salts from accumulating in the soil. Other than the few treatments considered previously herein, however, little short of complete reclamation can be expected to greatly change the productivity of seriously affected *sodic soils* (Hausenbuiller, 1974: 377).

1. Irrigation Water Quality

All irrigation water contains at least a small quantity of dissolved inorganic substances. Thus, when applied repeatedly to land where evaporation is high, irrigation waters can result in salt accumulations that are much like those occurring under natural conditions. The problems that result may be due to increased solutes in the soil or they may reflect an increased level of exchangeable Na. The latter effect is caused principally where HCO_3^- and CO_3^{2-} ions are introduced with the irrigation water. These ions, when present in sufficient quantity, cause the precipitation of Ca and Mg as carbonates, thereby enhancing the uptake of Na on the soil's exchange complex (Hausenbuiller, 1974: 377).

Precipitation of Ca and Mg by HCO_3 and CO_3 takes place when the selective loss of water by evapotranspiration causes saturation of the soil solution with respect to Ca and Mg carbonates. The point at which this state is achieved depends, to a large extent, on the concentration of Ca, Mg, HCO_3, and CO_3 in the irrigation water. Once attained, however, the proportionate quantity of these components subsequently lost by precipitation varies directly with the continued decrease in the soil water content caused by evaporation and plant use. There is thus a general relationship between water loss by evapotranspiration and the precipitation of soluble components from irrigation waters used ta widely scattered locations. The extent of precipitation is indicated by the loss of HCO_3 + CO_3 from the irrigation waters after their application to the land. Initially, the concentrations of HCO_3 + CO_3 in the irrigation waters vary over a rather narrow range, a condition that allows them to be considered together in this discussion. Evapotranspiration is required to initiate carbonate precipitation from the waters. On the average, carbonate precipitation appears to take place when the volume of added (irrigation) water is reduced by about 25%. Soil water loss beyond this point results in a paralleling decrease in the concentration of HCO_3 + CO_3. If, through precipitation by HCO_3 and CO_3, the concentration of soluble Ca + Mg is reduced much below that of soluble Na, an increase in the level of exchangeable Na can be anticipated in the soil. Potentially, the situation is most serious when there is sufficient HCO_3 and CO_3 to precipitate not only the soluble Ca and Mg in the irrigation but also that occurring in exchangeable form in the soil. A reduction in exchangeable Ca and Mg will almost certainly result in a corresponding increase in the level of exchangeable Na in the soil (Hausenbuiller, 1974: 377-378).

2. Water Quality and Leaching Requirements

Due to the potential for salt influx from irrigation water, adequate leaching of irrigated soils is essential to their continued use. Thus, without adequate leaching of irrigated soils, injurious salts accumulate in in the soils in proportion to the amount of water added and all HCO_3 and CO_3 added can be effective in the precipitation of Ca and Mg. With adequate leaching, however, water of rather high salt content can be used indefinitely without causing serious deterioration of the soil or harm to crop plants grown on the soil (Hausenbuiller, 1974: 378; Brady & Weil, 2015).

Leaching requirements depend on the total salt content of irrigation water and its potential to precipitate $CaCO_3$ and $MgCO_3$ when added to the land. Where salts are rather low and there is little tendency for Ca and Mg to precipitate, standard irrigation practices, which usually result in limited leaching each time water is applied, provide ample (enough or more than enough) protection against the development of a serious salt problem in the soil. Where either the salt content or the potential for Ca and Mg precipitation is high, however, special care in irrigation is usually necessary to prevent salt accumulation or a build-up of exchangeable Na in the soil. Generally, the usual precaution is an increase in the frequency with which irrigation water is added to the land, with the consequence that only a fraction of the stored plant-available water in the soil is used (for instance, by growing plants) between irrigations. Due to the increased frequency of irrigation, each application of water to the soil is made (carried out; undertaken) before the salt concentration has reached damaging proportions in the soil or before the soil solution has become saturated with respect to Ca and Mg carbonates. The quantity of water added to the soil should be sufficient to flush residual salts beyond the depth of rooting of plants. The residual salts so leached from plants' rooting depth by sufficient irrigation waters will ultimately be lost from the soil in drainage (Hausenbuiller, 1974: 378-379).

As with most of the problems of salt-affected soils, the development of an irrigation-management programme to prevent salt build-up in soils must be geared towards local environmental conditions. Involved in decisions regarding the programme are such things as the composition of the water (water available in the immediate locality for the planned irrigation project) and its availability for leaching, the tolerance of crops to salts and exchangeable Na, and soil characteristics, including (but not restricted to) internal drainage, that influence the potential for successful leaching. Satisfactory internal drainage of soils is particularly important, because without it, subjection of arid-region land (or soils) to irrigation will likely result in its eventual abandonment as a result of accumulated salts (Hausenbuiller, 1974: 379).

3. Drainage of Irrigated Land

Excess water in irrigated soils has the same adverse effect as it does under other conditions and, in arid regions, has the further disadvantage of encouraging salt accumulation in soils. Irrigated agriculture often suffers because the land most suitable for water application (irrigation) is also the most difficult to drain. Such a land is commonly located on flat areas where surface water flow is relatively slow and where ground water derived by seepage or other means already exists at rather shallow depths. A problem may not arise until excess water supplied to irrigate the land causes the groundwater to rise dangerously near the soil surface. Much good land has been rendered useless because of the failure to provide drainage along with an irrigation system. Provisions for land drainage are usually imperative, because excess water is virtually always applied to the land, even where irrigation is performed with a high a degree of efficiency (Hausenbuiller, 1974: 435).

The application of excess water to irrigated land cannot be avoided most of the time. Efficient rill irrigation customarily requires rates of application in excess of the soil's infiltration capacity; some water is, therefore, lost as runoff and will contribute to the ground water supply if not properly disposed of. Furthermore, the removal (flushing; leaching) of salts from, or the avoidance of their accumulation in, soils sometimes necessitates the application of more water than is used consumptively by plants. Such requirements can be anticipated and should be taken into consideration in the planning of drainage facilities for an irrigation project (Hausenbuiller, 1974: 435).

Problems of drainage resulting from excess surface-applied irrigation water, like those associated with human-accelerated soil erosion, can be reduced through use of sprinklers. Sprinklers, when used, permit the relatively uniform application of water to soils at a rate and in a total quantity that prevents unwanted surface runoff and deep percolation. This irrigation method is particularly beneficial where, because of steep or complex topographic pattern, water cannot be applied properly under gravity flow (Hausenbuiller, 1974: 435).

In many locations throughout the world, the construction of irrigation canals through permeable soil materials has been the principal cause of rising ground water. In some of these systems, there may be as much water lost by seepage as is finally delivered for use on the land. The control of seepage, which is usually accomplished by lining canals with an impermeable material, provides the dual benefit of minimizing unwarranted deterioration of land by soil waterlogging and increasing the efficiency of the water-delivery (supply) system (Hausenbuiller, 1974: 435-436).

4. Benefits of Soil Drainage

The removal of excess water from soils (i.e., soil drainage [SoD]) is of both direct and indirect value to plants. Some of the benefits of SoD relate to improvement in soil physical, chemical, and biological properties that contribute to plant growth functions. Usually, however, the change/improvement (in soil properties resulting from drainage) that most favours plants is the increased availability of oxygen (O_2) to plant roots (Hausenbuiller, 1974: 436).

A lack of O_2 in the soil reduces the uptake of soil nutrients and water by plant roots. Oddly, plants may wilt even when their roots are bathed in water if the roots do not obtain sufficient O_2 for respiration. Not only are root absorptive processes hindered by poor soil aeration, but root exploration of the soil, which is highly important to the process of making soil nutrients positionally available, is also restricted, and plant growth may be limited for this reason (Hausenbuiller, 1974: 436).

There are other ways in which poor soil aeration affects plant growth adversely. Most often associated with poorly aerated, waterlogged soils, particularly where wetness is accompanied by a low pH, are the nutrient toxicities due to excess soluble manganese (Mn). The decay of SOM and the mineralization of organically bound nutrients are retarded, with organic sulphur (S) often being released as toxic hydrogen sulphide (H_2S) rather than as the SO_4^{2-} ion. Also, denitrification, which converts nitrates to volatile forms of nitrogen (N), proceeds most rapidly in poorly aerated soils (Hausenbuiller, 1974: 436).

Excessive soil wetness limits the use that can be made of land. Slow soil drying in the spring delays cultivation and seeding. It also slows soil warming, so that seed germination and the subsequent development of plant roots and shoots are retarded. In combination, all of these effects delay harvest or may so shorten the length of the effective growing season that only a few kinds of plants can be grown (Hausenbuiller, 1974: 436).

SoD increases the rate at which surface-applied water is absorbed (taken in) by soils (i.e., increased soils' infiltration capacity for irrigation or natural precipitation water). This benefit is due partly to the reduction in the average water content of the soil, but it also reflects better soil structural conditions that result when drainage permits cyclic wetting and drying as well as an increase in the rate of soil microbial activity. Increased intake of water by soils (i.e., increased soils' infiltration capacity) is of particular importance in flood and soil erosion control (Hausenbuiller, 1974: 436).

IX. SUMMARY

In this work, basically, an account has been given of the origin of salts in soils, some chemical aspects of salt accumulation in soils, and characterization and classification of salt-affected soils. The work has also discussed plant growth relationships in salt-affected soils, reclamation and management of these soils as well as the quality of irrigation water that should be used as part of management of these soils. The work has been rounded off with a brief presentation of a discussion on the drainage of irrigated land and the benefits of soil drainage.

CONCLUSION

Salt-affected soils are soils that have been adversely modified for growth of most crop plants by the presence of certain types of exchangeable ions or of soluble salts. The 3 major classes of salt-affected soils based on chemical properties are saline, sodic, saline-sodic soils. Soil salinity is basically estimated by measuring the electrical conductivity (EC) of the soil solution. The SI unit of measurement of EC is mhos per centimetre. Excess neutral soluble salts' accumulation in soils principally harm plants growing on such soils by reducing the availability of water in the soils for plant use. The accumulation of excess exchangeable Na in soils is harmful to plants principally because it induces undesirable physical and chemical conditions.

The reclamation of salt-affected soils consists of the removal/leaching of excess neutral soluble salts or excess exchangeable Na, or both, from such soils to the extent necessary to return the affected soils to a normal productive state. It also involves estimating the amendment needs for the reclamation of such soils. Probably the most vital aspect of management of saline soils is to avoid excessive concentration of neutral soluble salts in the plants' root zone. For this purpose, frequent irrigations and careful irrigation management are recommended. An additional aid in the utilization of saline soils is to grow salt-tolerant plant species. Generally, several conditions must be met to accomplish satisfactory leaching of excess soluble salts from soils - irrigation water must be available, and if reclamation of salt-affected soils is to be rapid, there should be some means of impounding the water on the soil surface to provide extensive infiltration into the soil; a second requirement for successful leaching is adequate soil drainage; etc.

There are very few management tactics available for assuring satisfactory plant growth on sodic soils, including the planting of excess exchangeable Na-tolerant crops, preferably perennials that need not be re-established each year. These may include some, though not all, of the crop species also tolerant of excess neutral soluble salts. In due time, the level of exchangeable Na in the soil can be reduced and the soil's physical condition gradually improved if a sodic soil containing free lime is subjected to long periods of leaching without the application of a soil amendment, because soil reclamation is effected by the small quantity of Ca derived from the lime. Sometimes the application of plant residues or organic manures to sodic soils is recommended as a means of improving the physical condition of sodic soils. The use of saline irrigation water can improve a sodic-soil condition, provided soluble Ca, Mg, and Na occur in proper balance and some leaching is possible to

prevent the neutral soluble salts from accumulating in the soil. Besides the few treatments considered in this work, however, little short of complete reclamation can be expected to greatly change the productivity of seriously affected sodic soils.
Essential considerations in the irrigation management of salt-affected soils include irrigation water quality; water quality and leaching requirements; and drainage of irrigated land/soils. Some of the benefits of soil drainage (SoD) relate to improvement in soil physical, chemical, and biological properties that contribute to plant growth functions. Usually, however, the change/improvement in such soil properties that most favours plants is the increased availability of oxygen to plant roots. SoD also increases the rate at which surface-applied water (i.e., irrigation water or water from precipitation) is absorbed by soils. Increased soils' infiltration capacity, in turn, is of particular importance in flood and soil erosion control.

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