Management of saline soils under irrigation

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Gestion des sols salins irrigués.

Preventing and controlling salinity and drainage problems

To reduce problems of soil salinity and drainage
- Maintain clean, weed-free canals.
- Relocate canals in nonseepy lands.
- Line canals to reduce seepage.
- Carefully select lands to be irrigated, giving special attention to the type of soil and topography.
- Provide adequate surface drainage.
- Level the land to prevent ponding, and irrigate properly without applying too much water.
- Use proper cultural methods and special treatments, such as adding manure and organic matter to improve the physical condition of the soil.
- Do not summerfallow.
- Grow salt-tolerant crops and follow fertilizer recommendations.

To reclaim salinized land
- Control the sources of excess water.
- Line canals to reduce seepage.
- Relocate canals onto nonseepy land.
- Provide artificial drainage so that the water table remains below the root zone.
- Leach the salts periodically where the subsurface drainage is adequate.

Management of saline soils under irrigation

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INTRODUCTION

Management of saline soils is a complex, continuing problem in the irrigation districts of Canada. Because many factors are involved, the problems associated with a particular site are usually site-specific. However, there are general principles that apply to soil salinity as a whole. Each year more is learned about the management of saline lands, but the need for new, more effective solutions to the salinity problems in agriculture continues.

Soil salinity occurs mainly in waterlogged, poorly drained soils. Saline and saline-sodic soils, which occur in nonirrigated and irrigated land, contain enough water-soluble salts to affect crop growth. In Alberta, Saskatchewan, and Manitoba, more than 80 000 ha of irrigated lands and 2.5 million ha of nonirrigated lands are saline or saline-sodic.

In the irrigation districts, the main causes of salinization and waterlogging of the land are seepage from canals, poor water management, poor irrigation practices, and inadequate drainage. Under nonirrigated farming, the main causes are the introduction of cereal crops in the place of native range, summerfallowing of cereal cropland, and obstacles of human origin that trap snow and water and impede drainage. To alleviate the salinity problem, excess water must be prevented from entering the land, or the excess water from the affected area must be removed through drainage, followed by leaching to remove the salts and cultural practices that are compatible with the local conditions.

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 about 4% of the arable land is under irrigation, but it produces about 20% of the agricultural products. This publication is concerned mainly with salinity problems on irrigated land because it is so important. However, many of the same principles apply to nonirrigated land.

DESCRIPTION OF SALT-AFFECTED SOILS

The major salts in the soils of western Canada are sodium sulfate, magnesium sulfate, calcium sulfate, and potassium sulfate. Small amounts of chlorides, bicarbonates, and carbonates 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. Because of its limited solubility, calcium carbonate contributes little to soil salinity and is not harmful to plants, but it may make some nutrients less available to plants.

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

Three types of salt-affected soil can be differentiated on the basis of the amount and species of salt present: saline, saline-sodic, and sodic.

Saline soils

Saline soils are common throughout the prairies and are usually the easiest to reclaim. They are nonsodic but contain sufficient quantities of soluble salts to impair productivity. The electrical conductivity (EC) of the saturation extract, which is used to estimate the soluble salt content of the soil, is greater than 4 dS/m at 25°C. (For sensitive crops, growth restrictions may occur at an EC of less than 2.) The soil reaction ranges from near neutral to moderately alkaline. Soil structure is generally good, and 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 on the soil surface (Fig. 1). In the early stages of development, before the white crust appears, salt flecks can often be seen in the surface soil, 0-30 cm deep (Fig. 2), and crops with some salt tolerance may show vigorous growth because of the abundant water associated with salinity. 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. If there is a high water table, the plants may have a yellowish color, and growth could be stunted because of limited aeration as well as salt stress.

Saline-sodic soils

Saline-sodic soils contain a combination of soluble salts and exchangeable sodium in sufficient quantity to interfere with the growth of plants (Fig. 3). The EC of the saturation extract is greater than 4 dS/m at 25°C, and the sodium adsorption ratio (SAR, a relationship between the soluble sodium and divalent cations used to predict the exchangeable sodium of the soil) is 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 very common. Where salt problems are serious the soils are usually saline-sodic. In southern

Fig. 1. Sparse growth is a result of moderate amounts of salts. Reclaimed land is visible in the background.

Fig. 2. Salt flecks (arrows) are visible in the surface 30 cm of soil.

Fig. 3. Severely affected saline-sodic soil. Growth is mainly salt-tolerant weeds.

Alberta these soils generally do not puddle when they are leached after drainage; they usually contain sufficient lime and gypsum to prevent dispersion of the sodium-bearing clay particles.

Sodic soils

Sodic soils are nonsaline and contain sufficient exchangeable sodium to adversely affect crop growth and soil structure. The SAR of the saturation extract is greater than 13, and the pH of the saturated soil paste often exceeds 8.5. Many solonetzic soils are sodic. There are millions of hectares of solonetzic soils in western Canada, usually mixed with nonsodic soils.

CAUSES OF SOIL SALINITY

Salinity can be geological in origin (natural salinity), or it can be caused by humans and their activities (secondary salinity). Secondary salinity and its problems are discussed in this publication. There is generally no practical solution to problems associated with natural salinity.

The main cause of salinity is excess water, which dissolves, transports, and concentrates salts in the soil. Most soils in arid climatic zones of the Prairie Provinces contain a relatively high content of soluble salts but usually not in sufficient quantities to interfere with plant growth. When excess water percolates through the soil, it can either raise the water table and move salts from the subsoil to the surface, where it concentrates as the water evaporates, or it may move downslope to build up a water table elsewhere. In the process it dissolves, transports, and concentrates these salts in small surface areas where the water evaporates and salts are left to accumulate and salinize the soil.

Water that is not used by crops, whether it comes from seepage, too much irrigation, inflow from nonirrigated land (seepage or runoff), mismanagement, or precipitation, raises the water table or flows downslope as groundwater or runoff and raises the water table in the lower area (Fig. 4). When the water table rises to a level that is within 90-150 cm of the soil surface, the net rate of water movement to the surface may exceed the downward flow. At the surface the water evaporates, and salts accumulate and salinize the soil (Fig. 5). Furthermore, as the roots draw water from the soil, more water, carrying salts in solution, moves into the root zone to replace that extracted. Thus, salts also tend to be concentrated in the root zone. To reclaim these soils, the salts must be removed from the surface soil as well as the root zone, usually by leaching. The salts visible at the surface are usually a very small portion of those in the soil profile.

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

On several irrigation projects, 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 is high, e.g., in saline-sodic soil, the lands have often become salt-affected and waterlogged. As a result of research, lands are now being selected carefully. A complete survey of soil salinity is required before new land can be approved for irrigation.

Sources of excess water

Seepage from canals (Fig. 6) is an important cause of waterlogging and salinization of land in the irrigation districts. In Alberta a reported 70 to 80% of the waterlogged saline land is caused by canal seepage. Canals constructed in sandy soils generally seep, as do canals constructed above ground level. Weedy, dirty, and poorly maintained canals slow down the flow of water, which causes a buildup of a head of water in the canals and thus promotes seepage.

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

The source of excess water, whether it be canal seepage, overirrigation, ponding, or another cause, is usually located outside the affected area. Water enters the groundwater system and flows laterally downslope, dissolving salts on the way, to a place where a water table builds up to near the ground surface. There, it waterlogs and salinizes the land. Also, water from runoff can accumulate in depressions, causing waterlogging and salinization of the land. The excess water may be at a single point source, but most often it comes

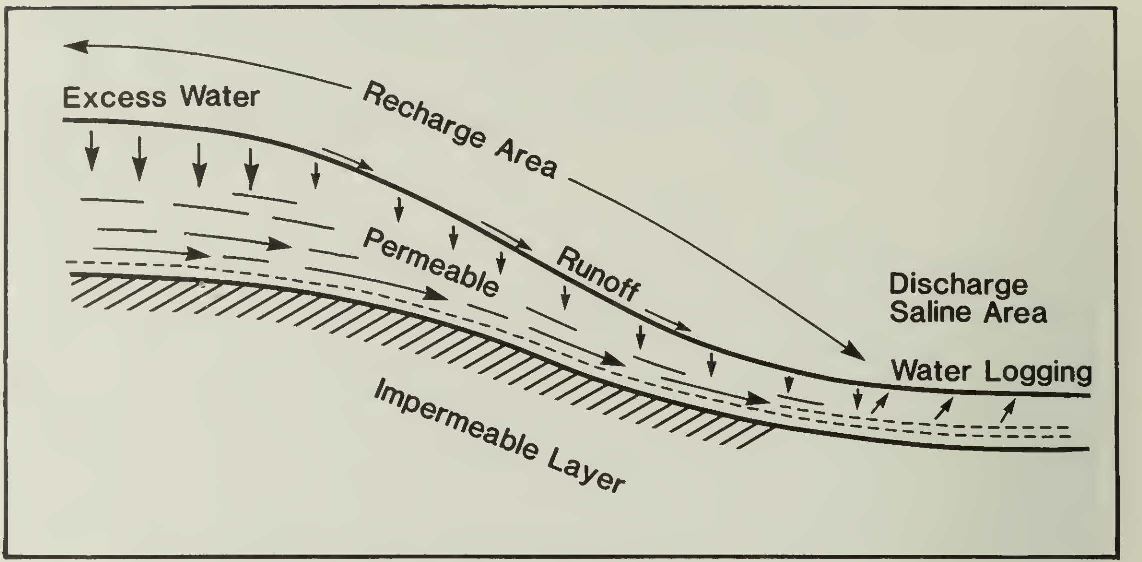

Fig. 4. Lateral seepage on an impermeable subsoil.

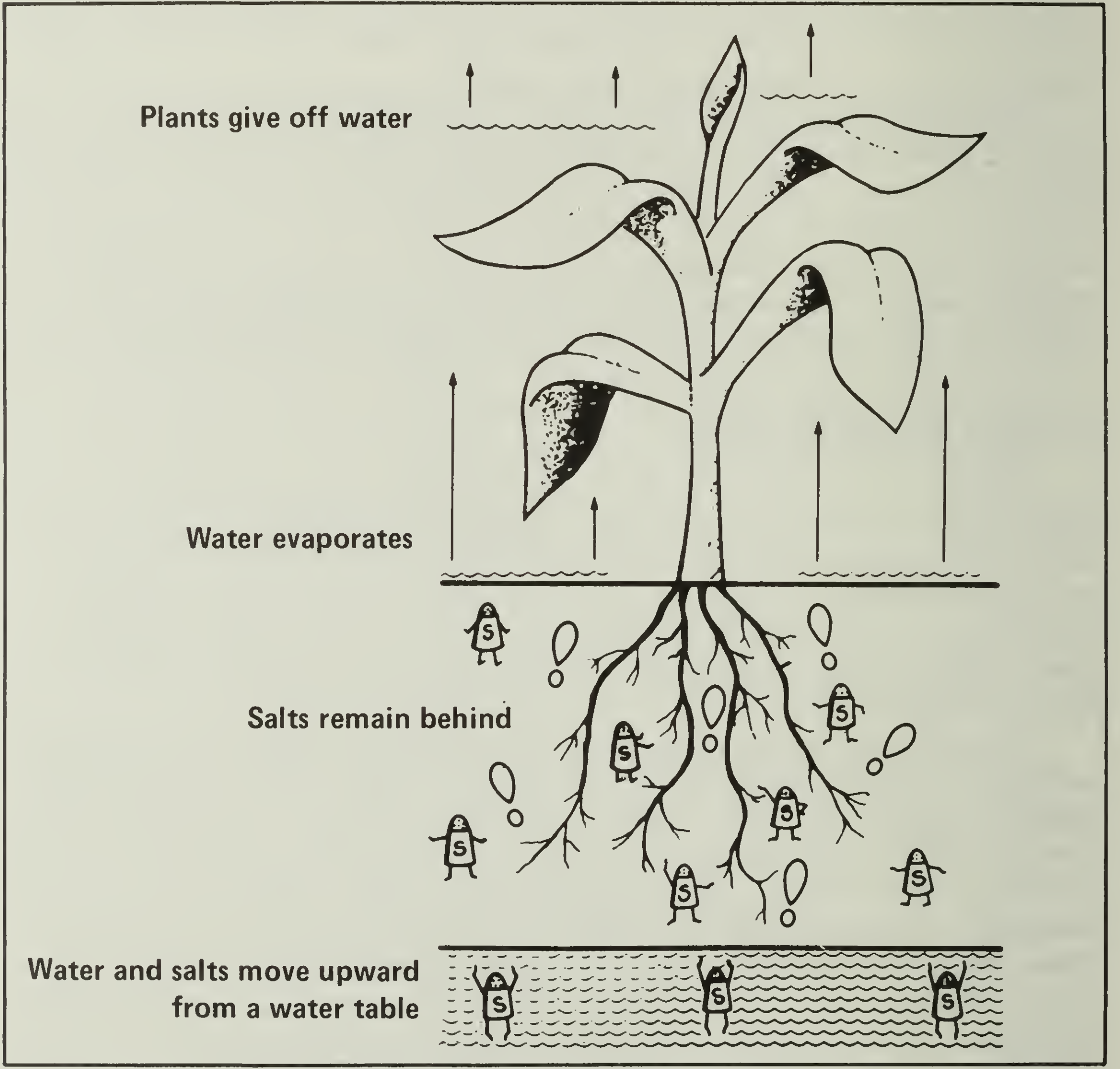

Fig. 5. Movement of salts to the root zone and soil surface from a water table by capillary action.

Fig. 6. Damage caused by seepage from canal.

from a particular area and from more than one source. For instance, there may be waterlogging caused by seepage along a canal, incoming seepage water from nonirrigated land upslope of the irrigated land, or excess water from around the affected area because of mismanagement. Consequently, good water management is everyone's responsibility. Mismanagement upslope can damage land downslope.

Occasionally, water from artesian sources contributes to the excess water. When this occurs, drainage is often the only solution.

RECLAMATION MEASURES

In any reclamation program the first essential step is to identify the source of the problem and decide what must be done to eliminate it. Generally, lowering the water table and removing salts from the soil are the first requirements in the restoration of land productivity. Because canal seepage is the biggest source of waterlogging, which causes salinization of irrigated land on the prairies, it should be eliminated where possible. This may be done by controlling seepage from canals and installing artificial drainage. Suitable cropping practices should be used to minimize the effects of waterlogging and salinity while reclaiming the land. Where seepage control or drainage are not practical, adopting cropping practices adaptable to the conditions can minimize the effects of the problem.

Seepage control

Canal seepage can be controlled by lining, relocating, or rebuilding faulty canals. Removing weeds and debris can also alleviate the problem. Because

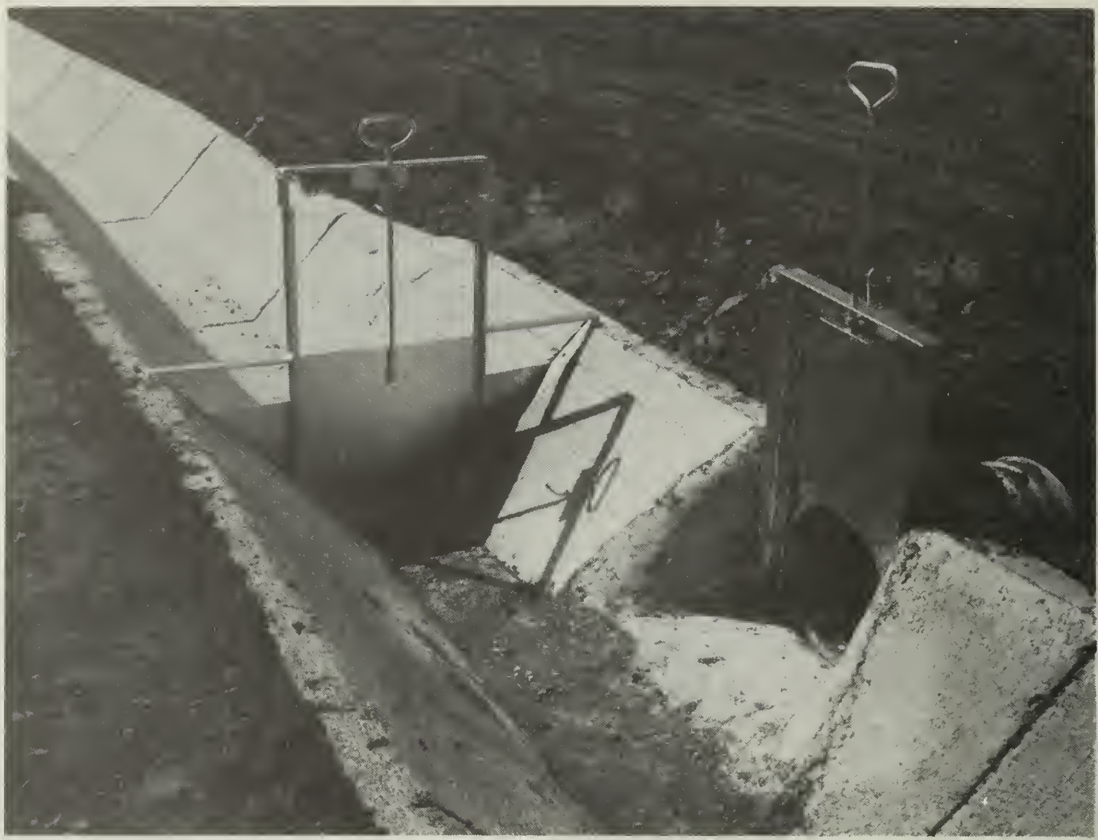

Fig. 7. Concrete lining installed in drainage canal.

Fig. 8. Slip form used to install concrete lining.

Fig. 9. Installing plastic lining, which will be covered with soil for protection.

lining is expensive, it is added only when absolutely necessary. More recently, underground pipe for water conveyance has been used in some situations.

Owing to climatic conditions, most linings have shortcomings. However, hard, smooth-surfaced, exposed canal linings, such as concrete (Fig. 7), have several advantages over conventional earthen canals. They tolerate a high water velocity, which eliminates the need for drop structures, and have a low resistance to flow, which increases water movement. They require less area than the conventional earthen canals, and they restrict weed growth. Although it is expensive to install, concrete has low maintenance costs and a long lifetime of service under ideal conditions. Ideal conditions, however, are rarely found in Canada's Prairie Provinces. Concrete linings in southern Alberta have been damaged extensively during the winter. Considerable research is being undertaken to improve concrete linings, to make them durable in the climatic conditions of the prairies.

The recent introduction of rotary excavators, which dig a canal to the required shape and grade, and of slip forms (Fig. 8), which lay the concrete in place without forms, has greatly reduced the labor and cost of installing concrete linings.

Other linings used include plastic (Fig. 9), asphalt membranes, asphalt cement, Butyl rubber, compacted clay, and chemicals (mostly sodium salts that disperse the clay and seal the soil). Of these, plastic has been used most often on the prairies. The cost of installation is less than that for concrete, but it has several disadvantages. Plastics deteriorate when exposed to ultraviolet light and must therefore be buried to prolong their life. When buried, the plastic can last for decades. To keep the overburden from slumping on the plastic, the slope of the banks should be at a ratio of at least 3:1 (horizontal to vertical); 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 used for weed control can damage the linings. Plastic is also easily damaged by rodents, large animals, and plants.

Asphalt membranes have many of the properties of plastic but are not suitable for lining canals. Asphalt cement, clay linings, and chemicals are not entirely satisfactory. Clay linings have been used successfully in some situations, but because of soil and climatic conditions in southern Alberta they have not always proved successful. More recently, canals have been constructed of ''clay'' (till with a high clay content), by overexcavating the canal by as much as 1 m and then rebuilding it entirely with ''clay''. Chemicals have been used to prevent seepage in ponds and 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 maintenance costs are fairly low.

At Lethbridge, researchers of Agriculture Canada and Alberta Agriculture have been developing and testing several linings, such as soil-asphalt emulsion, soil cement, aluminum panels, fiberglass-resin panels, reinforced concrete, thick plastics, ethylene propylene diene monomer rubber compound, and plastic covered with cement blocks. Some of these are performing well under test and are relatively inexpensive, compared with other materials.

Relocating and rebuilding canals in less porous materials has sometimes been successful in eliminating seepage. Removing weeds and debris from canals can also 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 for surface irrigation. If a run is too long, too much water is applied in the upper end of the field before the lower end receives enough. For surface irrigation, the land should be leveled to permit good water control, distribution, and drainage. 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 as much as 250 m. With sprinkler irrigation, the amount of water applied can be controlled by the length of time that the water is applied. Where possible, excess water that has ponded should be removed by surface drainage or pumped back onto the land.

Drainage

When it is impractical and uneconomical to control the sources of excess water and maintain natural drainage systems, artificial drainage is necessary. Drainage requirements of waterlogged saline lands in the semiarid climate of southern Alberta differ from those of nonsaline lands of the humid regions, where drainage is used to lower the water table so that farming operations are facilitated and a healthy root zone for the crops is provided. For waterlogged saline soils in the prairies, drainage is used not only to lower the water table but also to control salinity, which generally requires greater depth than that required in the humid areas.

To reclaim a waterlogged saline soil, some basic steps are required: the water table must be lowered, the excess salts must be leached out, and, 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 sufficient calcium in the soil to replace the sodium, and the addition of supplemental calcium is not necessary.

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.

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 the water quality are not significant. However, several drainage systems discharging into the same body of fresh water at the same time could cause problems.

Often it is possible to mix drain water with fresh water and use the mixture for irrigation. When using this water for irrigation it should be analyzed to ensure that the quality is suitable. If the water is too saline, or if it contains toxic substances, damage to the soil and crops could result.

Drainage investigations A thorough investigation should be conducted before a drainage system is installed. A suitable drainage outlet should be identified. The soil should be examined to determine its saturated hydraulic conductivity, zones of water transmission, and depth to the impermeable layer. The source of the water and the groundwater characteristics should be established. Also, topography and slope of the land and any other information that may be useful in developing a suitable drainage system should be determined. The drainage system is usually site-specific, as no two sites are alike.

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

Open-channel, or surface, drains are used to intercept water flowing in stratified soils and to remove and dispose of excess surface water. They are often havens for weeds, insects, and diseases and occupy land that might otherwise be used for farming. Open-channel drains across fields can obstruct farming operations and can be a danger to livestock. To perform effectively and efficiently, open-channel drains must be free of weeds, brush, and other debris that could impede the flow of water in them.

A subsurface drain is any kind of buried conduit that collects and conveys excess water from the soil. The most common type of drain material used in the prairies is lightweight, perforated, corrugated, polyethylene tubing. It is easily installed by drainage machines used in the prairies, which include the trenchless plow (Fig. 10), the chain trencher (Fig. 11), and the wheel trencher (Fig. 12). For small and special jobs the backhoe and dragline are often used.

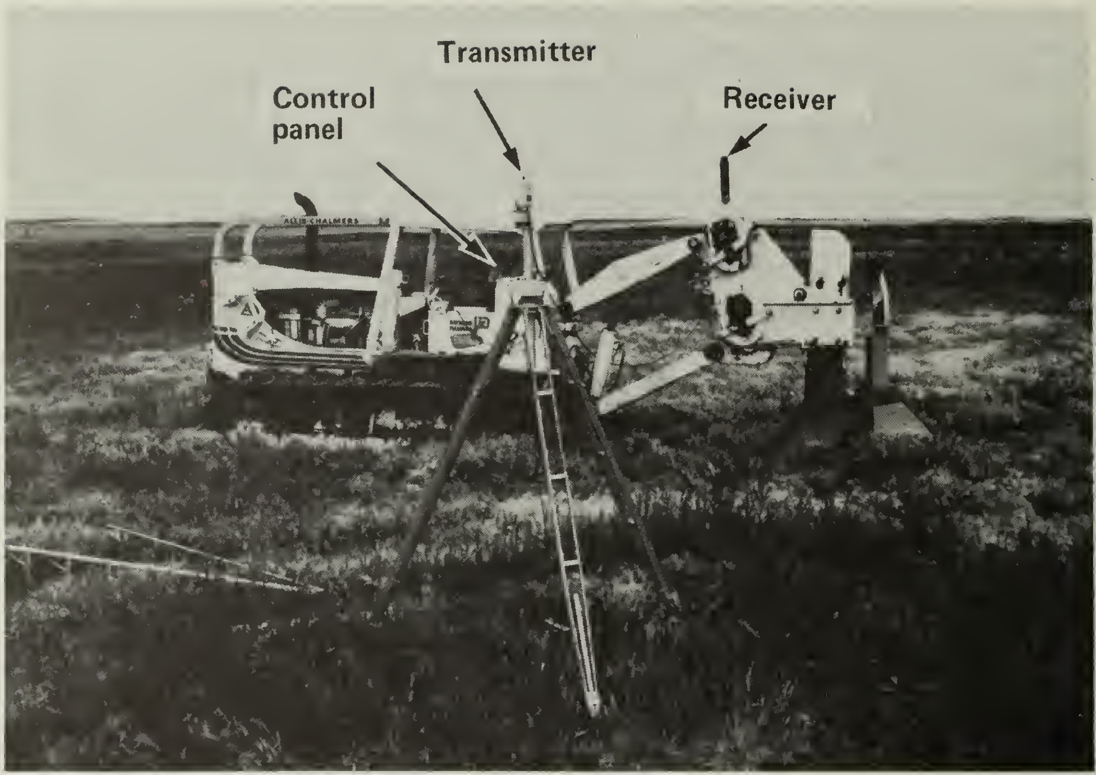

Fig. 10. Trenchless plow for installing subsurface drains, also showing laser transmitter, receiver, and control panel used for grade control of the drain.

The main advantages of installation of subsurface drains with the plow are the speed of installation and the elimination of the severe soil disturbance that occurs when drains are installed with trenchers. Drain depth is controlled with the use of automatic laser-grade control equipment (transmitting and receiving towers shown in Fig. 10).

Mole drainage has performed well in clay loam and fine-textured soils. It consists of a channel (mole) for water drainage, created by pulling a "torpedo" (Fig. 13) through the soil. In fine-textured soils, mole drainage can be used in conjunction with subsurface tube drainage in a bilevel system. The mole is installed at a shallower depth than the tube drains and feeds into the tube drains. This system requires less tube drainage than a single-drain system. Installation of the mole at a depth shallower than the tubes prevents damage to the tubes during installation. If a mole plow is available, installation is fast and inexpensive relative to tube drainage.

Subsurface drainage has advantages in that land containing the drains is not taken out of production. When properly designed and installed, subsurface drains require little maintenance and give years of satisfactory performance. In layered soils, where bridging (water flowing across the drains) is a problem, plastic barriers installed along with the buried interceptor drains have proved to be effective in preventing bridging and directing the water into the drain.

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

Fig. 11. Chain trencher for installing subsurface drains.

Fig. 12. Wheel trencher for installing subsurface drains.

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.

Fig. 13. Plow used for forming mole drains.

Leaching

Salt-affected soil is usually associated with a high water table. Lowering the water table by various methods as mentioned above does not necessarily reduce the soluble salt content in the soil root zone. Removal of the soluble salts from the root zone is required to restore productivity of the soil. Leaching is the only feasible method of reducing the soluble salts in the root zone.

Leaching water is commonly applied by gravity methods, continuous or intermittent ponding, or sprinkler application. Soluble salts move in soil water either by diffusion, convection, or both. Convection is the predominant process for salt movement in the soil, since diffusion is very slow. Therefore, to move excessive amounts of soluble salts from the soil root zone it is necessary to percolate excess water beyond that zone.

If TW is the total water applied as irrigation or precipitation and there is no surface runoff, then the water balance in the soil profile at steady conditions can be expressed as

$$[1] \qquad TW = EV + S + DW$$

where EV is the evapotranspiration, S is the soil storage, and DW is the drainage water from a given soil depth. The soluble salt (TS) balance can be expressed as

$$[2] \qquad TS = SS + TW \times Cw - DW \times Cd$$

where SS is the total soluble salt in the given soil depth, Cw is the soluble salt concentration of the applied water, and Cd is the soluble salt concentration of the drainage water. In southern Alberta, Cw of the precipitation and irrigation water is usually very small and can be ignored for estimating TS. Thus

$$TS = SS - DW \times Cd \qquad [3]$$

where Cd is a function of the solubility of the salts and contact time with the water; the longer the contact time, the higher the Cd will be.

The main objective of reclamation of salt-affected soil is to reduce TS (to a level where there is no significant reduction in crop yield) in the shortest period of time and with the least amount of water. Unfortunately, there is no single solution for reclamation of all salt-affected soils. The most suitable reclamation procedure for a site depends on the specific site conditions. Characteristics such as the type of soil, type and amount of soluble salts, targeted degree of reclamation, and economic, agronomic, and climatic conditions all need to be considered.

Type and amount of soluble salts The type of salts, which are primarily sulfates, chlorides, bicarbonates, and carbonates of sodium, magnesium, and calcium, and the amount of sodium salts relative to calcium and magnesium, determine whether the soil is saline, saline-sodic, or sodic. The reclamation procedures depend on the category of the soil.

For saline soils, removal of the excess water, by eliminating the source or by draining and leaching, is usually all that is required to reclaim the land in southern Alberta. The amount of salt leached from the soil depends on the amount of water applied and on the solubility of salts in the soil. Usually, chloride and bicarbonate salts are more soluble than sulfates and carbonates. Sodium salts are usually more soluble than magnesium salts, which in turn are more soluble than calcium salts. Also, the rate of movement of individual cations is affected by the cation exchange capacity of the soil and by the relative amounts of sodium to calcium plus magnesium adsorbed on the soil. The sodium adsorption ratio is an indication of the relative amounts of sodium and calcium plus magnesium adsorbed by the soil. When the sodium adsorbed by the soil exceeds about 15% of the cation exchange capacity, dispersion of the soil can be anticipated, a condition where the soil pores become plugged and water percolation is restricted.

The rate of salt reduction is most rapid in the beginning stages of reclamation. It is not possible to predict with accuracy the depth of water that must be applied to accomplish the desired reclamation. In general, though, for continuous ponding 70-80% of the soluble salts are removed when a depth of water equal to the depth of soil to be reclaimed is applied. That is, to reduce the salts in the surface 60 cm of soil by 70-80% of the original, one must apply 60 cm of water.

For saline-sodic soils in the prairies, dewatering and leaching are often sufficient for reclamation. These soils generally contain enough calcium salts to replace the sodium in the soil and provide sufficient electrolyte to prevent dispersion of the soil during the leaching. Amendments such as calcium salts, acids and acid-forming salts, organic matter, or other materials that stabilize the soil are not generally required for the reclamation of these soils.

Sodic soils, because of their high sodium content, frequently disperse and seal off during the leaching process of reclamation. In these circumstances the addition of amendments such as gypsum, acid, acidulants, or organic matter is required. Acid and acidulants are most effective in soils that contain precipitated calcium salts.

Soil type

Most salt-affected soils have poor or weak soil structure. Under these soil conditions, the total porosity of fine-textured soils (clay) is generally higher than that of coarse-textured soils (sand). However, coarse soils usually have more large pores than do fine soils, and water often percolates through coarse soils faster than through fine-textured soils. Since solution of a salt is dependent on the contact time of the salt with the water, rapid channel flow of water is not necessarily the best for reclamation of saline land. Usually the most efficient reclamation occurs where the water percolates throughout the whole soil matrix, even though the rate of percolation may be slower than that along large pores.

Intermittent ponding and sprinkler leaching increase the contact time and the drainage period. This encourages flow of water from the smaller pores to drainage and thus increases the leaching efficiency.

Other procedures, such as land leveling and deep tillage to increase the rate of deep percolation of the water, should be used in conjunction with leaching to make the reclamation process more efficient.

Land leveling

Reclamation of salt-affected soils is difficult if the land is not sufficiently level to allow uniform water distribution and infiltration. Leveled and graded land not only provides uniform water distribution but also allows better control of the rate and amount of water application for surface irrigation.

Deep cultivation

Stratified or layered soils such as layers of clay, sand, or hardpan frequently impede or prevent deep percolation of water, which is essential for reclamation. Irrigation to supply crop water demand and salinity control by leaching can be improved if these layers are broken and made more permeable to water. Subsoiling and chiseling are considered to be temporary improvements only and are often short-lived (1-5 years), whereas deep or slip plowing can improve internal drainage for a longer period of time. These are usually done after land leveling and drainage but before any reclamation measures. Deep or slip plowing is costly and usually necessitates growing an annual crop such as barley following the plowing to allow the disturbed soil to settle. Following one or two barley crops, a touch-up land planing to reestablish the proper grade is also usually necessary. In many cases, wind or water-deposited sands are sufficiently stratified and dense that deep plowing or deep chiseling will greatly improve crop response and yield.

In conclusion, there is no universal method used for reclaiming salt-affected soil. After the soil has been studied, a suitable reclamation procedure can be designed.

CROP RESPONSE TO SALINITY

Plants growing under saline conditions exhibit slower growth rates and are therefore more stunted than those growing under nonsaline conditions. Under conditions of moderate salinity, the salt-stress is often not accompanied by any overt symptoms of injury and is only evident by comparison with normal plants. In severe cases, crop growth may be completely inhibited.

Mechanisms of salt stress

Saline conditions impose two general physiological restraints to crop growth: osmotic effects and specific nutritional effects. Salinity greatly reduces the osmotic potential of the soil water, i.e., the potential becomes more negative. Early investigators believed that yield reductions were the result of restricted water uptake or ''physiological drought''. Recent investigations have demonstrated, however, that plants are able to maintain a constant water potential gradient between root and soil solution and thereby retain full turgor despite high external salt concentrations. The negative impact of the low (more negative) osmotic potential, therefore, arises not from the reduced availability of water but from the physiological cost of maintaining a low osmotic potential in the plant. Maintenance of low internal osmotic potential requires considerable expenditure of energy for active salt uptake or the synthesis of organic solutes and results in the potentially deleterious accumulation of solutes.

The soluble salts present in saline soils may also interfere with nutrient uptake and restrict crop growth. In some situations, plants growing under saline conditions may absorb toxic levels of ions such as sodium, chloride, lithium, selenium, bicarbonate, or boron. Conversely, concentrations of certain ions in the soil solution may lead to the deficiency of other ions by creating ion imbalances. For example, high concentrations of sodium or other cations may induce calcium deficiency in plants. In the saline conditions of western Canada, this deficiency may be exacerbated by precipitation of calcium with sulfate, which is the predominant anion in many of these soils.

High concentrations of soluble salts may also indirectly affect crop growth by their influence on biological and physical soil properties. Since soil microorganisms are restricted by soil salinity, microbially mediated processes such as nitrogen fixation, nitrification, residue decomposition, and organic matter mineralization may be inhibited in saline soils. Soil salinity may also increase the susceptibility of crops to some soil-borne pathogens, particularly under conditions of excess moisture, which often accompany salinity. In sodic soils and, to a lesser extent, in saline-sodic soils, plant growth may be severely restricted by deflocculation and the resulting poor soil structure.

Factors affecting crop response to salinity

Crop species and cultivar Crop species vary considerably in their tolerance for salt (Table 1). For example, barley growth will not be appreciably affected until salinity exceeds 8 dS/m, whereas field beans are adversely affected at levels greater than 1 dS/m. It should be emphasized that these critical values vary, depending on many of the factors described later.

Even within crop species, some variability in salt tolerance can be found. For example, studies conducted in western Canada suggest that six-row barley varieties are more salt-tolerant than two-row varieties. This variability offers potential for the development of more salt-tolerant crops through breeding programs.

Table 1. Relative salt tolerance of selected agricultural crops in order of decreasing salinity tolerance within each column

Salinity level (dS/m)	Field crops	Forage crops	Vegetable crops
severe (>8 dS/m)		Altai wild ryegrass Russian wild ryegrass slender wheatgrass tall wheatgrass beardless wild ryegrass salt meadowgrass	
moderate (4-8 dS/m)	sugar beets 6-row barley sunflower safflower 2-row barley oats fall rye wheat mustard flax rapeseed, canola	reed canarygrass meadow fescue intermediate wheatgrass bromegrass crested wheatgrass alfalfa sweetclover	tomatoes lettuce cabbage potatoes peppers spinach asparagus garden beets
slight (<4 dS/m)	soybeans field beans fababeans peas corn	red clover alsike clover timothy	peas beans onions celery radishes cucumbers carrots sweet corn

Note: This table was adapted from Holm and Henry 1982, Understanding Salt-Affected Soils, Plant Industry Branch, Saskatchewan Agriculture, Saskatoon, Sask.

Growth stage Some crops are more susceptible to salt-stress at certain growth stages than at others. Many cereal crops, for example, appear to be more sensitive to salinity during emergence and early seedling growth than during prior or subsequent stages. In contrast, sugar beets and safflower tend to be most sensitive during the germination stage. Frequently, crop yields in saline conditions are severely restricted by poor germination. Usually, this observation is indicative of very high concentrations of salts near the soil surface rather than a reflection of greater sensitivity to salt-stress during germination.

Soil water content The adverse effects of salinity tend to be mitigated by a favorable soil moisture content: the drier the soil is, the greater the concentration of salts in the soil solution and the lower (more negative) the osmotic potential of the soil solution. In essence, the salinity level to which the plant root is exposed is negatively related to the moisture content of the soil. Excessive moisture content, however, is also detrimental to crop growth because of reduced aeration and its interaction with salinity.

Soil fertility Correction of nutrient deficiencies increases yields under saline conditions. There is little evidence to suggest, however, that high nutrient levels can help to overcome the inhibitory effects of salinity. Indeed, the addition of high amounts of nutrients may result in yield declines because of toxicity or increased salinity.

Environmental factors High humidity, by reducing transpiration, tends to increase the salt tolerance of crops, usually to a greater extent in salt-sensitive than in salt-tolerant crops. Similarly, cool temperatures reduce transpiration and increase crop salt tolerance.

CROP MANAGEMENT UNDER SALINE CONDITIONS

The adverse effects of soil salinity on crop growth can be minimized by manipulation of the factors previously described to increase crop tolerance. The most effective method of reducing the effects of salinity is the selection of crops and crop cultivars that can tolerate the level of salinity present. Among the cereal crops, six-row barley is the most salt-tolerant. Other annual field crops that exhibit some salt tolerance are safflower, sunflower, and two-row barley. Under conditions of severe salinity, perennial forages may represent the best alternative. Some of the wheatgrasses and ryegrasses are particularly tolerant of salinity.

Irrigation management practices can be used to alleviate salinity stress to some extent. As the soil dries out, the concentration of salts in the soil solution, and hence the salinity stress, increase. By irrigating more frequently, the soil moisture content can be maintained at a higher level and the osmotic potential of the soil water can be increased. However, overirrigation should be avoided unless suitable drainage is provided, particularly on poorly drained soils. Light irrigations before seeding in spring may help to remove salts from the surface soil layer and increase germination.

Many soil amendments have been suggested for decreasing salinity stress on plants. Most of the chemical amendments suggested, including gypsum, lime, and elemental sulfur, are of little benefit and are not recommended. Organic materials such as barnyard manure, green manure, and crop residues, however, often result in yield increases by improving soil tilth, water penetration, and water retention. Application of fertilizers, particularly phosphorus, may also be beneficial. By increasing yields, fertilizer application may increase the amount of crop residue additions and water consumption, and thereby improve soil conditions. It should be emphasized, however, that fertilizer application will be of benefit only where nutrient deficiencies occur and should be based on prior soil tests. Because of the constraints posed by salt stress, crop response to fertilizers is usually less on saline soils than on nonsaline soils.

Time of seeding may significantly affect crop establishment. Seeding crops early in the season or shortly after a rainfall or irrigation, when salts in the surface soil have been leached downward, improves germination and seedling growth. Forage establishment may be improved by seeding in late fall and taking advantage of spring snowmelt to remove salts from the surface and promote germination. For row crops, germination may be improved by the use of double-row raised planting beds, in which the seeds are placed on the shoulder of the beds, below and away from the zone of highest salt accumulation. Salts tend to accumulate at the highest point. To some extent the reduced seedling germination can be compensated for by increasing the seeding rate. Also, yields and crop performance can be improved by planting salt-tolerant crops.

Tillage should generally be shallow to avoid bringing salts up from depth in conditions where the surface soil layer is somewhat depleted of salts. As much as possible, crop residues should be maintained on the soil surface to minimize evaporation losses. Because some weeds are very salt-tolerant and therefore provide strong competition to crops growing in saline conditions, adequate weed control with herbicides is essential.

PREVENTIVE MANAGEMENT PRACTICES

A number of agronomic measures can be adopted to prevent further salinization of agricultural lands.

- Establishment of appropriate crop rotations. Wherever possible, summerfallowing should be eliminated where salinity appears to be encroaching. Areas susceptible to salinization should be continuously cropped to prevent excessive accumulation of water in the soil profile.
- Perennial forage crops have important roles in crop rotations. Not only are many forages relatively tolerant of salinity, but they help to lower the water table and have a much longer season of active water use than cereal grains.
- Under irrigated conditions, the spread of salinity can be minimized by lining canals, avoiding overirrigation of poorly drained soils, and ensuring that soils to be irrigated have sufficient drainage.

- In a saline seep, the expansion of saline areas can be prevented by the use of interceptor crops. These crops are seeded upslope and in the recharge area of the saline discharge for the purpose of restricting lateral movement of water. Deep-rooted crops such as alfalfa are most effective for this purpose.

GLOSSARY

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 decisiemens per metre 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.

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

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.

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 dS/m 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 dS/m 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, which 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.