The Nature and Management of Salt-Affected Soils in Saskatchewan

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INTRODUCTION

Long before the first agricultural settlement was established large areas of Saskatchewan contained salt-affected soils. In recent years, however, there have been numerous reports of a severe spread of salinity. The problem has been due in part to agricultural practices and, to a certain extent, can be prevented. This bulletin will discuss causes of salt-affected soils, reasons for the spread, and methods for preventing further spread. Improvement of production on salt-affected soils will also be considered.

PART 1: THE NATURE OF THE PROBLEM

SALINE SOILS

It has been estimated that about 2,000,000 hectares (5,000,000 acres) of cultivated land in Saskatchewan are affected by salinity and of this about 400,000 hectares (1,000,000 acres) are severely affected. By far the most common salt-affected soil in the province is the saline type. We have therefore chosen in this bulletin to focus on saline soils, though other types will be discussed.

Properties

Saline soils have a high concentration of soluble salts (those which dissolve in water). The salts present include sodium sulphate, magnesium sulphate, calcium sulphate, sodium chloride, magnesium chloride, calcium chloride and others. In Saskatchewan soils the sulphate salts are most commonly encountered; the salt calcium sulphate is the compound sometimes referred to as gypsum. As we shall explain in the next section, only the soluble salts adversely affect crop growth. Calcium sulphate is less soluble than such salts as sodium sulphate and magnesium sulphate; it therefore does not affect crop growth as much.

Diagnosis of saline soils is fairly easy. On saline soils crops usually grow poorly or not at all. At certain times of the year the salts may precipitate out on the surface of the soil leaving a white crust (Figure 1). By digging in a saline soil it is sometimes possible to see the streaks of salts present even though they may not appear as white crusts on the surface (Figure 2). However, in some saline soils it is not possible to see the salts and soil analysis must be used to confirm their presence.

Vegetation can frequently assist in the diagnosis of saline soil problems. Of the common field weeds Russian thistle, kochia, wild barley and goosefoot species are commonly found in areas of high salt concentration. In uncultivated areas plants such as samphire (*Salicornia rubra*), desert salt grass (*Distichlis stricta*), and greasewood (*Sarobatus vermiculatus*) are frequently dominant species.

Figure 1. Salts often appear as a white crust on the soil surface.

Figure 2. In some cases white crusts are not evident but streaks of salts can be seen within the soil.

Effects of Salt on Plant Growth

The primary effect of salts in saline soils is to deprive plants of water, which contains nutrients essential to plant growth. The dissolved salts in the soil increase the "osmotic pressure" of the soil solution. What happens is that the solution in the soil becomes more concentrated than the sap in the plant roots. This tends to decrease the rate at which water from the soil will enter the roots. If the solution in the soil becomes very saturated, it may actually draw water from the roots. Thus the plants slowly starve, though the supply of water and dissolved nutrients in the soil may be more than adequate. Simply put, the salts prevent the water and the nutrients dissolved in it from entering the plant (Figure 3).

There is another way in which salts dissolved in saline soils can affect plant growth. Some plants – depending on environmental and other conditions – may be adversely affected by certain elements, such as sodium. Thus, if toxic quantities of an element are taken up, growth could be retarded or the plant may die. In Saskatchewan, however, this does not appear to be a major cause for concern. In this province we are dealing primarily with a problem involving a high concentration of total salts.

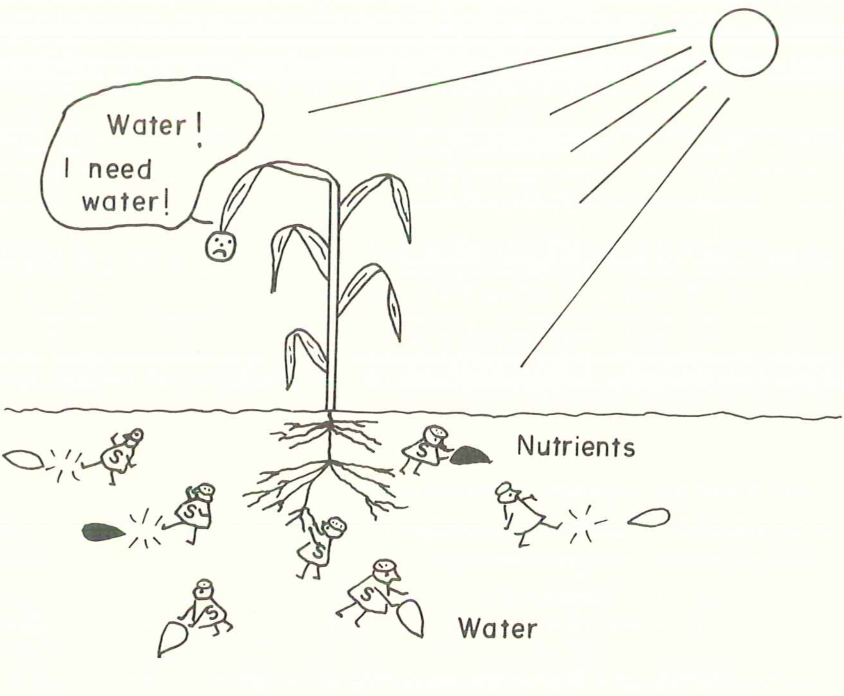


Figure 3. The presence of salt in the soil makes it difficult for crops to take up water and nutrients.

Sources of Salts

Weathering of Rocks and Minerals: Over a period of time salts contained in rocks and minerals are gradually released into the soil by chemical and physical weathering. It is important to realize, however, that weathering alone seldom produces a soil salinity problem. This will be explained in more detail in the section "Groundwater Effects".

Evaporation of Ancient Seas: Millions of years ago large areas of the province lay submerged under an immense sea. Gradually the sea evaporated, leaving marine shales with high concentrations of sodium salts. Then the glaciers came and these, too, eventually disappeared, depositing as they melted the materials that formed our soils. In some areas, where glacial deposits were relatively shallow, the underlying marine shales became mixed in with the surface deposits. In these areas the total supply of salts is large and the threat of salinity and other salt-related problems is very great.

Irrigation Water: All irrigation water contains some salt. Over an extended period of irrigation salts will accumulate in the soil and a salinity problem may develop. It may then become necessary to flush out these accumulated salts by applying excess water. Water being used in major irrigation projects in Saskatchewan is of very high quality and little risk of salt buildup is likely. However, farmers considering the development of small irrigation systems utilizing sources of water such as ponds, sloughs or groundwater may face problems. Any water source for irrigation should be analyzed to make certain that it will not result in a rather quick buildup of salts.

Development of Saline Soils

The term "development" refers to the way in which salts accumulate in the soil. To the obvious question, "How did the saline soil in my area develop?" there is no simple answer. A number of processes, all of them closely interrelated, were probably responsible.

Groundwater Effects: When drainage is good, any salts formed by the weathering process are washed down through the soil and out of the root zone (Figure 4). When drainage is restricted, however, the salts meet a quite different fate (Figure 4). Under these conditions the water table rises. At a certain point it rises so high that the water, moving upwards by capillary action, reaches the surface. This water, which contains the dissolved salts, gradually evaporates and the salts are left on the surface.

The rate of evaporation is determined by the temperature, humidity, and wind. During dry hot periods evaporation is quite high and the salts can concentrate at the surface very rapidly. As the salt builds up on the surface, however, the rate of evaporation slows down, due to the attraction of salt particles for water. Thus these areas of high salt concentration tend to stay wet for long periods of the year. Very often these areas begin as small wet patches in a field and then spread to take up larger areas.

This whole process of salt buildup is reduced to some degree by the presence of plants, which take in water through their roots and therefore reduce the amount of water that reaches the surface of the

Figure 4a. Where natural drainage is adequate salts are removed from the root zone.

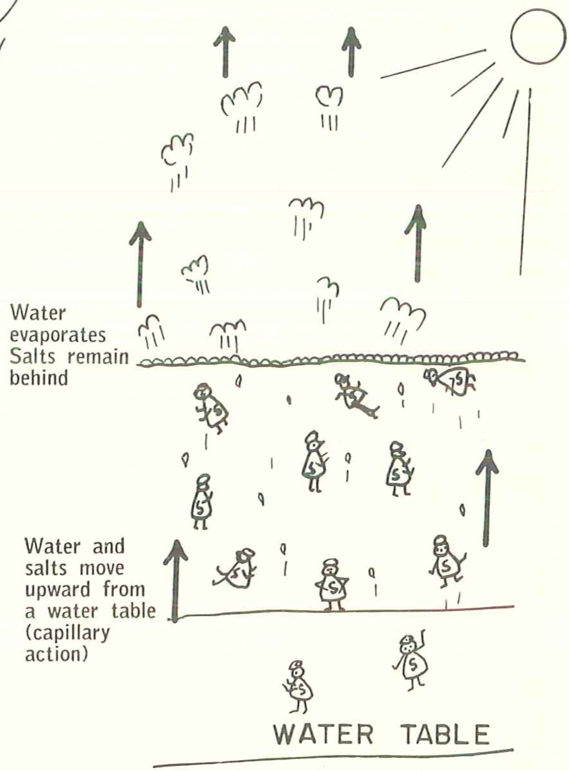


Figure 4b. Salts build up in a soil where internal drainage is not adequate and a shallow water table exists.

soil. When no plants are present, as during summerfallow, almost all of the water loss takes place at the surface of the soil. The salt concentration thus builds up rapidly during summerfallow and later interferes with germination and establishment of plants.

Water is the key to development of saline soils. Areas adjacent to natural sloughs and waterways are often affected by excess salt. Artificial ponding due to road construction, dugouts, or any construction which interferes with normal drainage patterns can cause the water table in the area affected to rise, resulting in the development of salinity.

Saline Seep: The groundwater effects described above account for the development of salinity in the vicinity of sloughs and poorly drained areas. It has been frequently observed that salinity also occurs in upper slope positions, often halfway up the slope on very long and high hills. To adequately explain why this happens it is necessary to consider the process known as "saline seep".

Typically what happens is that rainwater falls on the upslope position ("recharge area") and moves down through the soil, picking up salts on the way. The water that is not used up by the crop growing in the area continues to move down until it reaches an impermeable layer, which impedes its progress. It then flows laterally (seeps) until it reaches a position lower down the slope ("discharge area") where the water table is closer to the surface. There it causes the water table to rise to a critical level — from which the salt-laden water reaches the surface

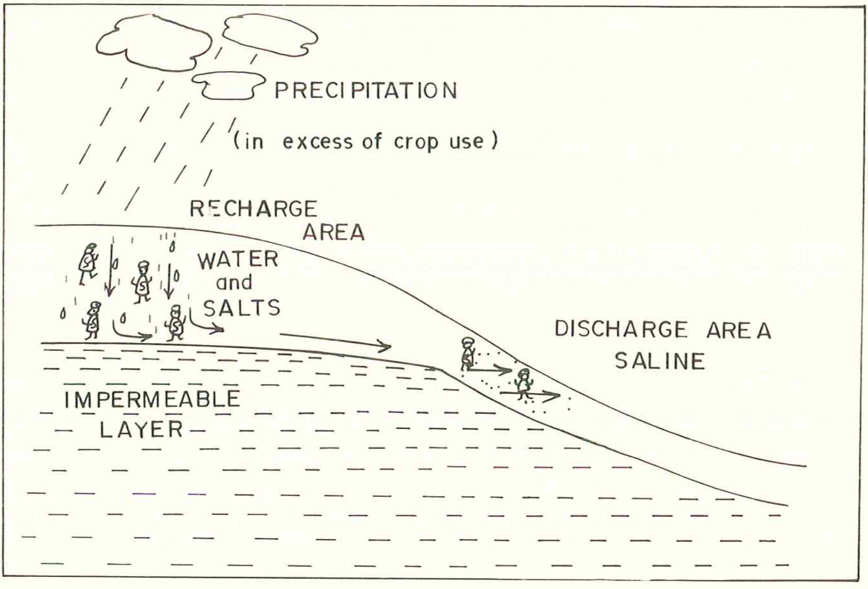


Figure 5. Saline Seep development

by capillary action. At this stage the process described under the heading "groundwater effects" comes into play, and salinity problems begin to develop. The whole process is illustrated in Figure 5.

The seep phenomena can take place over relatively short distances within the same field or over distances of several miles. For example, work done by geologists has shown that the Quill Lake Basin area is a discharge area receiving input waters from both the Allan Hills Upland to the west and the Thickwood Hills Upland to the south and east.

The seep phenomenon, particularly when it occurs within an area over which an individual farmer has control, presents the most promising case for corrective measures (see page 16).

ALKALI AND SALINE-ALKALI SOILS

Alkali soils are characterized by a high pH (in excess of 8.5) and a high content of exchangeable sodium (see Appendix B for detailed explanation of exchange reactions in soils and the characteristics of soil in this group). Because of their high exchangeable sodium content they are often referred to as "sodic" soils.

Alkali soils are frequently in poor physical condition; the aggregates are broken down and the soil is said to be "puddled".

There are virtually no true alkali soils in Saskatchewan. We mention them here primarily so that they will not be confused with a salt-affected soil that is found in this province: the saline-alkali group.

Saline-alkali (also called saline-sodic) soils have characteristics in common with both the saline and alkali types. Like the saline soils, they have a high concentration of soluble salts; in common with alkali soils they also have a high content of exchangeable sodium. Saline-alkali soils frequently have a higher pH than normal soils, but the pH is almost always less than 8.5 (see Appendix B).

The physical condition of these soils depends on the balance of saline and alkali components. If the soluble salt content (the saline component) is relatively high, then the soils may be in good physical condition; if, on the other hand, the exchangeable sodium content predominates they can be in the puddled condition similar to true alkali soils.

Some of the large flat and depressional areas in Saskatchewan which are permanently affected by salts are in the saline-alkali category. Areas such as the Walsh Flats and the Dafoe Flats are examples of areas which do contain some saline-alkali soils. Most of the areas of saline-alkali soils are ones in which little or no cultivation has been attempted and a large percentage of the vegetation consists of salt-tolerant species of native plants.

SOLONETZIC SOILS

Properties

Solonetzic soils are of three types: solonetz, solodized-solonetz, and solod. We will consider the characteristics of the most easily recognized solonetzic soil: the solodized-solonetz. As shown in Figure 6 this soil consists of three main layers (sometimes called "horizons") each of which is different in composition:

A Layer — Surface layer itself consists of two distinct levels, the Ah and the Ae. The Ah level is high in organic matter; the Ae is highly leached, coarse-textured, and can be acid.

Bnt Layer — Upper subsoil level contains high amounts of clay and exchangeable sodium and is tough, dense, and impermeable, interfering with the penetration of both water and plant roots. It has a distinct round-top columnar structure.

Csa Ca Layer — Usually has a high concentration of soluble salts (including gypsum) and lime.

Thus it can be seen that solodized-solonetz soils exhibit the properties of acid soils in the A layer; alkali soils in the B layer; and saline soils in the C layer.

Solodized-solonetz soils do not often occupy a large continuous area; they are more likely to appear as a number of distinct patches within a given field. In such fields wind and water erosion may completely remove the A layer, leaving small scattered depressions in which crops do very poorly. Such is the origin of the term "burn-out", which refers to these small depressions and the "burned" crop within them.

The distribution of major areas of solonetzic soils in Saskatchewan is shown in Figure 8 on page 20.

Development

Each of the three types of solonetzic soils represents a distinct stage in the development of what begins as a saline soil containing large quantities of sodium salts. The process is caused by water and proceeds as follow:

Starting point — a saline soil with large quantities of sodium salts.

Step 1 — Soluble salts are leached out of the upper portion of the soil, leaving a high concentration of exchangeable sodium, which will eventually form the Bnt layer.

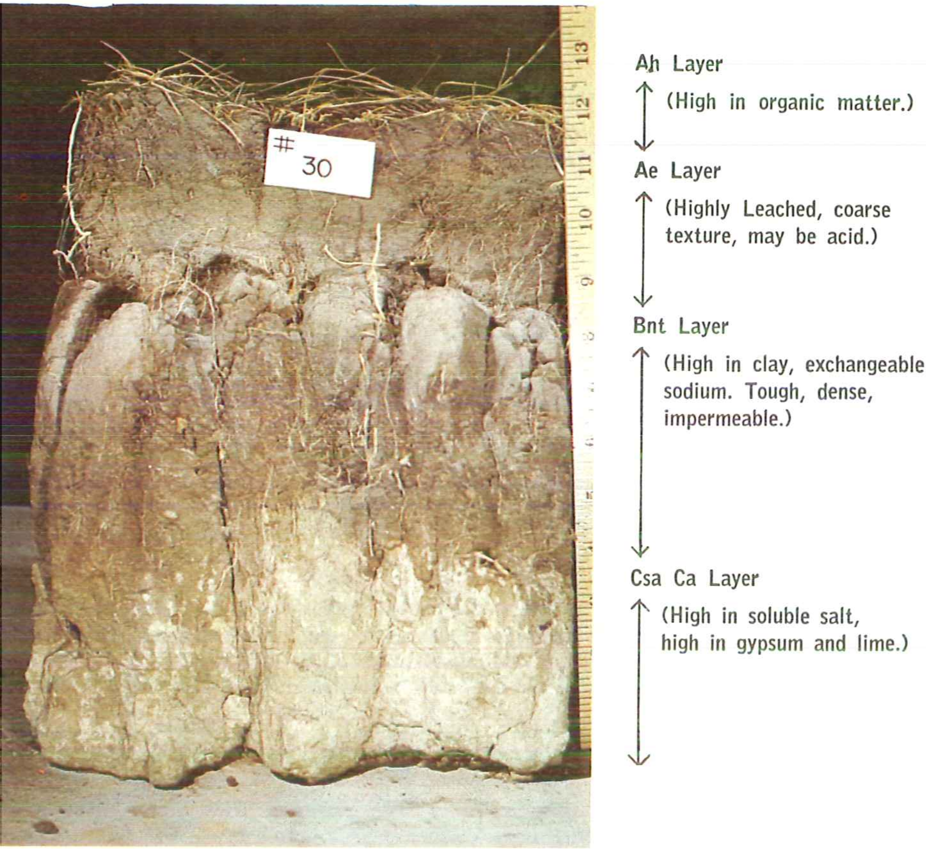


Figure 6. The characteristics of a solodized solonetz soil.

Step 2 – Clay and organic matter disperse, i.e. aggregates break down.

Step 3 – Clay leaches and the Bnt layer is formed. At this stage it is a solonetz soil.

Step 4 – The Ae level forms and may become quite acid. Round tops appear as a strong Bnt forms. It has now become a solodized-solonetz soil.

Step 5 – Further leaching removes exchangeable sodium from the upper portion of the Bnt layer, forming a third level in the A layer: the AB level. We now have a solod soil.

End point – A highly leached soil, not too different in productivity from other leached soils.

PART 2: MANAGEMENT OF THE PROBLEM

MANAGEMENT OF SALINE SOILS

In describing the development of saline soils we emphasized that water and its movement is responsible for the concentration of salts at certain locations. An understanding of the water flow pattern and water management is the key to any successful management program for saline soils.

Soil Testing

Soil testing can verify the presence of salinity and give an approximation of the severity of the problem. There are usually wide fluctuations in salinity levels over very short distances within a single field. Therefore, a large number of sites must be chosen to give a composite sample that represents the whole area affected. Sampling for salinity must be to a depth of at least 60 centimetres (24 inches) and samples at greater depths would assist in diagnosing the problem.

Information soil test reports for fertilizer use can also indicate a possible future salinity problem. When moderately saline conditions exist in the 30-60 centimetre (12-24 inch) depth, management practices should be instituted to prevent upward movement of these salts.

Crop Rotation

It is desirable to maintain plants on the land as a preventive measure against the development of salinity. During the summerfallow year excess rainfall may result in significant rise in the water table or saline seep into lower slope positions.

The widespread use of the two-year rotation in Saskatchewan has contributed significantly to the salinity problem in many areas. Therefore, on fields where salinity is becoming a problem, continuous cropping should be used or at least the rotation should be lengthened to the maximum extent possible.

In those parts of the brown and dark brown soils, where summerfallow is necessary for moisture conservation, strip cropping should be used on long slopes above salt-affected areas.

Strips should be not more than 30 rods wide on clay loam to clay soils and not more than 20 rods wide on loam to fine sandy loam soils. Strip cropping will reduce surface runoff and water erosion as well as wind erosion. Large areas in summerfallow on sloping land increase runoff and ground-water seepage.

Where salinity has reached the stage that cereal crops no longer produce well it may be necessary to shift at least a portion of the acreage to forage crop production. Many of the forage crops have superior tolerance to salinity conditions. There are two more reasons for utilizing forage crops in rotation on saline soil:

1. The water use patterns of annual cereal grains are such that the maximum water use takes place during the months of June, July and August. If excess rainfall occurs during the late fall or early spring it could result in movement of water below the root zone and a rise in the water table or the development of saline seep. In contrast, forage crops use water much earlier in the season and use water well into the autumn period. In cases of moderate salinity the use of winter annuals such as fall rye would also provide earlier use of water.

2. Many of the forage crops, such as alfalfa, are deep-rooted and extract water from considerable depth and result in a drop in the water table and a reduction in the salinization process.

The inclusion of sweet clover in a rotation by underseeding sweet clover in the grain crop year using the clover crop for either ploughdown or fodder production is a good practice where a salinity problem is just emerging. Where the problem is acute it may be necessary to use long-term forage to make any major change in the groundwater pattern.

Selection of Salt-Tolerant Crops

The selection of a crop which will best withstand salinity is one of the main management practices that a farmer has at his disposal.

The tolerance of various forage and field crops to salinity is outlined in Table 1. Of the cereal grains barley is the most salt-tolerant. Possible variety differences in barley or other crops has not been fully tested.

Alfalfa is quite tolerant of salinity once established but is not highly tolerant in the seedling stage. Therefore, the seeding practices and timeliness of seeding can be quite critical in obtaining good establishment of alfalfa. With irrigation it is possible to apply water to temporarily wash the salts out of the surface few centimetres of soil. Alfalfa should then be planted as soon as possible and at a very shallow depth. For dryland farmers, of course, it is not possible to effect this degree of timing. However, it is possible to seed the crop in very late fall and rely on spring snow melt to temporarily wash the salts down and allow alfalfa to become established. Alternately, it may be possible to pick a time just after quite heavy rain and seed the alfalfa as soon as possible to attempt to get it established before the salts return to the surface of the soil.

Mixtures of forage crops offer advantages in many situations due to the great range of salinity levels within a field. Alfalfa should be a component in the mix in all areas except those subject to more than two weeks of flooding. In areas of the field where alfalfa does become established it will provide high quality feed and root deeply to prevent further spread of the problem.

Table 1. The relative tolerance of crops to salinity.

DEGREE OF SALINITY TOLERATED[1]

	Non to slightly saline	*Moderately saline*	*Severely saline*
		Annual — Field Crops	
Salt Tolerance Increasing	Soybeans	Rapeseed	Barley may produce some crop but this land best suited to tolerant forages.
	Field Beans	Mustard	
	Fababeans	Wheat	
	Peas	Flax	
	Corn	Fall Rye[2]	
	Sunflowers	Oats	
		Barley[2]	
		Sugar Beets	
		Forage Crops	
Salt Tolerance Increasing[4]	Red Clover	Reed Canary	Altai Wild Rye
	Alsike	Meadow Fescue	Russian Wild Rye
	Timothy	Intermediate Wheat	Slender Wheatgrass[2]
		Crested Wheat	Tall Wheatgrass
		Brome	
		Alfalfa	
		Sweet Clover[2]	

[1] For conductivity values of salinity levels see Table A1 page 22.

[2] These crops not tolerant of flooding, which is common in some saline areas.

[3] Under dry conditions slender wheatgrass is more tolerant than tall wheatgrass.

[4] Differences of one or two places in the ranking may not be significant.

Interceptor Cropping

Interceptor cropping may play a significant role in preventing the further development of saline seep areas (see Saline Seep page 10). The idea behind this management practice is to inhibit lateral movement of water. The crop planted on the upslope "intercepts" the water which would otherwise flow laterally and cause salinity problems further downslope. In this way, the problem is attacked in the upper slope position above the affected area. Figure 7 shows how this system might work in one particular field. Because of its deep-rooting habit alfalfa is likely the best crop to utilize in an interceptor cropping program. It may be necessary in some situations to plant alfalfa on a large portion of the recharge area to bring about any major improvement.

Figure 7. Alfalfa is a good crop to use to intercept seeps.

Fertilizers

On moderately saline soils the use of phosphate fertilizers with the seed of cereal grains has given excellent yield increases. The better crop produced will also extract more moisture and assist slightly in preventing further salinization.

The research information on phosphate use on saline soils is limited and detailed recommendations on rates are not available but rates of approximately 20 to 30 Kg P_2O_5/hectare (18-27 lbs/acre) are suggested.

For severely saline soils fertilizers have been shown to be of very little benefit and are not recommended.

Where the management program for saline soils includes extending the crop rotation, some level of nitrogen use will likely be needed on the second and subsequent crops. Nitrogen rates of approximately 20 to 40 KgN/hectare (18-36 lbs/acre) are recommended; it is not advisable to apply higher rates in view of the risks associated with cropping saline soils.

It should be emphasized that fertilizer use is one additional aid in crop production on some moderately saline soils. However, fertilizer use will not solve the problem of salinity itself in these soils.

Manure

High rates of manure application, 34 to 45 tonnes/hectare, (15-20 tons/acre) have improved crop establishment and crop yields on saline soils. The manure applications increase the organic matter content and water-holding capacity of the soil. In this way more water is available to plants even though salts are present. Manure also adds nutrients and improves the structure or tilth of the soil.

For short periods of time, when the manure mulch is present on the soil surface, it will assist in reducing evaporation and concentration of salts at the surface of the soil.

Neither fertilizers nor manure actually get rid of the salts. Better crop growth can result from fertilizer or manure and more moisture will be used. Manure will also assist in water movement through the soil to leach the salts down.

Tillage and Weed Control

Since salt concentrations are frequently higher at depth than they are at the immediate soil surface, shallow tillage is generally recommended for saline soils. Deep tillage may, in many cases, simply bring more salts to the surface and make the problem worse.

Tillage practices should maintain all possible residues at the soil surface. This can best be obtained with cultivators and rod-weeders rather than disk implements.

Shallow seeding is just as critical on saline soils as it is on normal soils. Timeliness of seeding is particularly important for small seeded crops such as flax, alfalfa, sweet clover and rapeseed. These crops should be seeded early to have them germinate when surface salt levels may be temporarily lowered.

A number of the weeds mentioned earlier are very tolerant of salts. Chemical weed control along with tillage is essential to get crops, particularly forages properly established.

Chemical Amendments

There are no chemical amendments which will "neutralize" the salts present in the soil. The salts that are causing the problem are neutral salts (neither acid nor base). The many "wonder products" that are sold to help salinity are doing nothing more than relieving the farmer of some of his money.

In areas of the world where true alkali soils do exist the application of elemental sulphur or gypsum can have beneficial effects. Elemental sulphur applications assist in reducing the pH where an extremely high pH is the problem. The gypsum applications supply calcium to replace the sodium and improve the soil structure. However, as we have no true alkali soils in Saskatchewan these applications would be of no benefit. In most areas of saline soils, gypsum (calcium sulphate) is one of the major salt constituents and the application of gypsum would simply be supplying more of the same material that is already present in abundance.

Drainage and Leaching

The only known way to reclaim saline soils and put them back to a fully productive state is to install drainage (such as tile drains) and provide a source of leaching water. In irrigation areas it is possible to apply whatever quantities of water are required to leach the excess salts out of the soil. In dryland areas drainage is seldom an economic proposition. On dryland, desalinization of the soil would not take place upon installation of drainage, without extra water to leach the salts out of the soil.

In some dryland areas it may be possible to institute a program of surface drainage of small sloughs or other water bodies that are contributing to the problem. In areas where saline seeps have been identified, it may be possible to determine a source of surface water (such as an upland slough) which is contributing to the problem and to drain that particular water body. Drainage is a very controversial issue in that one must always be concerned with where the water is going. There is little point in solving a problem on one field if it is simply contributing to the further development of a problem on an adjacent field.

There has been little research work done to date in Saskatchewan on the use of gypsum on saline-alkali soils. It may be possible that for certain areas of saline-alkali soils, where the conductivity values are not too high, but where exchangeable sodium values and pH are moderately high, gypsum applications may have some benefit. Until further research proves that such applications will be of any benefit the farmer would be taking a large risk in putting any input dollars into such products.

MANAGEMENT OF SOLONETZIC SOILS

It is not the purpose of this bulletin to present detailed information on solonetzic soils. If the reader requires further information on solonetzic soils he is referred to the publications listed below.

In managing solonetzic soils the major management tool available is timeliness of tillage operation. Tillage operations and seeding must be done when the soil is at the correct moisture content. If the soil is worked when it is too wet, the structure breaks down completely. If tillage is left too late, the soil dries out and it becomes almost impossible to get proper penetration of tillage implements.

Deep plowing is a reclamation practice for solonetzic soils which has been extensively researched in Alberta and North Dakota.

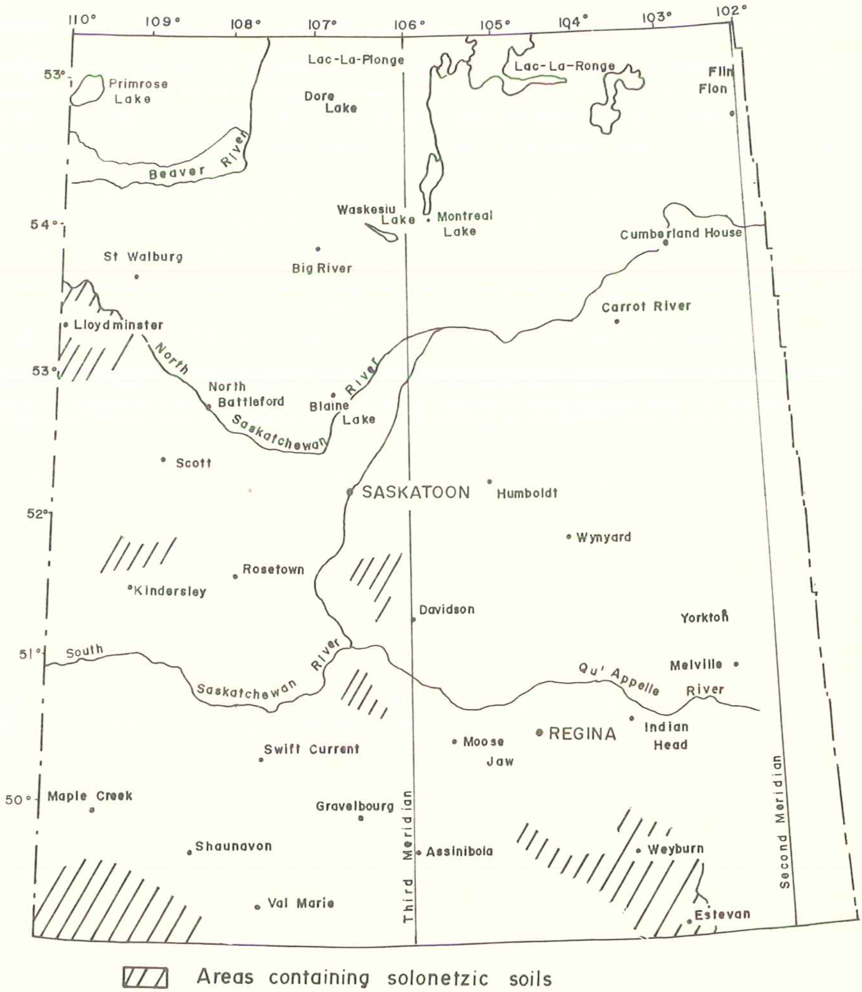


Figure 8. Major areas in Saskatchewan in which some solonetzic soils occur

The most common depths for deep plowing operations have been from 2 to 3 feet. The actual depth required for a specific soil depends on the nature of the soil profile. It is necessary to plow to sufficient depth to reach the layer containing gypsum and to mix this with the other layers. If plowing were done in such a way as to include only the A and B horizons (Figure 6) there is little doubt that the practice would do more harm than good.

Before proceeding with any deep plowing projects the farmer should consult the publications mentioned and be certain that his problem is in fact one of solonetzic soils and that the plowing operation has some chance of success. The areas of Saskatchewan where solonetzic soils are common is shown in Figure 8.

Deep plowing is not a management or reclamation practice for saline soils.

1. "Solonetzic Soils and Their Management" by R. R. Cairns and W. E. Bowser. Canada Department of Agriculture Publication No. 1391.

2. "Solonetzic Soils Technology and Management" ed. by J. A. Toogood and R. R. Cairns. Department of Extension, University of Alberta Publication No. B-73-1.

APPENDICES

MEASUREMENT OF SOIL SALINITY

Saturated Paste Method

In this method water is added to a given weight of soil until the soil is saturated and just reaches the flow point. This condition is referred to as a saturated paste. The saturated paste is allowed to sit for approximately two hours for equilibration. At that time the water present is extracted with the aid of a suction apparatus. This extract is referred to as the saturation extract. The electrical conductivity of this extract is then measured. The higher the salt concentration in a specific soil the higher will be the conductivity of the saturation extract. The conductivity is expressed in mmhos/cm (millimhos per centimetre).

Conductivity values determined on a saturation extract have been the standard method of measuring soil salinity by research workers throughout the world for many years. Thus, almost all available research data on crop tolerance is related to the saturation extract values.

Unfortunately, the determination of salt content by the saturation extract method is too costly and time consuming to allow this method to be used routinely on the thousands of samples that are processed by the Saskatchewan Soil Testing Laboratory. Therefore, the Saskatchewan Soil Testing Laboratory utilizes a quick-test method which is described in the next section.

The 1:1 Soil:Water Method

In this method a given weight of water is added to the same weight of soil to provide a suspension. This suspension is allowed to equilibrate for a short period of time (approximately ½ hour). At this time a conductivity probe is inserted in the suspension and a conductivity reading is made directly. Thus, laborious paste preparation and vacuum extraction are not required.

The actual conductivity value obtained by the 1:1 suspension method is not as easily interpreted as that for the saturated paste. However, recent research work has determined the relationship between the values obtained by the different methods. This relationship varies for soils of different texture as outlined in Table 1.

Table A1. The relationship of conductivity determined by 1:1 method to that obtained by the saturated paste method

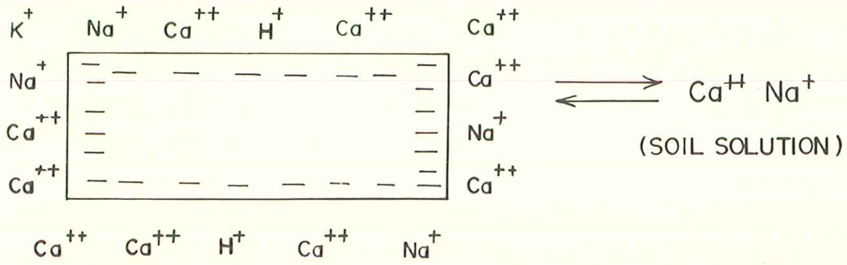
Textural Group	Degree of Salinity				
	Non-saline	Slightly saline	Moderately saline	Severely saline	Very severely saline
	Conductivity (mmhos/cm) by 1:1 Method				
Coarse Sand (CS) to Loamy Sand	0 - 1.1	1.2 - 2.4	2.2 - 4.4	4.4 - 8.9	8.9+
Loamy Fine Sand (LFS) to Loam	0 - 1.2	1.2 - 2.4	2.4 - 4.7	4.7 - 9.4	9.4+
Silt Loam (SiL) to Clay Loam (CL)	0 - 1.3	1.3 - 2.5	2.5 - 5.0	5.0 - 10.0	10.0+
Silty Clay Loam to Heavy Clay	0 - 1.4	1.4 - 2.8	2.8 - 5.7	5.7 - 11.4	11.4+
Saturated Paste (any texture)	0 - 2	2 - 4	4 - 8	8 - 16	16+

Texture	*Ratio-Paste/1:1*
Coarse Sand to Loamy Sand	1.8
Loamy Fine Sand to Loam	1.7
Silt Loam to Clay Loam	1.6
Silty Clay Loam to Heavy Clay	1.4

CHEMICAL REACTIONS AND CRITERIA FOR SALT-AFFECTED SOILS

Cation Exchange Reactions

Clay particles in soils carry a negative charge. Because of the negative charge they attract positively charged ions to their surface as illustrated in the diagram below.



Exchange reaction then takes place between the cations (positively charged ions) on the clay surface and the cations in the soil solution. The ability of a soil to retain and exchange cations is referred to as CATION EXCHANGE CAPACITY (CEC).

The cation exchange capacity of a soil is expressed in milliequivalents per 100 grams of soil.

Organic matter particles also carry negative charges. The entire complex of clay and organic matter and mixed clay-organic matter material in soils is referred to as the EXCHANGE COMPLEX. Hence, when we refer to certain cations as being present on the exchange complex of soils we are referring to those cations that are held by the negative charges of either clay or organic matter or complexes of clay and organic matter.

The reaction that takes place between the exchange complex and the soil solution is similar to that which takes place in a water softener as illustrated in the diagram below. The softener is "charged" with sodium ions (Na^{+}) which attach themselves to the negatively charged exchange resin. Calcium ions (Ca^{++}) in the hard water enter the water softener where they displace some of the sodium ions. The calcium ions remain "stuck" to the exchange resin in the softener and the displaced sodium ions go with the water that leaves the softener.

The measurement of the cation exchange capacity of a soil involves the saturation of the exchange complex with a particular cation, replacement of this cation with a second cation and the measurement of the total amount of the first cation that was present on the exchange complex. This procedure is laborious, time consuming and expensive. Therefore, it is not economically feasible for large numbers of samples to determine the cation exchange capacity or the amount of individual cations that are present on a soil.

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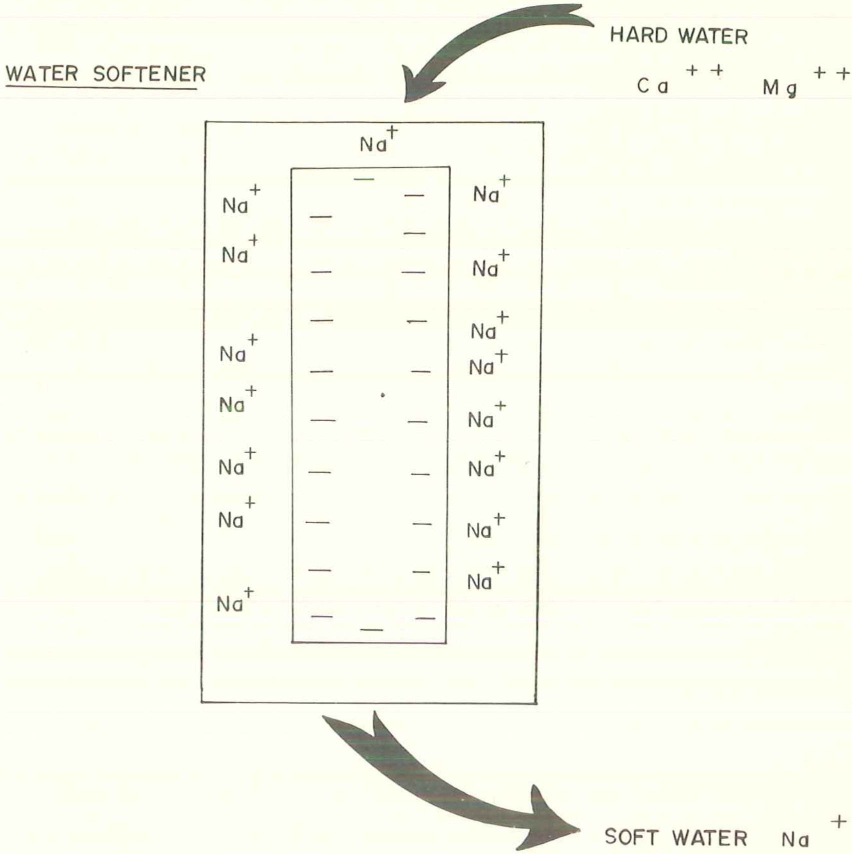
*For more detailed information on the chemistry of salt-affected soils the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" United States Dept. of Agriculture. Handbook No. 60.



Fortunately, for Saskatchewan soils it is possible to make an estimation of the cation exchange capacity of a soil if one knows the clay and organic matter contents of that soil.

The equation relating cation exchange capacity to the clay and organic matter contents of soils is:

$$\text{CEC (meq/100 g)} = 0.5\ (\%\ \text{clay}) + 2.0\ (\%\ \text{organic matter})$$

The Effect of Cation Type on Soil Physical Conditions

Soils with calcium on the exchange complex will be well granulated and in good physical condition. They will be well aerated and will allow water to enter.

Soils with sodium on the exchange complex will be "puddled" and in poor physical condition and will not allow water to enter readily.

The above phenomena have led to the often quoted expression:

Soft water makes hard land.
Hard water makes soft land.

From the above discussion it can be seen that the amount of sodium present on the exchange complex is a critical criterion that will dictate the physical condition of the soil. The next section will examine the criteria relative to sodium content that are utilized to characterize the various classes of salt-affected soils.

Criteria for Defining Salt-Affected Soils

The exchangeable sodium percentage is one of the major criteria utilized to separate salt-affected soils into three categories. The exchangeable sodium percentage is defined as:

$$ESP = \frac{\text{Exchangeable Na (me/100 g soil)}}{\text{Cation exchange capacity (me/100 g soil)}} \times 100$$

The specific criteria used to define saline, saline-alkali and alkali soils are given in Table A2 below.

TABLE A2

Chemical Criteria for Salt-Affected Soils

	Conductivity mmhos/cm	E.S.P.	pH
Saline	4	15	8.5
Saline-Alkali	4	15	usually 8.5
Alkali	4	15	8.5 - 10

The exchangeable sodium percentage gives information on what percentage of the cations on the exchange complex are sodium. As indicated previously the measurement of cation exchange capacity and exchangeable sodium is difficult and laborious.

A laboratory measurement which is more readily conducted on large numbers of samples is the determination of the cations present in the saturation extract. Refer to page 21 for a description of the saturation extract.

By measuring the cations present in the saturation extract it is possible to determine the sodium adsorption ratio (SAR). Sodium adsorption ratio is defined as:

$$SAR = \frac{Na^{+}}{(Ca^{++} + Mg^{++})/2}$$

NOTE: Concentrations in milliquivalents per litre of extract.

As the sodium adsorption ratio is much more readily measured than the exchangeable sodium percentage it is frequently used as a criterion to define the sodic nature of specific soils. In many reference works on soil salinity the SAR is quoted and hence we have to have some knowledge of the interpretation of SAR values.

It conveniently turns out that SAR and ESP values are approximately numerically equivalent up to values of about 25. The specific equation relating these two is given below:

$$\text{ESP} = \frac{(1.47 \times \text{SAR}) - 1.26}{(0.0147 \times \text{SAR}) + 0.99}$$