Management of saline soils

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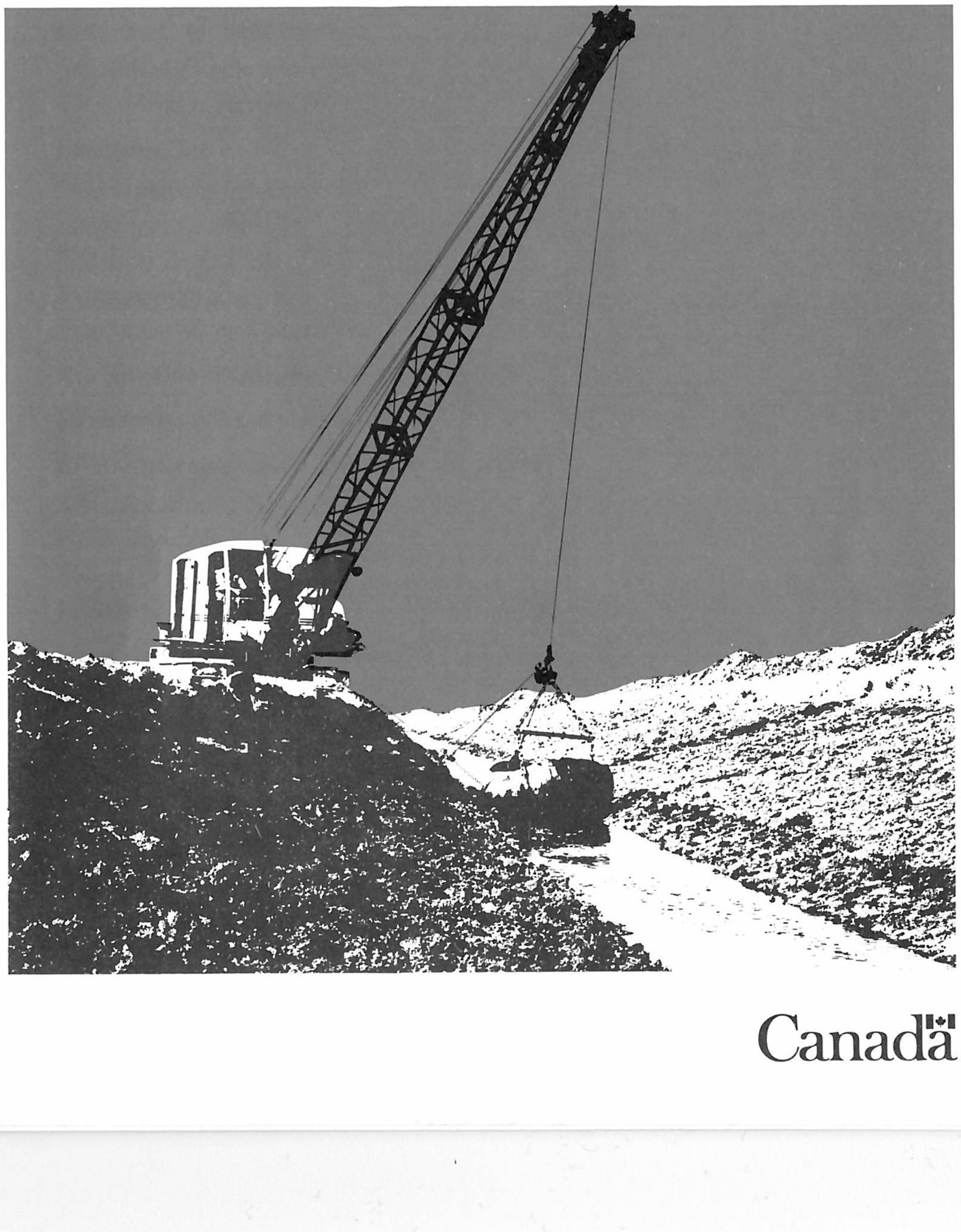

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Management of saline soils

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Introduction

Soil salinity causes problems mainly in waterlogged, poorly drained soils. Saline and saline–sodic soils contain enough water-soluble salts to affect crop growth. These soils occur in both irrigated and nonirrigated lands. In Alberta, Saskatchewan, and Manitoba, more than 0.08 million ha of irrigated lands and 2.0 million ha of nonirrigated lands are saline and saline–sodic.

In irrigated districts, the main causes of salinization and waterlogging of the land are seepage from canals, poor irrigation practices, and inadequate drainage. Under dryland farming, the main causes are the introduction of cereal crops in place of native range, summerfallowing of cereal cropland, and man-made obstacles that trap snow and water and impede drainage. To alleviate the salinity problems, excess water must be prevented from entering the land, if possible, or the excess water and salt must be removed from the affected area through drainage, leaching, and cultural practices.

The area of land under irrigation is a small portion of the arable land in the prairies, but its production is high. For instance, in Alberta, less than 4% of the arable land is under irrigation but it produces about 20% of the agricultural products. Because this land is so important, this publication is concerned mainly with salinity problems on irrigated land. However, many of the same principles can be applied to nonirrigated land.

Description of salt-affected soils

The main salts in western Canadian soils are calcium sulfate (gypsum), magnesium sulfate (Epsom salts), sodium sulfate (Glauber's salt), and potassium sulfate. Small amounts of bicarbonates and chlorides are usually combined with these salts, which may be present in varying amounts.

Calcium carbonate (lime) is often present near the soil surface and exposed on knolls. It is not harmful as a salt but it may make some nutrients less available to plants.

During wet periods, the water table may rise and cause the salinity to increase. During dry periods, the water table falls and movement of salts to the surface stops when the water table exceeds a critical depth. Any rain that falls tends to leach the salt downward. The effect of the salts is seen in crop response, but the amount of salts in a soil is determined only by a soil test.

Crop response, type of vegetation growing in the area, salt flecks in the soil, and salt crusts on the land are all indicators of soil salinity. Salt crusts may be visible during the growing season as well as in early spring after an open, dry winter. The visible salts are a minor fraction of the total in the soil.

Saline soils

Saline soils are the most common type of salt-affected soils and are usually the easiest to reclaim. They are nonsodic but contain sufficient quantities of other soluble salts to impair productivity. The electrical conductivity (EC) of the saturation extract (which is used to estimate the soluble salt content in soil) is greater than 2 mS/cm at 25°C. The soils range from neutral to slightly alkaline. Their structure is generally good, and their tillage characteristics and permeability to water are similar to those of nonsaline soils. Saline soils are recognizable by spotty growth of crops and often by white crusts of salt on the soil surface (Fig. 1). When saline soils are in an early stage of development, before the white crust appears, salt flecks can often be detected in the surface soil, and crops with some salt tolerance may grow vigorously because water is abundant. Most crops grown in the prairies have some salt tolerance, and productivity is not impaired by a small amount of salinity. Plants affected by soil salinity often have a blue green tinge.

Saline–sodic soils

Saline–sodic soils contain a combination of soluble salts and exchangeable sodium that is sufficient to interfere with the growth of most crop plants (Fig. 2). The saturation extract has an EC greater than 2 mS/cm at 25°C and a sodium adsorption ratio (SAR, a relation between the soluble sodium and divalent cations used to predict the exchangeable sodium of the soil) greater than 13. The soils are alkaline but the pH of the saturated soil paste is usually 8.5 or less. In Western Canada, saline–sodic soils are the most common where salt effects are serious. These soils do not puddle when they are leached after drainage, and so they remain permeable. The high content of lime and gypsum in the subsoil prevents dispersion of the sodium-bearing clay particles.

Sodic soils

Sodic soils contain sufficient exchangeable sodium to interfere with the growth of most crop plants. They have a high sodium adsorption ratio, greater than 13, and a low salt content. They are strongly alkaline, and the pH of the saturated soil paste often exceeds 8.5. Sodic soils may overlie a somewhat impermeable hardpan and include the blowout or Solonetzic soils, which have poor structure. There are millions of hectares of sodic soils in Western Canada, usually mixed with nonsodic soils. Their effect on productivity depends on the proportion of sodic soils in the soil complexes.

Causes of soil salinity

The main cause of salinity is excess water, which dissolves, transports, and concentrates salts in the soil. Most soils in the arid climatic zones of the Prairie Provinces contain soluble salts, but usually not in sufficient quantities to interfere with plant growth. However, when excess water percolates through the soil, it can dissolve, transport, and concentrate the salt into small areas downslope and cause the soil there to become saline.

Water in excess of crop use, whether it comes from seepage, too much irrigation, mismanagement, or precipitation, raises the level of the water table or flows down a slope and raises the level of the water table in the lower area (Fig. 3). When the water table rises to within 90–150 cm of the soil surface, the net rate of water movement to the surface by capillary action, carrying dissolved salts with it (Fig. 4), may exceed the downward flow. At the surface, the water evaporates and the salts accumulate and salinize the soil. Furthermore, as the roots draw water from the soil, more water, carrying salts in solution, moves up to replace it. Thus, salts also tend to be concentrated in the root zone. To reclaim these soils, the salts must be washed downward, as well as from the surface soil. The salts visible at the soil surface are usually only a small fraction of those in the soil profile.

Most river water used for irrigation in the Prairie Provinces contains some salts, which may contribute to salinity. Water from wells or natural ponds often contains harmful amounts of salts, particularly sodium, and should be tested to determine its suitability for irrigation. However, salts that cause soil salinity originate mainly in the soil itself; these salts are carried by water to the problem area, where they become concentrated through evapotranspiration.

On several irrigation projects, most of the salts originally present in the upper 180 cm of soil have moved downward after about 5 years of irrigation. This applies particularly to soils whose sodium adsorption ratio is low. Where the sodium adsorption ratio in the original soils was high, the lands have often become salt-affected and waterlogged. Many saline–sodic soils are in this category. As a result of research, lands for irrigation are now being selected carefully. A complete survey of soil salinity and drainage is required before the land is approved for irrigation.

Sources of excess water

Seepage from canals (Fig. 5) is an important cause of salinization and waterlogging of land in irrigation districts. In Alberta, about 70% of the salinized and waterlogged land is a result of seepage. Canals constructed in sandy soils generally seep, as do canals constructed above ground level. Also, weedy, dirty, and poorly maintained canals slow down the flow of water, which builds up a head of water in the canals and thus promotes seepage.

Overirrigation and ponding of water also make the land become salinized and waterlogged. The soil has a limited capacity to hold water, and when too much water accumulates because of overirrigation or ponding, it percolates through the soil below the root zone and builds up a water table.

The source of excess water, whether it comes from canal seepage, overirrigation, ponding, or another cause, is usually located outside the affected area itself. Water from the source enters the groundwater system and flows laterally, dissolving salts on the way; it then reemerges downslope to salinize and waterlog the soil. Also, water from runoff can accumulate in depressions, causing waterlogging and salinization of the soil. Consequently, everyone in the irrigation district must manage water supplies with care, because mismanagement upslope can damage lands downslope.

Occasionally, water from artesian sources contributes to the excess water, but this source is rare on the prairies. Where it does occur, drainage is the only solution.

Groundwater control

Canal seepage can be controlled by lining the canal or by relocating or rebuilding it. Removing weeds and debris may also alleviate the problem. Because lining is expensive, it is added only when absolutely necessary. Of the several linings used, concrete is the most common. It is expensive to install, but maintenance costs are usually low and it has a long lifetime of service. Concrete-lined canals have several advantages: they tolerate high water velocities, which eliminates the need for drop structures; they have a low resistance to flow, which enhances water movement; they cover a smaller area than conventional earth canals; and they do not provide good conditions for weed growth. The recent development of rotary excavators (Fig. 6), which dig a canal to the required shape, and of slip forms (Fig. 7), which lay concrete in place without forms, has greatly reduced the labor and cost of installing concrete linings. Concrete linings in southern Alberta have recently been extensively damaged during the winter.

Other linings used include plastic (Fig. 8), asphalt membranes, asphalt cement, Butyl rubber, clay, and chemicals. Of these, plastic has been used most often in the prairies. The cost of installation is lower than that of concrete, but it has several disadvantages. Plastics deteriorate when exposed to ultraviolet light, and they therefore must be buried to prolong their life. When buried, the plastic can last for several decades. To keep the overburden from slipping off the plastic, the side slope of the banks should be at a ratio of at least three to one; hence, plastic-lined canals require much more area than concrete-lined canals. Also, the canal grade must be carefully controlled so that the overburden does not erode and the canal does not become filled with silt. The overburden provides an excellent medium for weed growth, and, because the plastic is under it, mechanical methods of weed control can damage the linings. The plastic is easily damaged by plant roots, rodents, and large animals.

Asphalt membranes have many of the properties of plastic but are not as suitable for lining canals. Asphalt cement, clay lining, and chemicals are not entirely satisfactory. Clay lining has been used successfully in some areas, but because of soil and climatic conditions, it has not been successful in the prairies. Chemicals have been used to stop seepage in ponds or dugouts, but they are not recommended in systems with flowing water. Butyl rubber has been used with good results; it is expensive to install but the maintenance costs are fairly low.

At the Lethbridge Research Station, an asphalt lining has been developed in the laboratory by mixing anionic asphalt emulsion, bentonite, and an enzymatic wetting agent with soil. This membrane has proved satisfactory in the laboratory and in 6 years of field testing. If it can be used successfully in the field, it should be similar to concrete in performance but lower in cost. A soil–cement lining has been developed that needs field testing. Other materials, such as fiber glass–resin panels, are being tested by the Alberta Department of Agriculture.

Relocating canals and rebuilding them in less porous material has sometimes been successful in eliminating seepage. Also, removing weeds and debris from canals can reduce or eliminate seepage.

Overirrigation and ponding, resulting in the application of too much water, are usually caused by carelessness, such as leaving a setting for too long or using too great a length of run. If the length of run is too great, too much water is applied at the upper end of the field before the lower end receives enough. For flooding, the land should be leveled to permit good water control, distribution, and drainage, and the length of run should vary according to the soil. On sandy soils, runs should be short, about 90 m, whereas on fine-textured soils they can be increased to about

257 m. With sprinkler irrigation, the amount of water applied can be controlled by the length of time the sprinklers are turned on. Where possible, excess water that may pond should be removed by surface drainage or pumped back on the land as irrigation.

Generally, sandy soils, loams, and clay loams retain about 2.5, 3.6, and 3.8 cm of plant-available water, respectively, in 30 cm of soil. Thus, sandy soils require more frequent and lighter irrigation than fine-textured soils. With flooding methods, it is difficult to apply less than 5 cm of water in one irrigation. In hot weather, when moisture consumption by the plants is high, most crops use more than 0.9 cm of water a day. In cool weather, the consumption is lower. Also, the moisture consumption varies with the season and the crop. The greatest consumption is usually in midseason, when the temperature is high and the crop is in a stage of rapid vegetative growth. Cereals usually require less water than forage crops and sugar beets. Thus, the frequency and amount of irrigation are determined not only by soil texture but also by season, crop, and stage of growth. When it is impractical and uneconomical to control the sources of excess water and to maintain natural drainage systems, artificial drainage is necessary.

Drainage

To reclaim a waterlogged, salt-affected soil, some basic steps are required. First, the water table must be lowered; second, the excess salts must be leached out; and third, where the sodium content of the soil is high, the sodium must be replaced with a more desirable cation, such as calcium. In the Prairie Provinces, there is usually enough calcium in the soil to replace the sodium.

The need for drainage may not be evident in the early stages of waterlogging. A high water table, poor plant growth, death of trees, encroachment and rank growth of salt-tolerant weeds, and plant root diseases can be early signs of the need for subsurface drainage. An early indicater is above-normal rankness of crops.

Drainage investigations

Four main factors should be considered in making a drainage investigation — topography, soil, slope and nature of the water table, and water source. Each of these factors is important. An intelligent analysis of all factors should result in a practical solution. Any existing information should be collected and reviewed before proceeding with a detailed field investigation.

First, study the topography of the area visually. Aerial photographs, if available, often provide valuable information. A topographic survey is often necessary, unless the problem can be solved readily.

Study the soils to determine the character of the soil profile to a depth of at least 300 cm. Soil variation within the problem area should also be studied. The ability of the various subsoil layers to transmit water (hydraulic conductivity) dictates the type and design of drainage system needed.

Observing the position of the water table and its fluctuations (Fig. 9) for at least one irrigation season provides valuable information for the design of the drainage system. Auger holes, small cased observation wells, or piezometers are used to observe the height of the water table and establish the direction and velocity of flow. Drainage is often more effective and less costly if the damaging water is intercepted before it reaches the problem area.

A survey of the water source often suggests ways of reducing the flow. When the origin of the water is known, the quantity to be drained can be estimated. The salinity of the groundwater must also be determined before the problem can be solved.

Location of drains

Excess water may be removed by relief drains that lead the water away from the problem area or by interceptor drains that collect and divert water before it reaches the area. Open drains, subsurface drains, or pumped wells can be used for these purposes. Relief drains are used where the land has little or no slope, and interceptor drains where the topography is irregular.

For perched water tables, relief drains are satisfactory, but an interceptor drain may also be needed. Lateral groundwater flow is influenced by soil stratification and other natural soil characteristics. Interceptor drains may be used to cut off the lateral seepage before it reaches the surface.

In designing a drainage system, proper placement of the drains is important. The problem of draining irrigated lands is more one of location than of spacing. In soils that vary within the profile, consider the nature and extent of the subsoil layers. Generally, drains should be oriented at right angles to the direction of groundwater flow and, where possible, they should be placed in permeable layers. In soils of alluvial origin, the orientation of permeable and impermeable materials may be such that a few well-placed drains may control the water table better than more drains spaced uniformly.

FIG. 1 Sparse growth is a result of moderate amounts of salts. The area was later reclaimed by pump drainage and leaching.

FIG. 2 Severely affected saline–sodic soil. Growth is mainly salt-tolerant weeds.

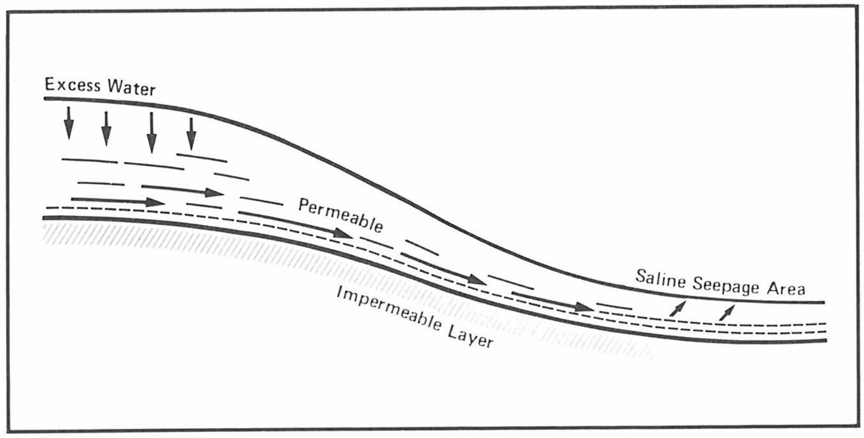

FIG. 3 Lateral seepage on an impermeable subsoil.

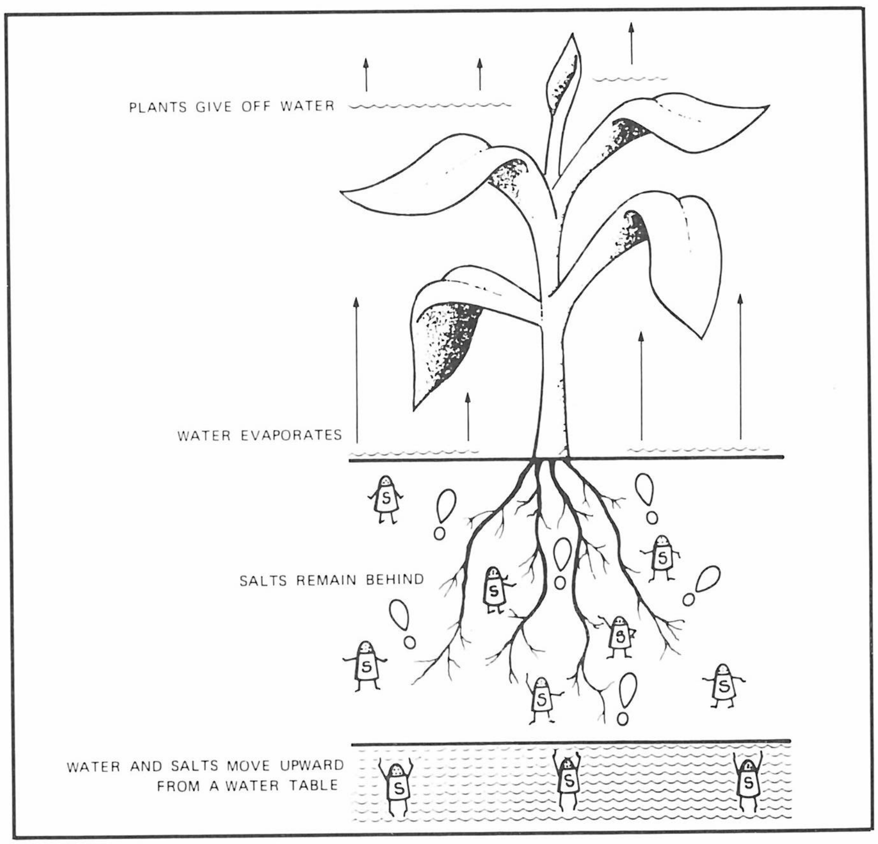

FIG. 4 Movements of salts to the root zone and soil surface from a water table by capillary action.

FIG. 5 Damage caused by seepage from canal.

FIG. 6 Rotary excavator used for excavating and shaping the canal to prepare it for concrete lining.

FIG. 7 Slip form used to install concrete lining.

FIG. 8 Installing plastic lining.

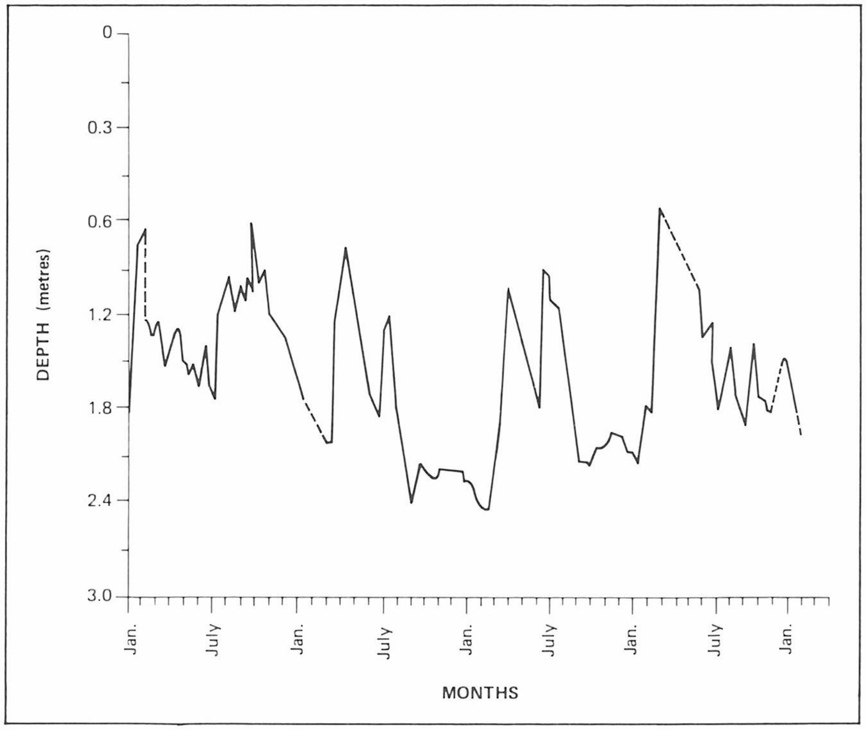

FIG. 9 Water-table hydrograph showing the position of the water table and its fluctuations.

FIG. 10 Open-channel drain constructed by dragline. Note the salt deposits and water-table line on the right side.

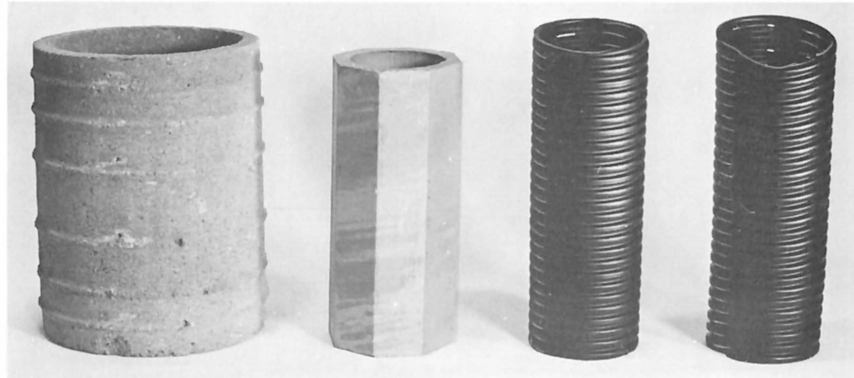

FIG. 11 Drain materials commonly used for subsurface drains. *Left to right:* concrete tile, clay tile, corrugated plastic drain tubing with slits, and corrugated plastic drain tubing with holes.

FIG. 12 Corrugated plastic drain tubing in rolls.

FIG. 13 Plow used for forming mole drains.

FIG. 14 Wheel trencher for installing subsurface drains.

FIG. 15 Chain trencher for installing subsurface drains.

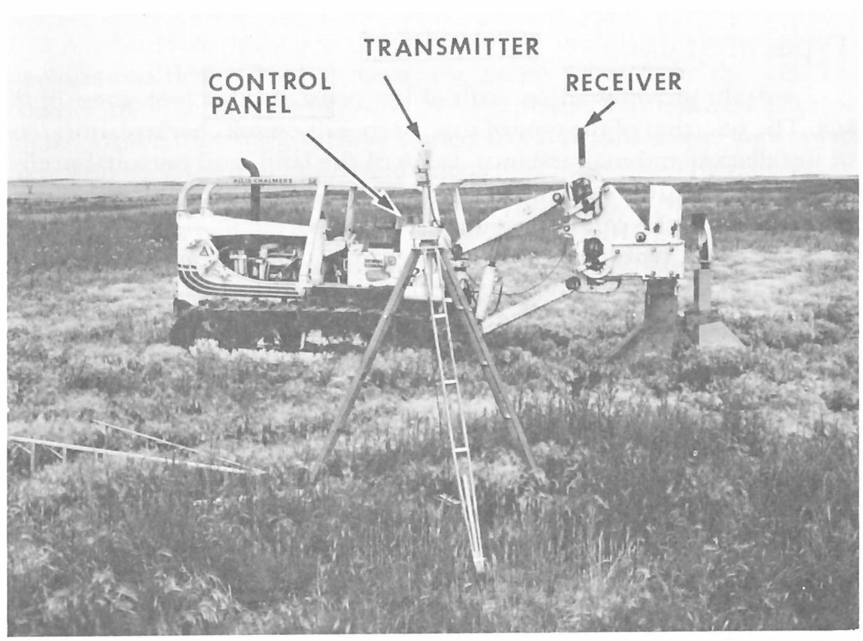

FIG. 16 Trenchless plow for installing subsurface drains, also showing laser transmitter, receiver, and control panel used for grade control of the drain.

FIG. 17 A dragline is used to lay tile drain under adverse conditions.

Types of drains

A drain provides a flow path of low resistance for free water in the soil. The selection of the type of drain depends on soil characteristics, cost of installation and maintenance, value of the land, and personal preference. Some features of construction and uses are unique to irrigated regions and to the conditions in specific areas.

The main types are open-channel (or surface) drains, covered (or subsurface) drains, and pumped wells.

Open-channel drains

Open-channel, or surface, drains (Fig. 10), called drainage ditches, are used as interceptor drains in stratified soils to remove and dispose of excess surface water. They are the most economical means of removing large quantities of surface water rapidly and they often minimize the need for costlier subsurface drainage.

Although their main function is to handle surface drainage, open drains may be used to lower the water table and provide internal drainage. Where subsurface drains are uneconomical or physically impossible to install, as in heavy clay soil or in locations with a nearly flat topography, open drains may be the only practical means of draining the land. Where the depth is sufficient and other conditions are suitable, open ditches also serve as outlets for subsurface drainage systems.

One of the main disadvantages of open drains is that they occupy land that might otherwise be farmed. Open ditches across cultivated fields obstruct farming operations. In pastures, open drains may be a danger to livestock. They are more costly to maintain than subsurface drains.

Open drains are usually constructed with the use of large power-driven draglines, backhoes, power shovels, or clamshells. Blade graders, elevating graders, scrapers, and bulldozers can also be used. The cost of construction varies with the material excavated, the size of equipment, and the size of the drain. An estimate of cost may be obtained from an experienced ditching contractor.

Drains cannot provide efficient drainage if they are obstructed by brush or weeds, or if their banks have collapsed so that they are partly filled with silt. Clean out the obstructed drains to their original depth as needed.

Machines have been developed for ditch cleaning, but generally the best method is to use the same machinery as was used in the original construction. Brush and weeds can sometimes be controlled more effectively by burning and herbicides than by machine cleaning.

Preventive measures are often cheaper than corrective measures and may delay the need for maintenance.

Subsurface drains

A subsurface drain is any type of buried conduit with open joints or perforations that collects and conveys excess water from the soil. The conduit may be made of clay, concrete, plastic, bituminized fiber, or metal. Other materials, such as buried trees, brush, straw, and gravel, have also been used to improve drainage.

If they have been properly installed, subsurface drains need little maintenance. They are often preferable to open drains because they do not remove land from cultivation or interfere with farm operations. However, they are usually more expensive to install than open drains, and in some cases, such as in impermeable soils, they may not be effective.

Clay and concrete tile have been widely used for subsurface drainage (Fig. 11). Clay tiles are usually available in 30- and 60-cm lengths and have an inside diameter of 10–25 cm. Water enters the tiles at the butt joints, or spaces between adjacent sections. Concrete tile is available in diameters larger than 25 cm. Where sulfate salts are present in the soil and concrete tile is to be used, the tile should be made with sulfate-resistant cement. Clay tile is not affected by sulfate salts. Both types of tile may have fitted ends and be perforated for easier entry of water. All drain tile should meet standard specifications.

Perforated plastic drain tubing is manufactured mainly from polyethylene and has corrugated walls for increased strength and flexibility. For agricultural use, perforated tubing is available in 8- to

30-cm diameters. The smaller diameters, up to 15 cm, are available in rolls (Fig. 12); the large diameters are available in lengths for easy handling and installation. The small-diameter tubing can also be obtained with filter wrap or installed with concentric envelope placement. Filters or envelope materials may be needed for unstable sandy and silty soils.

Water enters the drain tube through perforations, either sawed slits or punched holes, spaced uniformly in the bottoms of the corrugations around and along the tube. Plastic drain tubing is light, and although it is bulky, can be handled easily; a 75-m coil of 10-cm tubing weighs 32 kg. Because the tubing is flexible and is laid in continuous lengths, it is particularly suitable for draining unstable soils such as sands and organic soils, and it does not shift out of alignment as readily as tile drains sometimes do.

Bituminous-fiber or tar-impregnated pipe, perforated for drainage purposes, is suitable where surface loads are heavy. Corrugated metal pipe is used in special locations, such as under high embankments or roadways. Culvert pipe of small diameter is also used for outlets on the end of tile drains.

Mole drains, which are channels left by a bullet-shaped device (Fig. 13) pulled through the soil, have been used successfully in some cases. For best results, the mole drains should be installed in soil that has a fairly high clay content and is wet enough to be cohesive so that it forms channels as the moling device passes through. Plastic-lined moles have been more successful than unlined moles. Mole drains are cheaper to install than tile or plastic tubing, but their duration of service is variable, ranging from 1 or 2 years to 10 or more, depending on circumstances.

Blind inlets, or French drains, may be useful for removing small amounts of surface water impounded over the drain line. They are constructed by filling a section of tile trench with gravel or crushed rock. Their useful life may be only a few years, but they are economical and easy to replace.

Most subsurface drains in the prairies are installed with a trenching machine (Figs. 14 and 15) or with a trenchless plow (Fig. 16). In some cases, backhoes or draglines are used (Fig. 17).

Sometimes, adverse soil conditions make it impossible to lay tile in a narrow trench. A dragline must then be used to dig a wider trench with sloping sides. Where bedding conditions are especially poor, the drain pipe may have to be placed on wooden cradles, sod, or a thick bed of gravel. Second-grade sewer tile with loose joints or perforated metal pipe are sometimes useful in unstable soils.

Corrugated plastic drains can be installed by the same trenching equipment used for rigid drain pipes. However, because the corrugated plastic tubing is flexible and easy to manage, it is especially adaptable to plow installation or trenchless drainage (Fig. 16). The tubing is available in long rolls and is easy to handle and connect. It can be installed fairly rapidly. Recently, there has been a move to jumbo rolls that incorporate at least 300 m of tubing, adding to the speed and convenience of installation.

The main advantages of plow installation of subsurface drains are speed of installation and elimination of the soil disturbance caused by trenching. The plow-type machine, with a blade similar to that of a mole plow or subsoiler, is pulled through the soil. The plastic tubing is led into the soil directly behind the blade. The machine is usually mounted on a crawler tractor. Most trenchless drainage machines are designed to install corrugated plastic tubing only. With special attachments, gravel envelopes of selected material can be installed.

Manual regulation of the drain depth is difficult, mainly because of the machine's relatively high speed of travel. For this reason, the depth of installation is usually regulated by automatic laser-grade control (transmitting and receiving towers shown in Fig. 16). Most drainage contractors have automatic grade-control equipment on their machines.

After a subsurface drainage system has been installed, a suitable map should be made and filed with the property deed. The map should show the location of all ditches and subsurface drains, as well as tile size, grade, depths, and spacing. Any subsequent change should also be recorded on the map. The record can be valuable to present and future landowners when the drain system needs repair or maintenance.

A subsurface drainage system requires little maintenance if it is properly designed and installed. The outlet ditch should be kept free of sediment. The drain outlet should be protected against erosion and undermining. Sandtraps should be inspected and cleaned out once or twice each year.

If a drain line becomes filled with sediment or roots, uncover the line at some point downstream to locate the obstruction. If the line is not completely clogged and water is available, the sediment can sometimes be flushed out. A suitable plug, swab, or sewer rod can be used to remove the blockage. A high-pressure water jet may be needed to clean out some lines. Often, it is more economical to replace the entire plugged section.

Roots of nearby trees can block subsurface drains. Shrubs and trees, such as willows, poplars, and cottonwoods, growing within 30 m of a tile line should be removed. Where it is impractical to remove the vegetation, install sealed bell and spigot tile, tar-impregnated pipe, or metal pipe. When tile lines become filled with roots, it is best to dig up and replace the clogged sections and remove the troublesome trees at the same time.

Subsurface drainage is becoming a more common practice in Western Canada. The feasibility of shallow drainage and the introduction of plastic drain tubing have made subsurface drainage more economical. In 1979, about 750 km of tubing was installed in Alberta, almost half in irrigated areas. On nonirrigated lands, subsurface drainage is being used for consolidation of sloughs and potholes, reclamation of waterlogged soils, and interception of seepage water.

Where soils are underlain by porous aquifers, it is often possible to lower the water table over large areas by pumping. To find out whether the pumping would be effective, drill test wells and pump them. Determine the area of influence by measuring water levels in adjacent observation wells or piezometers. Spacing, depth, capacity of the pumped wells, and other operational details may be determined from these tests.

Pumped drainage water may be used for irrigation if the quality is acceptable. The value of the water nearly always offsets the pumping costs. Poor-quality water may sometimes be mixed with better quality water to provide a supplemental irrigation supply.

Drainage design

The drainage design is usually site specific. The system to be used depends on whether water is being intercepted or the water table in general is being lowered. Soil characteristics determine depth and spacing. Drains should be placed in pervious soil and as deep as possible. The shallower the drains are installed, the more intense the management must be to reclaim the land and maintain it.

Economics of drainage

With escalating land costs, drainage is becoming more attractive economically. Reclaiming land often costs less than replacing it. The presence of weeds and insects, road damage, and aesthetic values are justifiable reasons for drainage.

Reclamation measures

In any reclamation program, the first essential step is to lower the water table; the next is to remove the salts; and finally, to restore productivity to the land. The best depth for the water table in any given locality varies with the climate, soil characteristics, and type of crops grown. If the water table cannot be maintained at an adequate depth, irrigation and management practices may sometimes be altered to sustain crop production.

Leaching by percolation of water through the soil profile can be done naturally or artificially. Good subsurface drainage is absolutely necessary. Where drainage is inadequate, water that is applied for leaching can cause the water table to rise and can aggravate the salt problem.

Leaching is most effective when it is possible to inundate the entire surface. This may require expensive and extensive land preparation unless the land is flat. Where the land is sloping, use of a contour-dike system or a border-dike system with cross dikes down the slope provides effective leaching at a small percentage of the cost of preparing level basins. It is best to apply the leaching water as successive floodings or rinsings rather than by continuous ponding. Moderately effective leaching can be accomplished through excess irrigation. The leaching can be done whenever it would not interfere with other operations. It is often convenient to leach in the fall, when water is plentiful. Water-table and drainage conditions may be more favorable in the fall than during the regular irrigation season, and because there is less evaporation, a greater proportion of the water can move downward. Good soil and water management is essential after leaching to ensure successful reclamation.

Restoration of productivity often can be achieved by drainage and leaching only. In some cases, amendments such as gypsum, manure, or other forms of organic matter must be added.

Environmental considerations

Drain water is often very saline, especially in the early stages of drainage, and it may contaminate the fresh water into which it is discharged. Usually, the saline water is sufficiently diluted by the fresh water and its effects on water quality are not significant. Several drainage systems discharging into the same body of fresh water can cause problems, because if the salt load is excessive the water will become seriously contaminated.

Facilities for the disposal of saline drain water vary with local conditions. If it is not feasible to dispose of this water in fresh water or through irrigation, it may be possible to discharge it into saline streams and lakes or saline aquifers.

It is sometimes possible to dilute saline drain waters with fresh water and to use the mixture for irrigation. However, the salt can seriously damage the irrigated land and crops. Consequently, this technique should be used only on the advice of an expert. Both the saline and the fresh water must be analyzed to establish the necessary dilution for the saline water. Also, the soil must be studied carefully to determine its suitability for irrigation with poor-quality water. In general, deep, coarse-textured soils are more suitable than fine-textured soils for irrigation with poor-quality water. Furthermore, some crops are more tolerant of salts than others (see Table 1).

Effects of excess salts and water on plants

The more salts that are in the soil water, the more difficult it is for plants to take up water. Also, very high salt levels are toxic to plants. Salts

Table 1. Tolerance of crops for salts from the late seedling stage (crops are listed in descending order of sensitivity)

Low tolerance	Moderate tolerance	High tolerance
	Field crops	
field beans	flax	barley (six-row)
soybeans	canola	Jerusalem artichokes
peas	mustard	Sugar beets (after establishment)
fababeans	spring wheat	
corn (field)	oats	
	winter wheat	
	sorghum	
	barley (two-row)	
	safflower	
	sunflower	
	Forage crops	
meadow foxtail	orchardgrass	birdsfoot trefoil
red top	creeping foxtail	crested wheatgrass
timothy	cicer milkvetch	western wheatgrass
alsike clover	meadow fescue	intermediate wheatgrass
white dutch clover	reed canarygrass	sweetclover
red clover	alfalfa	tall fescue
		Russian wild ryegrass
		Altai wild ryegrass
		beardless wild ryegrass
		slender wheatgrass
		tall wheatgrass
	Vegetables	
corn (sweet)	peppers	spinach
carrots	potatoes	asparagus
cucumber	cabbage	beets (garden)
radishes	broccoli	
celery	lettuce	
onions	tomatoes	
beans		
peas		

in the soil also remove water from the plant roots by osmosis and cause their cells to collapse (plasmolysis). The presence of some salts reduces the activity of soil microorganisms; this in turn affects the availability of nutrients to plants and alters other characteristics, such as soil structure.

Plants may grow well in moderately saline soil with a high moisture content, because the soil solution is then diluted. When the moisture content of the soil decreases, however, plants may be injured because the salt concentration has increased. When water is added to sodic soils, they often disperse and the infiltration rate and aeration are impaired. These soils often crack when dry, and it is difficult to establish stands of forage and cereals on them. Salt is less injurious in clay or loam soils because their water-holding capacity is higher than that of sandy soils.

Free subsoil water often makes land wholly or partly unproductive, especially where there is a general upward movement of soluble salts. The excess water affects crop production because the roots may be injured by the lack of aeration and by the excess soluble salts. Drainage removes only water that is free to move under the influence of gravity. This water is superfluous and not available to plants.

Salt tolerance of crops

The first evident effect of salinity on crops is delayed seed germination. Emergence is not affected, but further increases in salinity may reduce it. Growth also becomes slower as salinity increases.

The soil should be analyzed for salinity if crop injury from salts is suspected. Commercial and provincial laboratories are designed to make these determinations. Because crop growth is a useful guide, representative soil samples should be taken from areas showing no growth, sparse growth, and adequate growth. Samples should be taken at depths of 0–15, 15–30, and 30–60 cm. For most purposes, the salinity of the soil is determined by measuring the EC of the saturation extract of the soil for salt content; EC is expressed as millisiemens per centimetre at 25°C. The alkalinity (pH) and the sodium adsorption ratio (SAR) are also determined. Soil salinity tests can often be made in conjunction with fertility tests, which are necessary in planning crops and management practices for salt-affected soils. A plant that is drought resistant is often salt tolerant. Slow-growing plants are usually more salt tolerant than fast-growing plants. Also, deep-rooted plants with a low shoot-to-root ratio are more salt tolerant that shallow-rooted plants with a higher shoot-to-root ratio. The salt tolerance of some field, forage, and vegetable crops is given in Table 1. Salt tolerance is based on the ability of a crop to survive on saline soil and on its yield relative to that of the same crop grown on nonsaline soil and under similar growing conditions. Crop yields are not usually decreased by salinity until a threshold level is reached. Beyond this level, the yield usually decreases linearly with increasing salinity. The rate of decrease is greater for some crops than for others. Germinating crops sometimes differ from established crops in their tolerance for salt (Table 2).

Field crops

None of the common field crops grow well on strongly saline soils, but some withstand moderate levels of soil salinity. Six-row barley has the greatest tolerance for salt, but it is sensitive to the excessively wet conditions that often exist on saline soils. Sugar beets and canola are fairly tolerant once the plants are well established, but in the seedling stage they are sensitive to salinity. Rye, wheat, oats, and flax are moderately tolerant if fertility levels are sufficient and if adequate moisture is available during germination. Winter wheat appears to be more salt tolerant than either spring wheat or oats. Beans and peas are very sensitive to soil salinity. For some crops, certain varieties are more salt tolerant than others; for example, six-row barleys are more salt tolerant than two-row barleys.

Forage crops

Forage crops tend to tolerate salt better than most cereals. Because most forage crops are perennials, they shade the soil longer than cereals do. The shade reduces evaporation from the soil surface. The fibrous roots of forage crops improve the physical condition of the soil because they add organic matter to it. Alfalfa, once established, is relatively tolerant and removes a large amount of water from the soil. Unfortunately, grasses that are highly tolerant of salt are not as palatable as those that are not tolerant, but with proper management they can produce satisfactory hay, seed, and grazing.

Table 2. Tolerance of crops for salts at two stages of growth

	Growth stage	
Crop	Germinated	Established
barley	high	high
rye	high	moderate
corn	moderate	low
wheat	moderate	moderate
alfalfa	low	moderate
sugar beets	very low	moderate
beans	very low	very low

Fruit and tree crops

Fruit crops are more sensitive to salinity than field crops. Each variety has an individual salt-tolerance level. Tree crops are also sensitive to salts, especially seedlings and transplants of evergreen and deciduous trees. Even small amounts of salts in the soil have affected the survival of evergreen transplants. Because trees are extremely sensitive, they should be planted only in areas that are comparatively salt-free. If there is any doubt, test the soil.

Managing salt-affected lands

To reduce or correct a salinity problem, the following management practices are recommended:

- Where possible, remove the excess groundwater, either through drainage or by removing the source, such as seepage, overirrigation, or ponding. In some cases, where the water table is not too close to the soil surface, deep-rooted crops that have a high water requirement (such as alfalfa, other forage crops, or sugar beets) may use up some of the excess water.
- Use salt-tolerant crops. This is probably the best method of managing the salt-affected lands, because these areas are often wet. When selecting crops for salt-affected lands, use mixtures of forage crops rather than single varieties.
- Improve surface drainage. Leveling the land prevents the accumulation of water in low areas and thus reduces waterlogging.
- Manage irrigation water properly. Where drainage is adequate, apply enough water to leach salts downward, but avoid overirrigation.
- Apply barnyard manure to saline or sodic spots to improve the soil tilth. Plow under green manure such as sweetclover and alfalfa.
- Seed when moisture conditions are most suitable, especially in nonirrigated areas. Fall seeding is usually recommended to take advantage of spring moisture. Frequent light irrigations, preferably by sprinkler, help to leach salts from the surface and allow seeds to germinate.
- Avoid summerfallowing whenever possible. Fallow encourages the buildup of a water table because the water is not being used.
- Try various fertilizers. Applications of nitrogen and phosphorus are usually effective if salts are not excessive. Nitrogen fertilizers have been beneficial on some Solonetzic soils where moisture was adequate. Test the soil before applying fertilizer.
- Cultivate at the right time. Blowout or Solonetzic soils puddle if they are worked when wet and are difficult to cultivate if they are too dry.

Deep plowing to mix the lime and gypsum with the layers that are high in sodium has been beneficial on these soils.

- Chemical amendments, such as gypsum, lime, and sulfur, are often recommended but have not been beneficial on the prairies in Canada. The subsoils contain adequate quantities of these chemicals.

Glossary

alkaline soil Any soil that has a pH level higher than 7.0.

aquifer A porous, water-bearing geologic formation.

blowout soil A small area of blowout land, usually barren; shallow depressions with a flat or irregular floor (B horizon if Solonetzic soil) consisting of a layer that is resistant to weathering and to water and root penetration.

capillary action The way in which water in the small pores of the soil is elevated and held by surface tension.

dispersion The process whereby compound particles are broken into component particles. For example, sodium tends to disperse clay aggregates into finer particles, which move downward in the soil.

drainage The process of removing excess groundwater or surface water from a soil or area.

electrical conductivity (EC) The measure of conductivity of irrigation or drainage water, or solution extract of the soil. This measurement can be used to estimate the soluble salts in solution, usually expressed in units of millisiemens (mS) per centimetre at 25°C.

evapotranspiration The loss of water from a given area during a specified time by evaporation from the soil surface and by transpiration from the plants.

groundwater Water in the soil below the water table.

hydraulic conductivity The proportionality factor in Darcy's law as applied to the viscous flow of water in the soil; the quality of a soil that enables water to move through it.

infiltration rate The maximum rate at which water enters the soil under specific conditions, including an excess of water.

leaching The process of removing soluble salts from the soil by the passage of water through the soil.

observation well A well for determining the level of a water table. It is usually an open hole cased with a perforated pipe.

percolation The downward movement of water through the soil.

permeability The ease with which gases, liquids, or plant roots penetrate or pass through a soil.

pH The degree of acidity or alkalinity of a soil as determined by means of a glass electrode or other suitable electrode or indicator at a specified soil-to-water ratio; acidity and alkalinity are expressed in terms of the pH scale, where 7.0 is neutrality, lower numbers show increasing acidity, and higher numbers increasing alkalinity.

piezometer An open-ended pipe placed in the soil to measure the water pressure in the soil at the end of the pipe.

plasmolysis Loss of water from within a living cell due to an external cause.

reclamation For saline or alkaline soil, the process of removing excess water, soluble salts, and exchangeable sodium, where necessary.

saline–sodic soil A soil containing a combination of soluble salts and exchangeable sodium sufficient to interfere with the growth of most crop plants. The EC and SAR of the saturation extracts are greater than 2 mS/cm at 25°C and greater than 13, respectively. The pH level is usually 8.5 or less in the saturated soil paste.

saline soil A nonsodic soil containing enough soluble salts to impair its productivity. The EC of the saturation extract is greater than 2 mS/cm at 25°C. The term *white alkali* has often been used in error to indicate a saline soil.

salinization The process of accumulation of salts in soil.

salt-affected soil Soil that has been adversely modified for the growth of most crop plants by the presence of soluble salts, exchangeable sodium, or both.

saturation extract Water extracted from a soil–water mixture, which fills all the spaces between the soil particles.

seepage The slow movement of water into, through, or from soil.

sodic soil A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants; or, a soil in which the SAR of the saturation extract is 13 or more.

sodium adsorption ratio (SAR) A relation between soluble sodium and soluble divalent cations that can be used to predict the exchangeable sodium percentage of the soil equilibrated with a given solution. It is defined as follows: SAR = sodium (milliequivalents/litre)/[calcium + magnesium (milliequivalents/litre)/2]$^{0.5}$.

Solonetzic soil Soil with a thin, friable surface layer underlain by a dark, hard, columnar layer that is usually high in sodium; formed in arid, semiarid, or subhumid climates.

waterlogged A soil condition in which a high water table is detrimental to plant growth because most of the soil air has been replaced by water.

water table The upper surface of groundwater or the level below which the soil is saturated with water; the elevation at which water stands in a hole dug down to the water table. A perched water table is a local water table formed above the main water table and separated from it, usually by a slowly permeable subsoil layer; it may be either temporary or permanent.