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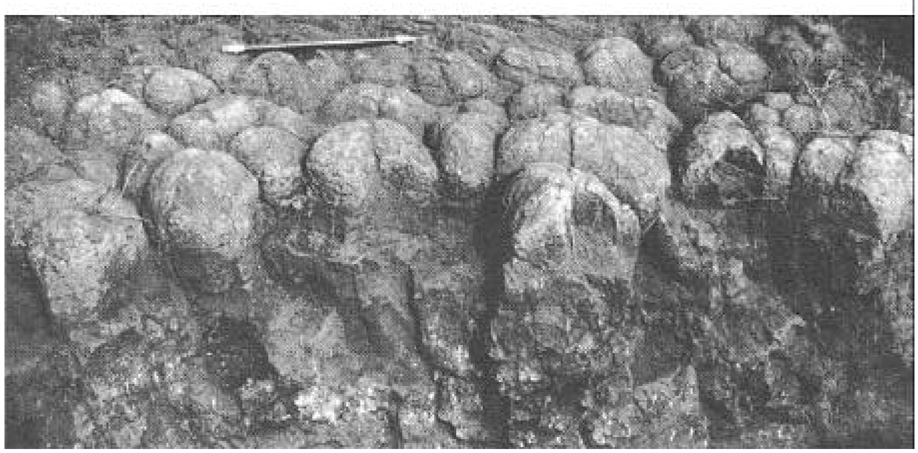
Salinity and Sodicity

IN NORTH DAKOTA SOILS



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WHAT IS SALINITY AND SODICITY?

Soil salinity and sodicity are related problems that are commom in North Dakota. Both eastern and western North Dakota have their share of saline and sodic soils. For example, 24 and 17 percent of the soils in Grand Forks County and Slope County, respectively, are affected by salinity or sodicity (Soil Survey Staff, 1987). Further, soil survey data from 34 of the 52 coun-ties in North Dakota show approximately 1,900,000 acres affected by sodium and 700,000 acres affected by salinity. These problem soils compose about 9 percent of the 34-county area.

Salinity and sodicity are often seen as bare ground with whitish crust that has a scabby appearance. Scab-land, salt-land, alkali, alkaline, and sour-ground are a few of the local terms that describe these areas. Some of these terms are misleading, because they imply problems that are not necessarily related to salinity or sodicity. For instance, alkaline and sour-ground actually refer to soil acidity. Alkaline soils are basic ($pH > 7$) and sour-ground is acid ($pH < 7$). Many soils in North Dakota are basic in pH but are not affected by salinity or sodicity. On the other hand few soils in North Dakota have high enough acidity to reduce crop yields. Acid soils are occasionally found in in in the extreme south-central and southwestern parts of North Dakota. They have formed in acid sediments of the Fox Hills formation and are generally used as rangeland.

We are concerned with salinity and sodicity levels high enough to affect production. Clear definitions of these two problems are necessary for proper identification and management.

SOLUBLE SALTS AND SALINE SOILS

Soils with high amounts of soluble salts are called saline soils. They often exhibit a whitish surface crust when dry. The solubility of calcium sulfate or gypsum ($CaSO_4$) is used as the standard for comparing solubilities of salts (Table 1). Salts more soluble than gypsum are considered to be soluble and cause salinity. Examples are sodium sulfate or Glauber's salt (Na_2SO_4) and sodium chloride, or table-salt (NaCl). Salts less soluble than gypsum are considered insoluble and do not cause salinity. Calcium carbonate ($CaCO_3$) or lime is an example of an insoluble salt commonly found in North Dakota soils.

Salts found in North Dakota soils are of three types: sulfates (SO_4); carbonates (CO_3); and chlorides (Cl). Most saline soils in North Dakota are composed of sulfate salts (Keller et al., 1984). However, the northern Red River Valley has extensive areas of saline soils that have high amounts of chloride salts. Soils with high amounts of carbonates of sodium occur rarely, and are usually associated with coarse textured materials.

SODIUM AND SODIC SOILS

Soils high in sodium (sodic soils) may present physical restrictions to plant growth. Sodium (Na^+) is a positively charged component, or cation, of many salts. Sodium problems are due to its behavior when attached to clay particles. If 15 percent or more of the clay adsorption sites are occupied by sodium (sodium-clay), poor physical condition of the soil often restricts root growth and makes tillage difficult.

The forces that hold clay particles together are greatly weakened when sodium-clay and water come into contact. In this condition clay particles are easily detached from larger aggregates, or dispersed (Figure 1). When dried, however, sodium-clay particles settle out in dense layers

Table 1. Composition and solubility of some common evaporite minerals (salts).

Mineral	Composition	Solubility	Chemical Name
		(moles/liter)	
Calcite (lime)	$CaCO_3$	0.00014	Calcium Carbonate
Gypsum	$CaSO_4 \cdot 2H_2O$	0.0154	Calcium Sulfate
----	$CaCl_2 \cdot 6H_2O$	7.38	Calcium Chloride
Magnesite	$MgCO_3$	0.001	Magnesium Carbonate
Hexahydrite	$MgSO_4 \cdot 6H_2O$	4.15	Magnesium Sulfate
Epsomite	$MgSO_4 \cdot 7H_2O$	3.07	Magnesium Sulfate
Bischofite	$MgCl_2 \cdot 6H_2O$	5.84	Magnesium Chloride
(Washing soda)	$Na_2CO_3 \cdot 10H_2O$	2.77	Sodium Carbonate
(Baking soda)	$NaHCO_3$	1.22	Sodium Bicarbonate
Mirabilite	$Na_2SO_4 \cdot 10H_2O$	1.96	Sodium Sulfate
Thenardite	$NaSO_4$	3.45	Sodium Sulfate
Halite	NaCl	6.15	Sodium Chloride

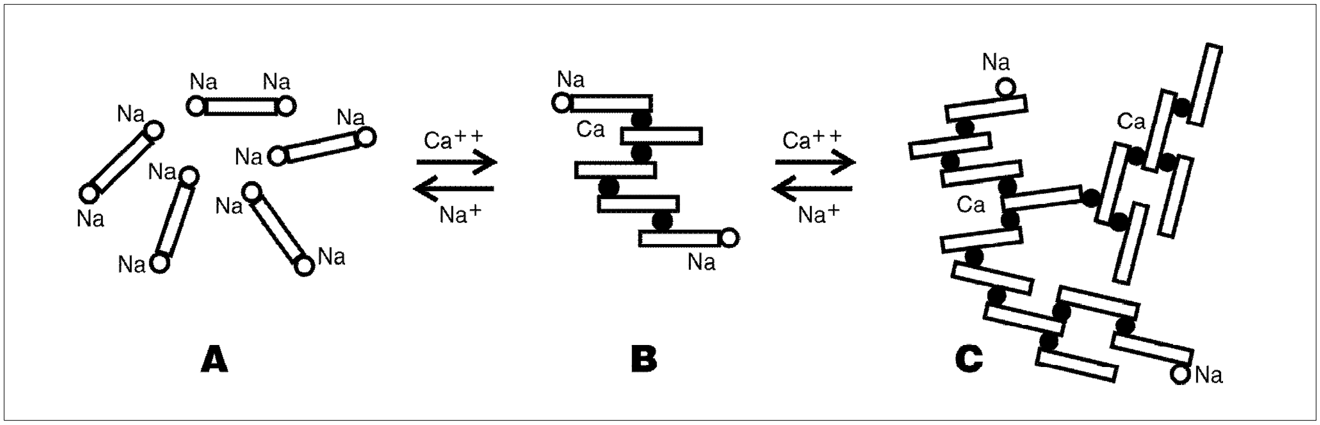

Figure 1. When the exchange complex has greater than 15 % sodium (Na) the clay is dispersed (A) resulting in poor soil structure. When calcium (Ca) replaces enough sodium the clay is flocculated (B); stable soil aggregates are formed that create good soil structure (C). (After Rengasamy, P., et al., 1984.)

that are impenetrable to plant roots and seedling emergence.

SODIUM ADSORPTION RATIO AND SODICITY

Sodicity can be defined in terms of the sodium adsorption ratio (SAR). The SAR is a calculation from laboratory measurements made on a water sample or water extracted from a soil. It is based on the concentration of sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) in the sample. There is a relationship between the amount of each ion in solution and its relative amount adsorbed on the clay; however, the relationship is not direct. Na^+, Ca^{2+}, and Mg^{2+} are adsorbed to the clay with unequal strength. Na^+ is weakly held compared to Ca^{2+} and Mg^{2+}. The SAR computation (equ. 1) accomodates the difference in adsorption strengths.

The U.S. Salinity Laboratory Staff (1954) determined a SAR of 13 from a saturated soil extract is comparable to 15 percent of the adsorption sites being occupied by Na^+. Because of the difficulty and laboratory expense of analyzing the amount of actual Na^+, Ca^{2+}, and Mg^{2+} adsorbed on the clay, the SAR determination has become the standard measure for sodicity.

To demonstrate the SAR calculation and the importance of the ratio of ions as opposed to the total concentration of sodium, let's look at the following two examples:

Example 1

$[Na^+] = 25$ meq/l

$[Ca^{2+}] = 60$ meq/l

$[Mg^{2+}] = 30$ meq/l

$SAR = 25 / \{(60 + 30) / 2\}^{1/2} = 25 / (45)^{1/2} = 25 / 6.7 = 3.7$

Example 2

$[Na^+] = 25$ meq/l

$[Ca^{2+}] = 4$ meq/l

$[Mg^{2+}] = 2$ meq/l

$SAR = 25 / \{(4 + 2) / 2\}^{1/2} = 25 / (3)^{1/2} = 25 / 1.7 = 14.7$

$$SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2} \qquad [1]$$

where: [ ] = concentration in milliequivalents/liter (meq./l)

The extracts from these two samples contain the same amount of sodium. However, because the amount of calcium and magnesium is different, only example 2 is from a soil that would have a sodicity problem. This points out the fact that some soils may have high amounts of sodium but are not sodic. The high amounts of calcium and magnesium counter-balance the sodium.

U.S. SALINITY LABORATORY CLASSIFICATION

The U.S. Salinity Laboratory Staff (1954) established a system for classifying saline and sodic soils in three broad categories.

Saline Soils

Saline soils are defined as having an electrical conductivity (EC) greater than 4 deciSiemens/meter (dS/m) and sodium adsorption ratio (SAR) of less than 13 in their saturation extract.

Saline-Sodic Soils

Saline-sodic soils have an EC greater than 4 dS/m and a SAR greater than 13 in their saturation extract.

Sodic Soils

Sodic soils have an EC of less than 4 dS/m and a SAR greater than 13 in their saturation extract.

NATURAL RESOURCES CONSERVATION SERVICE, USDA CLASSIFICATION

Saline and sodic soils are recognized and shown on soils maps made by the USDA Natural Resources Conservation Service (NRCS). Soils shown on maps are classified using a system that depends on both observable and laboratory properties. Although the NRCS has incorporated much of the U. S. Salinity Laboratory system into its classification scheme (Table 2), it relies heavily upon soil characteristics that can be observed in the field as opposed to laboratory determinations. Field observations of soil properties such as structure and salt crystals are used regularly, but laboratory data is determined on relatively few samples.

Table 2. NRCS classification of saline and sodic soils.
(Soils Survey Staff, 1993)

Saline Soils				
class	Non-saline	Very slightly to moderately saline	Strongly saline	
criteria	^S.E. EC < 2 dS/m	S.E. EC = 2–16 dS/m	S.E. EC > 16 dS/m	
Natric (Sodic) Soils				
class	glossic subgroups	typic or udic subgroups	leptic subgroups	aquoll suborder
subsoil criteria	*SAR > 13 weak claypan	*SAR > 13 strong claypan	*SAR > 13 claypan high salinity	*SAR > 13 claypan poorly drained

*Most natric soils meet this chemical requirement; however, some soils are also considered natric with SAR < 13 under certain conditions.
^Saturated extract (S.E.) electrical conductivity from the topsoil or the average of the soil profile, whichever is greater.

EFFECTS OF SALINITY AND SODICITY

OSMOTIC EFFECT

High salinity (high EC) causes dehydration of plant cells. Reduced plant growth and often death is the result. Dissolved salts cause plant cell dehydration by decreasing the osmotic potential of soil water. Water flows from high potential (low salts) to a low potential (high salt) (Figure 2). When a soil solution has a lower osmotic potential than plant cells, plants cannot extract water from the soil. The effect on a plant is similar to drought stress.

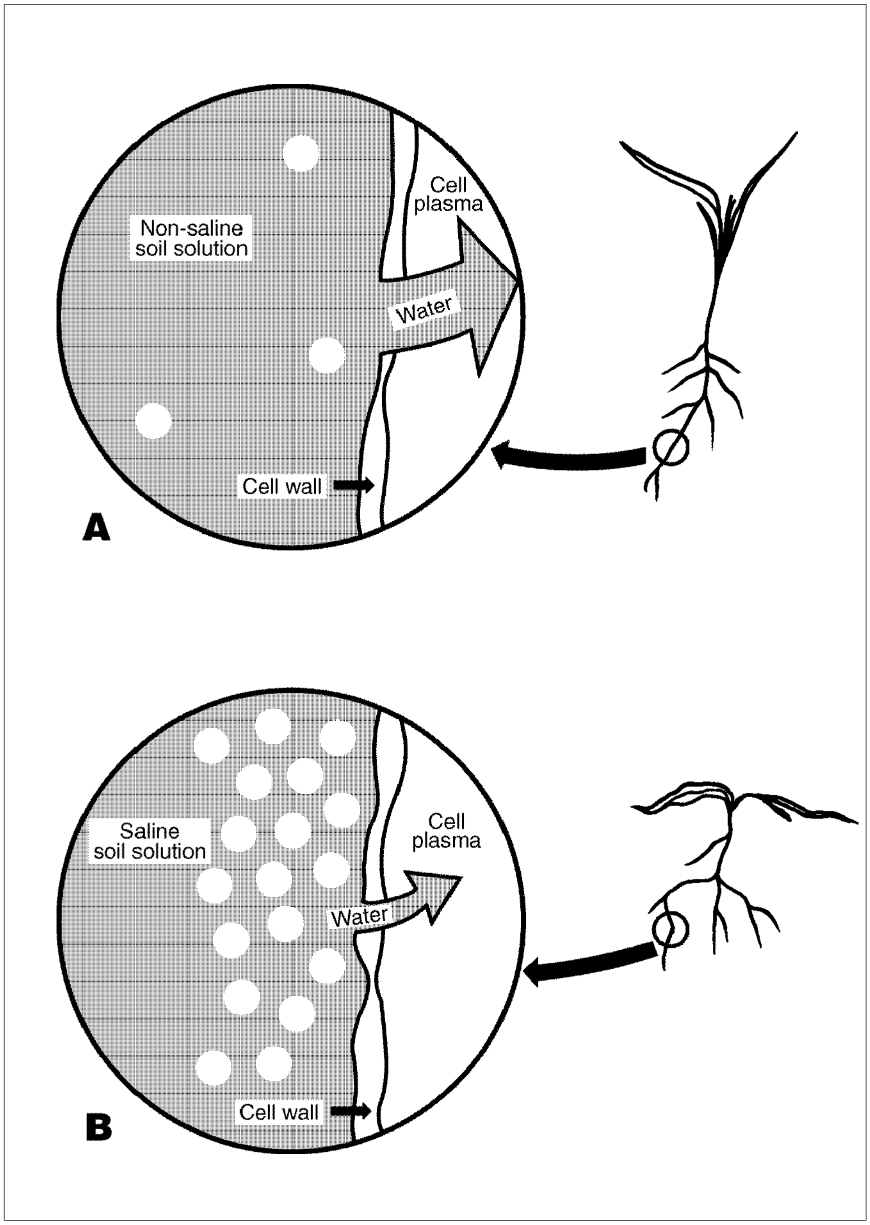

Figure 2. Plants can extract water easily from soils with high total water (A). This is a condition encountered in moist non-saline soils. Dry conditions and dissolved salts decrease the total soil water potential, thus retarding or stopping plant uptake of water (B).

Crop Yield and Soil EC

Yields of many crops are reduced noticeably when the soil extract EC reaches 4 dS/m (U.S. Salinity Laboratory Staff, 1954). Yields will decline proportionately as EC levels (salinity) increase above 4 dS/m. Some crops, such as sugar beets, are quite tolerant to EC between 4 and 8 dS/m. At an EC of 16 dS/m the growth and yields of nearly all crops are severely affected. The effect of salts on plant growth is the basis for the NRCS soil salinity categories (Table 2).

Crop Symptoms of Salinity

Crop symptoms from high salinity are generally the same as symptoms of moisture stress from dry conditions. Plants are stunted with cupped leaves to reduce water loss through the stomata. Initially some plants take on a deep blue-green color from excessive accumulation of wax as an attempt to reduce water loss. Eventually leaves become brown and brit-tle on the tips and margins as stress continues.

Salinity in the field is usually characterized by broad transitions that run gradually from high to low salinity. The pattern of crop response can also be a gradual change from normal plants to no growth at all. However, in some cultivated species, the plant is most sensitive to damage during germination or early growth stages. This may result in a pattern of sharp change from normal plants to bare ground where seeds failed to germinate. Often plants are able to flourish during later growth stages at salinity levels that would not have allowed germination or growth during earlier stages.

Plant Indicators

Plants can be used as indicators of saline and sodic conditions, because tolerance varies with plant species. All plants attempt to adjust to osmotic moisture stress caused by salinity. The osmotic adjustment requires energy that would otherwise be used for growth and production. As a result, when plants attempt to adjust, growth and yields are reduced.

HALOPHYTIC (SALT LOVING) PLANTS

Plants tolerant to salinity are known as halophytes. Technically, plants that can survive in soils that have greater than 0.5 percent (by weight) soluble salts are considered to be halophytes. Some halophytes have developed sophisticated systems of taking in saline water, extracting the salts, and then excreting the salts. Halophytes common to our area that can be used as indicators of high salinity include salt grass (*Distichlis spicata*), alkali grass (*Puccinellia nuttalliana*), cordgrass (*Spartina gracilis*), spearscale (*Atriplex subspicata*), saltwort (*Salicornia rubra*), and sea blite (*Suaeda depressa*). Other less reliable indicator plants are wild barley (*Hordeum jubatum*) and kochia (*Kochia scoparia*). Although they often occur on saline soils, they are also regularly found in non-saline environments.

VEGETATION PATTERNS AND SALINITY

A study of vegetation and saline seeps in northwestern North Dakota showed a consistent pattern of salinity and vegetation (Figure 3). Wild barley was the dominant plant along seep margins with low salinity. Kochia was the dominant plant on the interior of the seep with high salinity. This is a common pattern seen on salt affected soils in North Dakota. Salt grass was the dominant vegetation on sodic soils with high levels of surface salinity on pastureland in central North Dakota (Seelig et al., 1990).

SPECIFIC ION EFFECT – PLANT TOXICITIES AND DEFICIENCIES

Saline soils may also have specific ion effects on plant growth. Higher than normal concentrations of some ions can hinder or block nutrient uptake and certain physiological processes. Few instances of specific ion effects have been reported in North Dakota saline soils. Of the three common cations (Ca^{2+}, Mg^{2+}, and Na^{+}) responsible for saline soils in North Dakota, no toxic ion effects have been reported. Toxic ion effects related to sodium (Na^{+}) have been observed in some plants in other parts of the U.S.

Under rare circumstances, boron has been reported to cause toxic ion effects. Boron toxicity is a potential problem when concentrations in the saturation extract are greater than 1 milligram/liter (mg/l). This level of boron may occur in some saline soils in the northern Red River Valley. However, almost without exception, the osmotic effect plays the most important role in limiting plant growth and yield on saline soils in North Dakota.

Neither cloride (Cl^-) nor sulfate (SO_4^{2-}) have been shown to cause plant toxicities in saline soils. Plant toxicities from excessive bicarbonate (HCO_3^-) have been reported in other areas; however, few saline soils in North Dakota have high levels of soluble HCO_3^-. Many soils in North Dakota do have large accumulations of calcium carbonate ($CaCO_3$) that is quite insoluble. Both phosphorus and micronutrient deficiencies are pos-sible in high lime soils. It may be necessary to increase additions of phosphorus and micronutrients to overcome these problems.

HIGH pH AND SODIC SOILS

High pH (7.8 to 8.5) generally occurs in sodic soils. Extremely high pH (greater than 8.5) occurs in sodic soils when soda ($NaHCO_3$) or sodium carbonate (Na_2CO_3) is present. Sodium-clay, bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}) react with water to form hydroxyl (OH^-) ions that cause high pH [equations 2, 3,

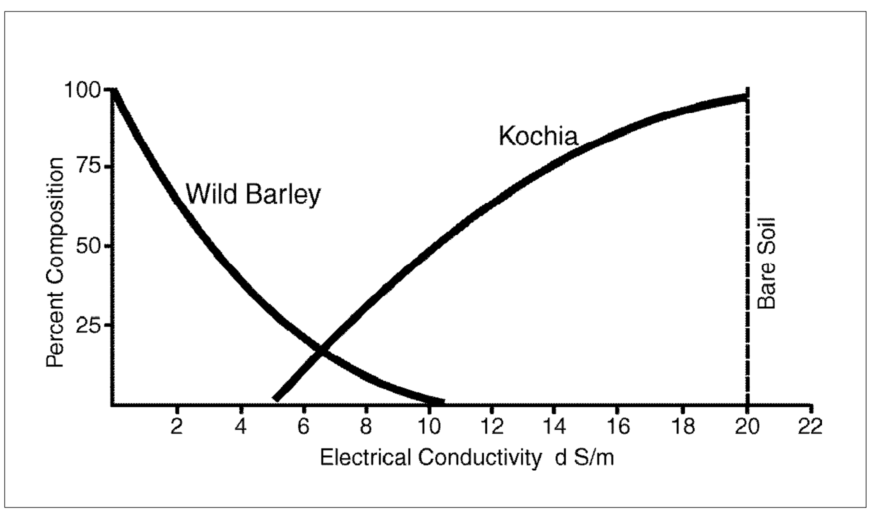

Figure 3. The dominance of plant species in saline seeps is shown by weight % versus EC. (After Worcester and Seelig, 1976.)

and 4]. Soda and sodium carbonate are relatively soluble; therefore, high amounts of soluble carbonate is available to react with water to produce OH^-. For this reason, sodic soils with soda and sodium carbonate are likely to have a pH greater than 8.5.

$$\text{Na-clay} + H_2O \rightarrow \text{H-clay} + Na^+ + OH^- \quad [2]$$

$$HCO_3^- + H_2O \rightarrow H_2CO_3 + OH^- \quad [3]$$

$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^- \quad [4]$$

Extremely high pHs (greater than 8.5) are generally not encountered in sodic soils of North Dakota, because soda and sodium carbonate are rarely present. When soluble carbonate salts are found, the soils generally have coarse textures. When the soil pH is greater than 9.5 live plant roots are vulnerable to deterioration.

Nutrient Availability and High pH

High pH affects plant growth by reducing availability of some plant nutrients. Phosphates are most available to the plant at a pH between 6 and 7. Micronutrients such as iron, manganese, zinc, copper, and cobalt are all much less available at a pH greater than 7.

RESTRICTIVE SUBSOILS AND CRUSTING PROBLEMS

Slowly Permeable Claypans

Soil structure in sodic soils is poor and permeability is low. Permeability is the ease of air and water movement through soils. Good permeability allows water and gasses (oxygen and carbon dioxide) to circulate eas-ily to and from plant roots. This is needed for good plant growth.

A dense layer of clay occurs at or near surface of sodic soils. This natural layer, often called a claypan, is a barrier to roots. Most roots are restricted to the topsoil above the claypan, because movement of water, nutrients, and gases is too slow in the claypan. A dry claypan can be hard enough to physically restrict root penetration. The overall effect on plant growth is one of stress similar to that caused by extremely dry or saline conditions.

UNDULATING OR SPOTTY PLANT GROWTH ON SODIC SOILS

Both claypan depth and root restriction vary considerably within a few feet. Depth to saline material is also highly variable. This variation in soil properties creates extreme differences in plant available water, plant rooting depth, and osmotic potential. Crop response to these extremes is an undulating or spotty pattern of growth that is characteristic of sodic soils.

Soil Crusting

Surface crusting is a common problem with cultivated sodic soils. Plowing mixes sodium-clay from the claypan with topsoil or surface material. Surface material with high amounts of sodium-clay is highly erodible, because it has low aggregate stability and is easily detached by rain drop impact. When dry, the surface forms a hard crust that is a barrier to seedling emergence.

Salinity and Metal Corrosion

Saline soils are corrosive with respect to certain materials commonly used for construction. When metal is placed in the soil, it is exposed to electrochemical reactions that change its physical properties; iron rusting is a good example. Soils high in soluble salts enhance electrochemical corrosion. Electrochemical corrosion can be reduced by coating the metal with organic materials, such as tar or pitch. Metal pipelines are often protected by passing an electrical current through them (cathodic protection) to replace the electrons lost to chemical reactions.

Sulfates and Concrete Corrosion

Soil solutions high in sulfate (SO_4^{2-}) are corrosive to concrete structures. The sulfate solution penetrates concrete and reacts with calcium in the cement to form $CaSO_4$ that precipitates within the pores. This reaction destroys the integrity of concrete in two ways. The cementing agent is changed to a non-cementing material ($CaSO_4$) and large crystals of $CaSO_4$ are formed within voids, causing physical disruption of the concrete.

Much of the damage caused by sulfate solutions can be avoided by using sulfate-resistant concrete. Type I (standard Portland cement) has little resistance to the corrosive action of sulfatic solutions. Type II has medium resistance to sulfates, and Type V has high resistance.

LOCATION AND OCCURRENCE OF SALINE AND SODIC SOILS

NATURALLY OCCURING SALINE SOILS

Saline and sodic soils generally occur on landscape positions where groundwater discharges by evapotranspiration from a shallow water table. In these soils, the water table will flucuate seasonally, but generally will be within 6 feet of the surface for a large part of the growing season. Because soil texture affects the flow of water through soil, it also affects the depth of the water table necessary to cause salinization. Coarse textured soils allow upward capillary movement of water to occur only over a short distance. Therefore a higher water table is required for salinization of coarse textured soils, such as sands or sandy loams, compared to finer textured soils, such as loams or clays. However, because the large pores in coarse textured soils offer much less resistance to water flow compared to the smaller pores in fine textured soils, salinization can occur much quicker in coarse textured soils.

As groundwater is discharged through the soil surface, dissolved salts precipitate and accumulate. Accumulations generally occur near or at the surface of the soil; however, they may occur anywhere in the soil where water is extracted by plant roots.

Discharge as evapotranspiration is only one part of the water balance at a given landscape position. Seasonal rain causes downward percolation of water that leaches salts from the upper parts of the soil.

Salinization occurs in those soils that favor discharge (evapotranspiration loss) over leaching. Not all soils with a water balance favoring discharge are saline. Salinization also depends on groundwater quality. If the groundwater has a only a small amount of soluble salts, salinization is very slow or may not occur at all.

Many combinations of groundwater discharge, water quality, and landscape position exist in North Dakota. As a result, a variety of different types of both saline and sodic soils have developed. Saline and sodic soils with similar properties can often be located by geographical area.

NORTHERN RED RIVER VALLEY

Saline soils in the Grand Forks County area (Figure 4) are the result of regional discharge of artesian groundwater from the Dakota Sandstone formation (Benz et al., 1961). The chemistry of these saline soils is uncommon for the northern Great Plains because of the accumulation of chloride salts. Sulfate salts generally dominate saline soils in North Dakota.

GLACIATED AREAS NORTH AND EAST OF THE MISSOURI RIVER

In glaciated areas, saline soils are associated with the edges of closed depressions or broad swales where discharge of groundwater can occur. Saline soils with most salts at the surface are associated with very shallow water tables. Saline soils with lower water tables may actually have the highest levels of salinity deeper in the soil (Seelig et al., 1987). Leached soils with little salt are often found in depressions within areas of saline soils.

WEST AND SOUTH OF THE MISSOURI RIVER

In nonglaciated areas of North Dakota the water table generally ap-proaches the soil surface on low slopes that gently grade to natural drainageways (streams or rivers). Surface water flow and storage is controlled by the system of interconnected drainageways. This is different than the hydrology in glaciated areas that is controlled by a system of closed depressions (potholes).

Some saline and sodic soils west of the Missouri River are not necessarily related to groundwater discharge. These soils inherited salts from sedimentary material (marine shales, sandstones, etc.) in which they formed. They may be found on landscape positions that have very deep water tables.

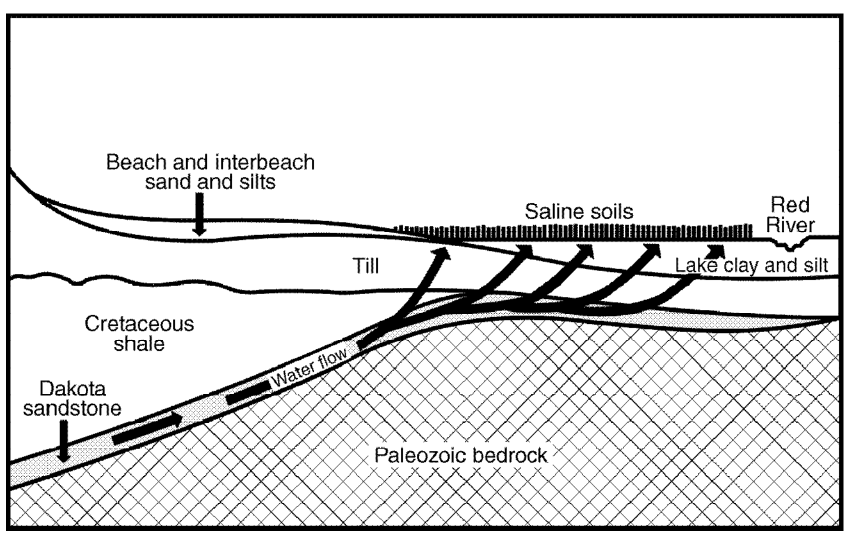

Figure 4. The geologic cross section of Grand Forks County shows the relationship between the Dakota sandstone and the overlying glacial deposits. (After Benz et al., 1961.)

Naturally Occurring Sodic Soils

Groundwater discharge may lead to the development of sodic soils as sodium salts are concentrated in the soil. During evaporation, sodium salts separate from calcium salts because of different solubilities. The soluble sodium salts concentrate high in the soil profile. As the soil solution becomes more concentrated with sodium, the percentage of sodium on the exchange complex also increases. Eventually there is enough exchangeable sodium to cause dispersion of clay and organic matter.

In the unglaciated parts of western North Dakota, sodium affected soils are quite common and the saline soils are generally also affected by sodium (Figure 5). Sodic soils are also found in the glaciated parts of North Dakota; however, saline soils unaffected by sodium are far more prevalent (Figure 5).

SECONDARY SALINIZATION

Secondary salinization is the term used to describe soils salinized as a consequence of human activities. In North Dakota there are five types of secondary salinization:

1) saline seeps;

2) salinization along road ditches;

3) salinization along lagoon margins;

4) salinization from irrigation;

5) salinization from wetland drainage.

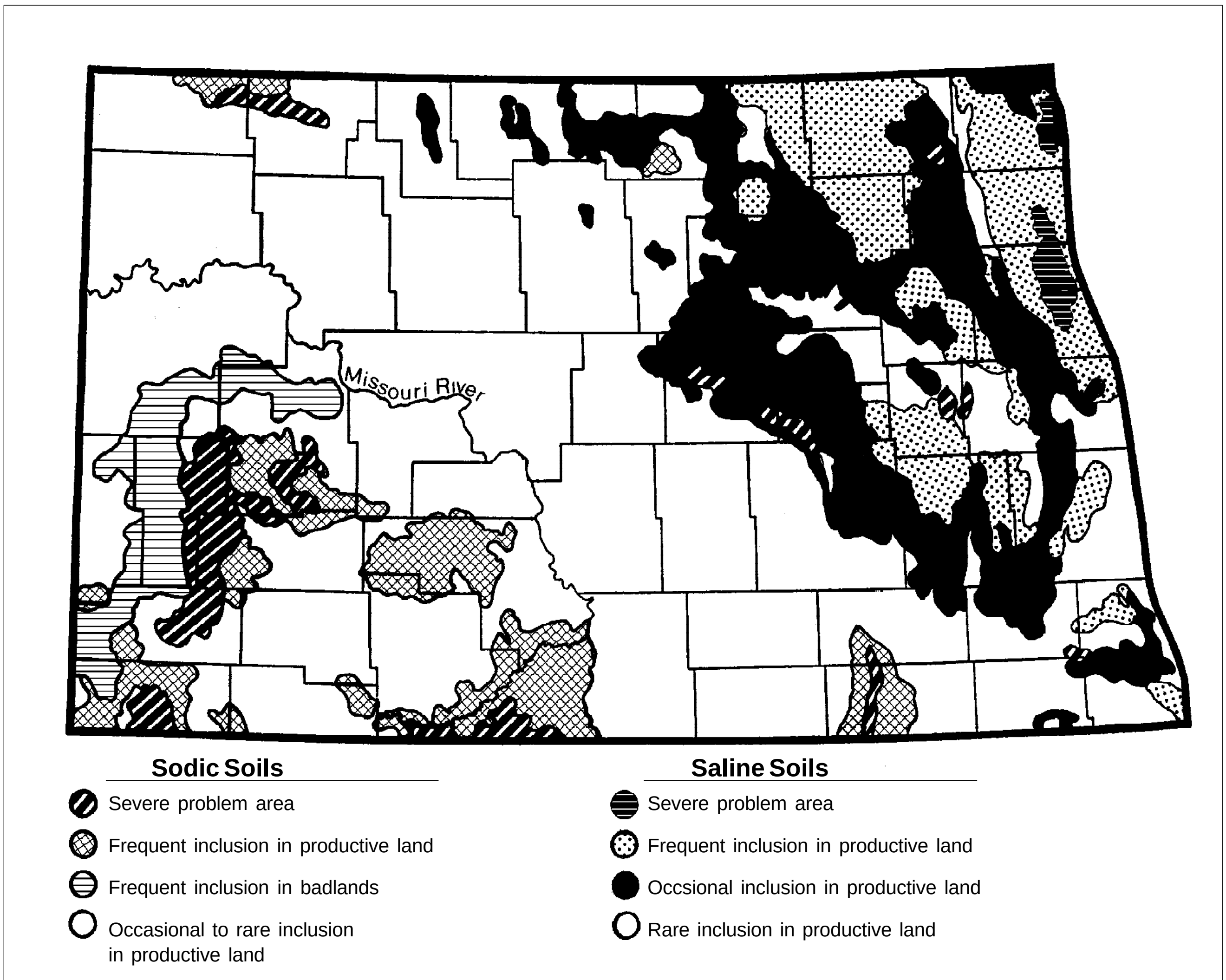

Figure 5. The distribution of saline and sodic soils in North Dakota. (Adapted by D. D. Patterson, C. Fanning, and B. D. Seelig from the General Soil Map of North Dakota, Soil Survey Staff, 1961).

Saline Seep Formation

Most saline seeps have developed recently (post settlement) in the northern Great Plains. In the last 20 years, investigators have concluded that saline seep formation is closely related to the practice of summer fallow for moisture conservation. Researchers have determined that the soil in the rooting zone under summer fallow reaches its storage capacity long before the end of the fallow period. Deep percolation of additional moisture beyond the rooting zone is likely to occur in this situation.

Rate and amount of downward percolation is controlled by soil tex-ture. Average pore diameter in coarse textured soils is larger than in fine textured soils. Faster rates of water flow and less water storage are directly related to larger pore diameters. As a result, deep percolation is more likely to occur in coarse textured soils. In some places relatively coarse textured soils overlay impermeable material of finer tex-ture. Under these circumstances, deep percolation leads to lateral water flow along the surface of the impermeable material (Deutsch, 1977; Seelig, 1978). If the contact between the two different materials approaches the soil surface along a hill slope, as often happens, the laterally moving water will create a wet spot that eventually becomes saline as the water is evaporated (Figure 6).

LOCATION AND TYPES OF SALINE SEEPS

Saline seeps are most common south and west of the Missouri River and on the Missouri Coteau. Areas most prone to saline seeps have sloping stratified geologic materials. They have been classified into six general groups according to the underlying materials (Figure 7). Doering and Sandoval (1976) estimated that 100,000 acres of western North Dakota cropland are affected by saline seeps. Although this is a small percentage of the total acreage of saline and sodic soils, saline seeps are a serious problem. They are responsible for deterioration of land that was once productive. Efforts to avoid wet saline spots on tracts of cultivated land increases costs of production, especially with today's farm machinery.

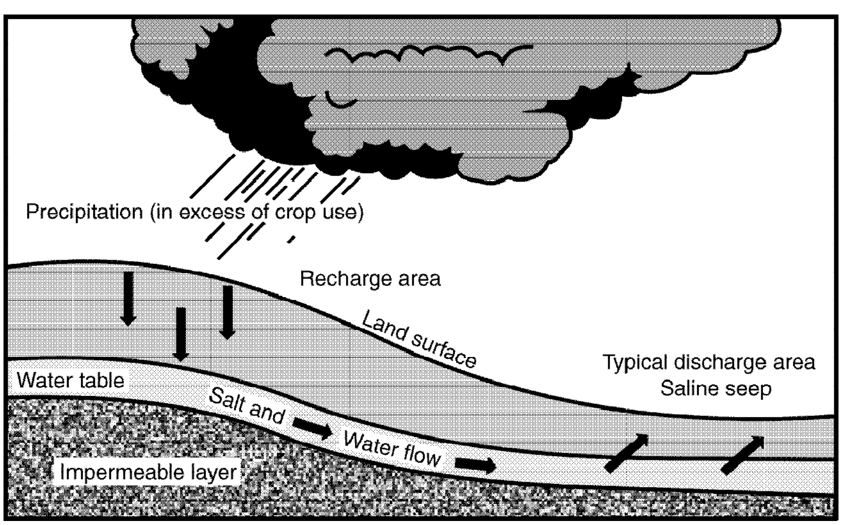

Figure 6. A generalized diagram of a saline seep.

Road Ditch and Lagoon Margin Salinity

Saline soils that have developed around lagoons and drainage ditches are also controlled by the water source. Salinity along drainage ditches is due to lateral movement of water from the ditches to adjacent fields (Figure 8). Extremely flat areas, such as the Red River Valley, are particularly susceptible to this type of secondary salinization. The low grade on most drainage ditches allows water to stand for long periods of time.

Salinity and Irrigation

Under irrigated agriculture, secondary salinization may occur if water is not properly managed. All water from sources other than precipitation contains some dissolved salt.
As irrigation water is used by crops, salts are precipitated in the soil. This process may eventually lead to saline conditions that plants cannot tolerate (Figure 9).

The rate at which salinization proceeds depends on the amount and quality of water added. Water with high amounts of dissolved salts will cause rapid salinization. Poorly designed and improperly managed irrigation systems have been responsible for salinization of thousands of acres in the U.S. Before an irrigation system is developed, soil and water compatibility should always be determined by a qualified soil scientist.

Wetland Drainage and Salinity

Drainage of certain types of wetlands in the northern Great Plains may also lead to soil salinization in the wetland interior. Class 3 and 4 wetlands are noted for their non-saline soils but are often surrounded by saline soils on the wetland edge. Hydrologically, many of these wetlands are called flowthrough

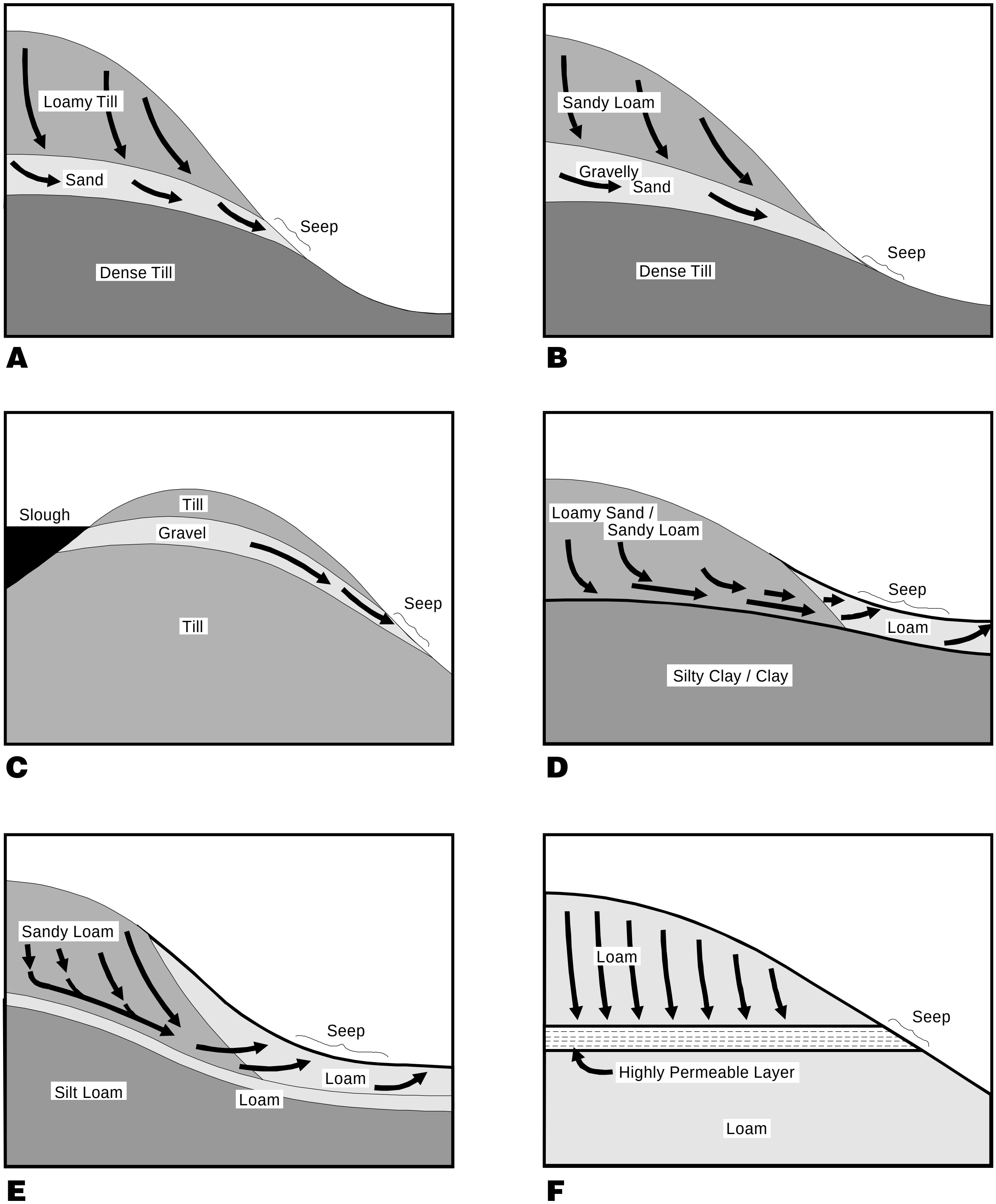

Figure 7. Six classes of saline seeps found in North Dakota. (After Worcester et al., 1975.)

wetlands, because water flows laterally through the wetland soils and does not allow accumulation of salts (Figure 10). When the hydrology of a flowthrough wetland is disrupted by drainage, evaporative discharge can occur through the drained wetland soil. Under the undrained condition, evaporative discharge is confined to the wetland edge; soils may be extremely saline at this location. When the area of evaporative discharge is expanded to the wetland interior, saline conditions may be expanded to the entire wetland (Figure 10). The final result of flowthrough wetland drainage is often no gain in crop production, but a loss of flood protection, groundwater recharge, and wildlife habitat.

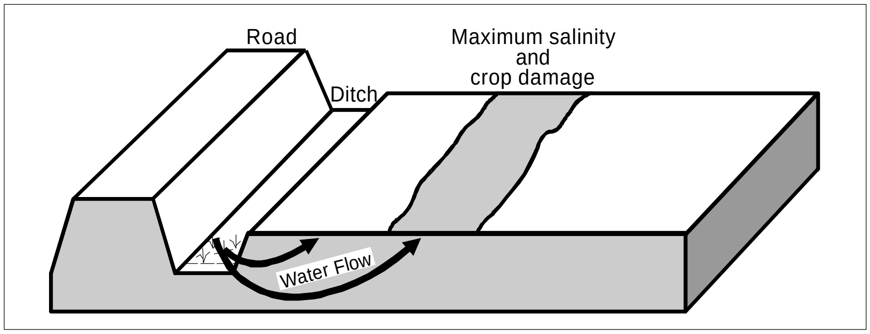

Figure 8. The location of maximum salinity and crop damage along a drainage ditch in the Red River Valley. (After Skarie et al., 1986.)

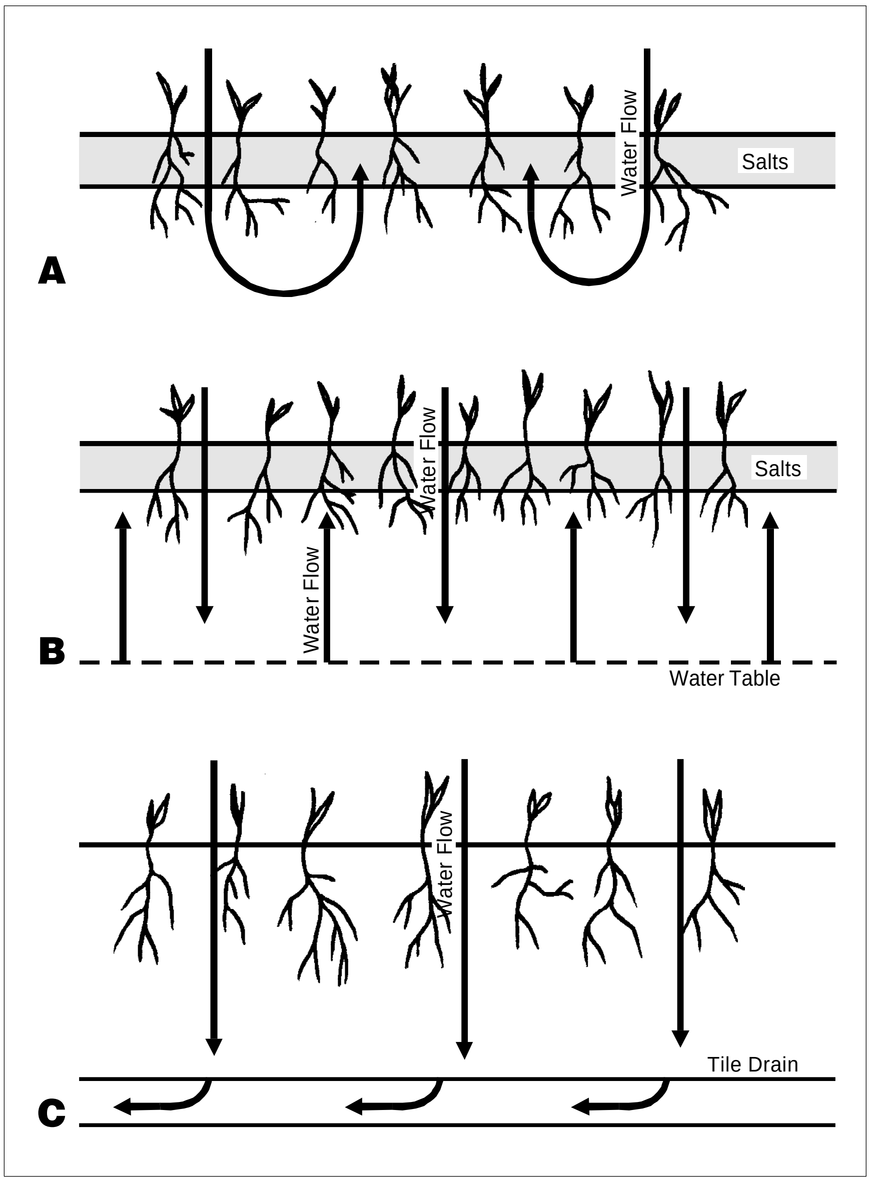

Figure 9. Secondary salinization by irrigation (A) and (B) may be prevented, if the field is adequately drained (C).

SALINE AND SODIC SOIL MANAGEMENT

Management stategies for saline and sodic soils must be designed with processes of salt accumulation in mind. Different management techniques may be necessary for soils with different salt compositions and water regimes.

Most saline and sodic soils are the result of evaporation from a shallow water table. Before effective methods of management can be designed for a specific parcel of land, the water table level must be determined. As long as a shallow water table exists, potential for salinization and sodification exists.

SALINE SOIL MANAGEMENT

The type of ions in the soil solution does not influence the osmotic potential to any large degree; it is the total of all ionic species that controls the osmotic potential. From a practical point of view, management of saline soils with different salt compositions is essentially the same.

Plant Tolerance to Salinity

Salt tolerant plant species should be selected on the basis of salt concentrations found in saline areas. Drought resistant plants such as grasses and small grains are generally more tolerant to salinity than row crops, trees, shrubs, and vegetables (U.S. Salinity Laboratory Staff, 1954). If an accurate estimate of field salinity is known, crop tolerance information can be used to determine the economic feasibility of growing certain crops.

Crop tolerance to salinity has been tested for some of the major crops in North Dakota (Figure 11). It is noteworthy that sunflower is more resistant to salinity than experience from other production areas would indicate.

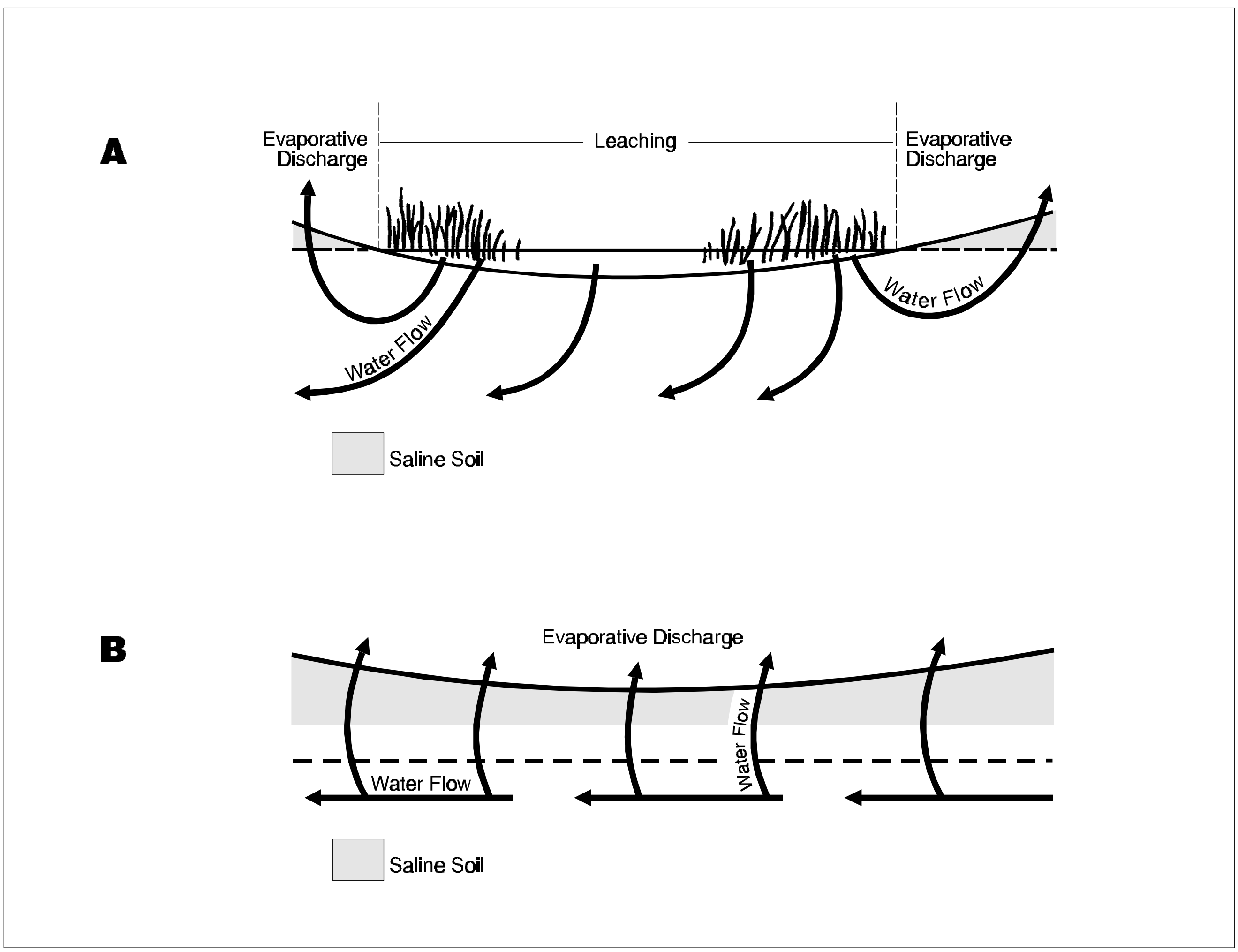

Figure 10. Salinity is confined to the edges of flowthrough wetlands (A), unless the wetlands are drained, and the area of evaporative discharge is expanded to the wetland basin (B).

Many cultivated crops are most susceptible to salinity during germination and early growth stages. If planting coincides with periods shortly after salts have been flushed from the surface, plant germination and seedling survival is more likely to be successful.

Reduction of Evaporative Discharge

Control of salinity must include management practices that reduce evaporative discharge. Subsurface drainage is an effective means of lowering the water table; however, it may not be economically feasible. Evaporative discharge is also affected by the condition of the soil surface and the plants growing on it. Surface mulches can be used to reduce evapotranspiration and salt accumulation.

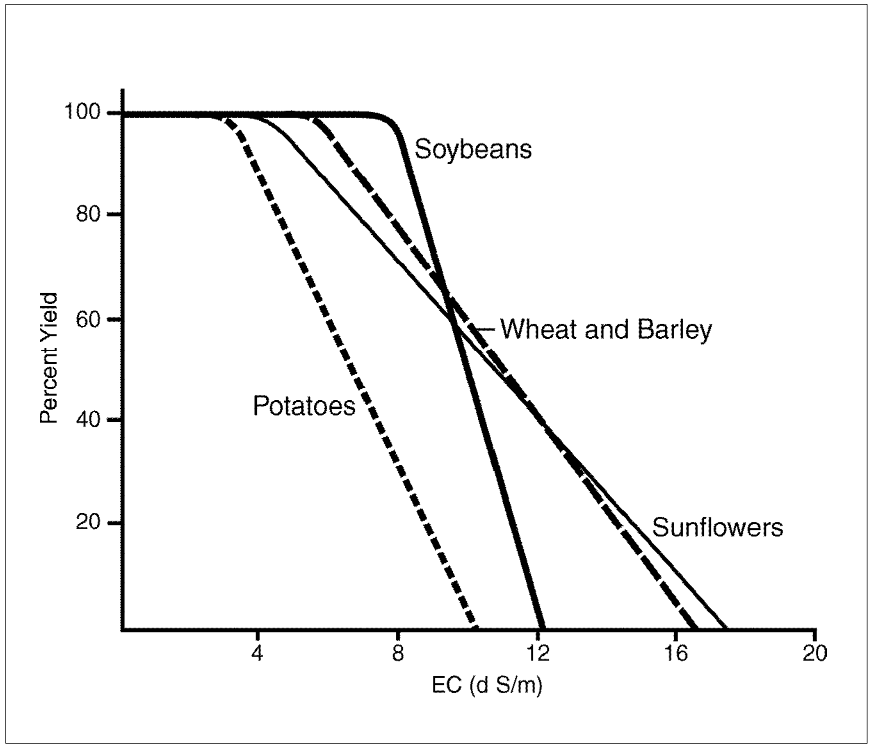

Figure 11. Thresholds of yield reduction due to salinity for some of the major crops in North Dakota. Salinity was expressed as the electrical conductivity (EC) of the saturated soil extract from the plow layer (0 to 6 inch depth). (After Maianu, 1983; 1984; and unpublished data; Maianu and Lukach, 1985; Nelson, unpublished data.)

SODIC SOIL MANAGEMENT

Soils affected by sodium must be managed similarly to saline soils with respect to drainage. Management for these soils includes drought tolerant plant species. Chemical amendments and physical disruption of the claypan may help to reduce the restrictive nature of these soils.

Calcium Amendments for Sodic Soils

Sodic soils may be improved by replacing adsorbed sodium with calcium. A number of amendments have been used with limited success over the years (U.S. Salinity Laboratory Staff, 1954). Amendments that release high amounts of calcium to the soil solution are the most effective. Unfortunately very soluble amendments, such as calcium chloride ($CaCl_2$), are cost prohibitive. Gypsum ($CaSO_4$) is an amendment less effective than calcium chloride but popular in many areas because of cost. Gypsum, however, is often ineffective on sodic soils in North Dakota, because they already have high amounts of gypsum in them. For those sodic soils in North Dakota that do not have gypsum in the upper part of the claypan, $CaSO_4$ may be an effective amendment. Soil inspection and analysis by a qualified soil specialist before calcium amendments are applied to fields with sodic soils is recommended.

Deep Plowing and Sodic Soil Improvement

Deep plowing has improved some sodic soils in western North Dakota (Sandoval, 1978). Deep plowing not only disrupts the restrictive claypan, but may also mix $CaSO_4$ from deeper soil layers into the claypan.

Caution should be taken not to plow too deep or too shallow. Plowing too deep may bring excessive amounts of soluble salts to the surface, creating a salinity problem. Plowing too shallow will not disrupt the lower part of the claypan and will not reach gypsum accumulations below it. The effectiveness of the deep plowing technique depends on the location of the water table and the presence of native gypsum in the soil.

Soil improvement through deep plowing is not expected to be sustained on a sodic soil that has a shallow water table, because sodium salts are continually introduced to the soil through evaporative discharge. If the claypan already has high amounts of gypsum, mixing of gypsum from deeper substrata will have no effect on replacement of adsorbed sodium. Consultation with a qualified soil specialist is recommended before deep-plowing is attempted to improve fields with sodic soils.

SALINE-SODIC SOIL MANAGEMENT

Saline-sodic soils have unique problems with respect to management, because they have both high salinity and sodicity. Some saline-sodic soils have well aggregated structure, although high amounts of sodium are present. The SAR ranged from 18 to 30 and EC ranged from 10 to 20 dS/m in a typical saline-sodic soil from northeastern North Dakota. High salinity counteracts the dispersive effect of sodium. Attempts to leach the salts will likely result in a puddled soil, because the counteractive effect against dispersion is lost as the salts are removed.

MANAGEMENT OF SOILS AFFECTED BY SECONDARY SALINIZATION

Saline Seeps

RECHARGE AREA MANAGEMENT AND SALINE SEEP CONTROL

Saline soil improvement often includes managing the water table. In the case of saline seeps, the water table may be controlled by reducing local groundwater recharge. Eliminating summer fallow in upland recharge positions is generally the most effi-cient method of controlling the water table in a saline seep. Compared to native vegetation, cropping systems may not use moisture efficiently, particularly when summer fallow is included in the rotation. The result is high water tables that contribute to evaporative discharge and salinization of farmland. Where feasible, reduced summer fallow, continuous cropping, and inclusion of hay or pasture in long term rotations should reduce groundwater recharge in areas prone to saline seeps. Deep-rooted crops such as alfalfa have been shown to effectively withdraw moisture from recharge areas and reduce discharge from saline seeps downslope (Brun and Worcester, 1974; 1975).

INTERCEPTION MANAGEMENT AND SALINE SEEP CONTROL

Other management practices focus on interception of lateral flow with tile drains or bands of deep rooted crops. These methods have been successful; however, they have serious disadvantages. Interception of saline water with tile drains can be costly, and the problem of saline water disposal is created. Interception of lateral water with deep rooted crops may be short lived if salts build up in the root zone. Interception methods fail to deal with the source of the problem, recharge from locations farther upslope.

Road Ditch and Lagoon Margin Management for Salinity

Lateral movement of water to soils adjacent to road ditches can be reduced by preventing water from standing in the drainage ditches. Ditches should be designed and maintained to move water rapidly and minimize standing water. Lagoons should be designed to prevent leakage that causes salinization of adjacent soils.

Irrigation Management to Prevent Secondary Salinization

LEACHING AND DRAINAGE

When subsurface drainage is adequate, salt accumulation in irrigated soils can be avoided by applying more water than is needed by the crop. Excess water dissolves salts and percolates beyond the root zone (Figure 9).

The amount of water needed to adequately leach the salts (leaching requirement) is determined by the quality of the irrigation water. Poor quality water (high salinity) dictates a larger leaching requirement. Proper subsurface drainage is absolutely necessary to prevent shallow water tables from developing below irrigated soils. A shallow water table under an irrigated soil defeats the application of leaching water, because leached salts are moved back into the rooting zone by capillary action (Figure 9).

FIELD LEVELLING

Secondary salinization can occur from uneven distribution of irrigation water due to irregular topography. Microdepressions act as points of focused recharge; salts are leached from the recharge locations (Figure

12). Adjacent microknolls, however, act as points of focused evaporative discharge; salts accumulate and may cause salinity problems at the discharge locations (Figure 12). Levelling irrigated fields allows more even water distribution and avoids concentration of water and salts at specific places in the field (Figure 12).

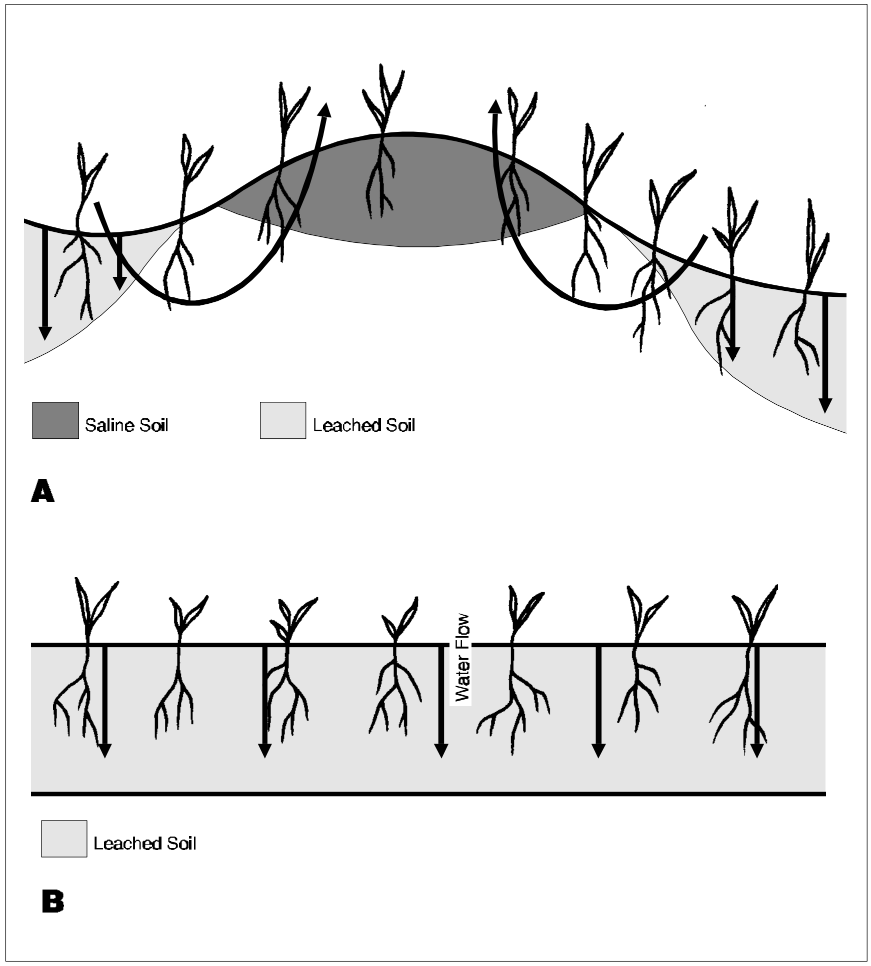

Figure 12. Secondary salinization in irrigated fields at points of evaporative discharge (A) may be eliminated by even distribution of irrigation water after field levelling (B).

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EB 57

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