PUBLICATION 1391

Solonetzic Soils and their Management

Agriculture Canada

PUBLICATION 1391, available from
Information Services, Agriculture Canada, Ottawa K1A 0C7

Cat. No. A53–1391/1977 ISBN: 0-662-00718-2
Revised 1977 Reprinted 1980 7M–6:80

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GOOD MANAGEMENT PAYS

Solonetzic soils are responsive to good management. Special attention must be given to surface drainage, seedbed preparation, seed placement, the use of forage crops, and fertilization. Soils that are so severely limited by the Solonetzic condition that they will not produce adequately even with good management may need to be plowed to a depth of at least 45 cm (*18 in.*).

Solonetzic Soils and their Management

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Revised by R. R. Cairns

INTRODUCTION

The word Solonetzic is of Russian origin and refers to soils that have developed under the influence of sodium salts. A soil that exhibits a strong influence of sodium is called a Solonetz, whereas one that exhibits a mild influence is called a Solod. Between these soils lies one called a Solodized Solonetz. Solonetzic soils occur in many parts of the world, including the southern part of the USSR, the eastern part of the Balkan area, Australia, the drier region of South America (mainly Argentina), the southwestern and north-central parts of the United States, and Western Canada.

Occurrence in Canada

In Western Canada, Solonetzic soils were originally called burnout or blowout soils. These terms were used because they described the patchy surface that was usually associated with the soils. In many places in southeastern Alberta and southwestern Saskatchewan, the surface is pock-marked with shallow pits 13–25 cm (*5–10 in.*) deep, which cover as much as half of the area. These soils are now classified as belonging to the Solonetzic order. There are 6–8 million ha (*15–20 million ac*) of Solonetzic soils in Western Canada, mainly in the grasslands and parklands. Figure 1 indicates the location of the larger areas.

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Fig. 1. Main Solonetzic areas in Western Canada. There are also many smaller areas.

Usually, these soils occur on fairly level land in areas where the glacial till or other recent deposits are rather shallow and the underlying bedrock is close to the surface. In general, they occur in places where the internal drainage has been, or is, restricted; where groundwater occurs or has occurred close to the surface; and mainly where the land can receive water percolating from surrounding higher land. Also, the soils are usually found near areas of bedrock shale containing a rather large amount of salt.

Identification

Solonetzic soils have rather distinctive and easily identifiable profile characteristics (Fig. 2). All soil profiles are composed of layers, called horizons, that differ from each other. The surface, called the A horizon, usually contains the greatest amount of organic matter; the subsurface or B horizon is usually more strongly structured and more clayey than the surface; and the subsoil or C horizon is the original parent material on which the soil was formed. The C horizon lacks the organic matter of the A horizon and the structure of the B horizon.

The A horizon of Solonetzic soils is usually rather thin and hard lumpy to coarse granular in structure. The B horizon is fairly thick and columnar. The columns vary from 3 to 8 cm (*1 to 3 in.*) in diameter, and the tops are often rounded and covered with a deposit of white silica. The B horizon contains much more clay than the A horizon, and it is very hard when dry and plastic or sticky when wet. It can be broken, with difficulty, into blocks that are dark-coated on the surface.

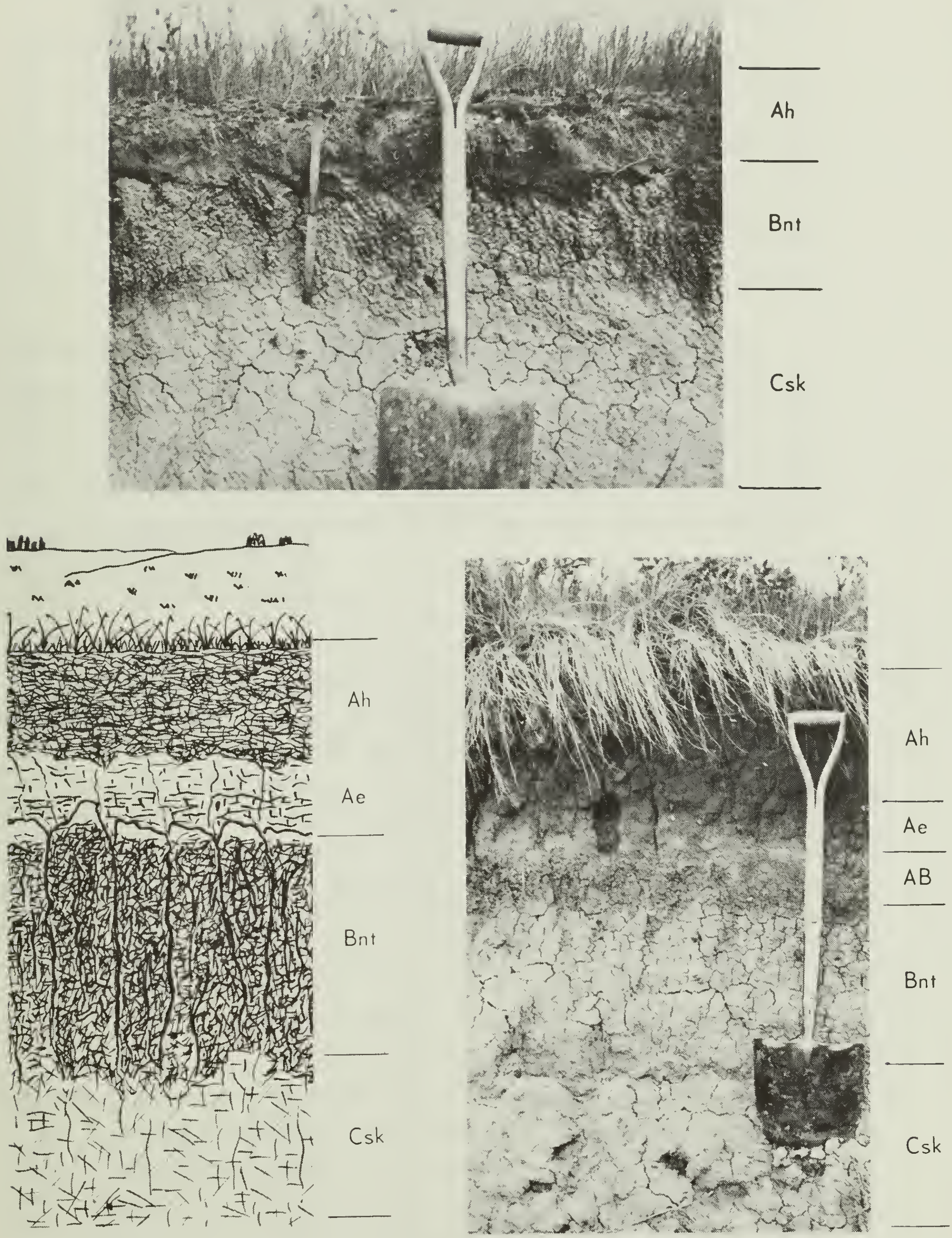

Fig. 2. *Upper:* **A Black Solonetz soil. Note the sharp break between the A and B horizons.** *Lower left*: **A schematic representation of a Solonetzic soil showing the main horizon separations.** *Lower right*: **A Black Solod soil. Note the gradual change from the A to B horizon. The AB horizon marks this transition.**

Very few roots penetrate into the columns; the roots that reach this level follow the natural cleavage lines between the columns. In most Solonetzic soils there is a light-colored horizon (Ae) dividing the A and B horizons.

The C horizon, which contains sulfates and carbonates of sodium, magnesium, and calcium, is usually very clayey but it is not strongly structured like the B horizon. The salt crystals and the white lime flecks can often be seen. The C horizon usually begins at a depth of 25–45 cm (*10–18 in.*) from the surface in the semiarid regions, or grasslands, and at a depth of 45–75 cm (*18–30 in.*) in the less arid regions, or parklands. Some characteristics of a Solonetzic soil in comparison with those of a field-associated Black loam textured soil are shown in Table 1.

For purposes of mapping identification, soil units, called series, are established. These are given a name, usually that of the district where they were first found. Various series are referred to in the text of this publication and in the tables. As an example, much of the soil at the Solonetzic Soil Substation at Vegreville, Alta., has been called Duagh silt loam; however, this series also occurs in various other places in Alberta.

Development

It is generally assumed that the soils became Solonetzic in the following way. The areas that are now Solonetzic were originally saline. The salt was a mixture of various compounds, mainly sulfates of sodium, calcium, and magnesium that were more or less uniformly distributed throughout the profile. Over the centuries rain gradually carried the salt to the lower horizons and during this process the clay became saturated with sodium. Clay in the presence of sodium tends to become highly dispersed, so the clay from the surface soil was carried down with the percolating water. This clay concentrated in what became the B horizon, making that horizon hard and sticky. Often the horizon became so compact that very little water could penetrate it. At this stage of development the soil is called a Solonetz.

As leaching by the rainwater continued, the light-colored Ae horizon developed and grew thicker. Sodium leaches more rapidly than calcium, so it was slowly removed from the clay particles of the B horizon and replaced by calcium. This resulted in softer soil that was more easily penetrated by water and roots. At this stage of development the soil is called a Solod. In general, Solod soils are more easily managed and more productive than Solonetz soils. In most Solonetzic areas there is a mixture of Solod and Solonetz soils.

Recent studies have shown that the processes involved in the development of Solonetzic soils were much more complex than those

Table 1. General characteristics, pH, organic matter (OM), electrical conductivity (EC), water-soluble constituents, and exchangeable sodium percentage (ESP) of two soils in a Solonetzic soil complex

Soil	Soil horizon*	Soil horizon thickness cm	*in.*	pH	OM %	EC (mmhos/cm)	Water-soluble constituents (meq/100 g) Ca	Mg	Na	K	SO_4	Acid-soluble P (ppm)	ESP
Black Solonetz: Duagh silt loam	Ah	15	*6*	6.0	10.76	3.0	0.08	0.11	1.68	0.03	1.65	67	24
	Bnt	15	*6*	7.2	4.53	5.9	0.26	0.57	4.74	0.04	5.57	68	28
	Csk	—†	—	7.8	1.49	15.9	0.71	1.57	9.98	0.06	11.30	79	33
Eluviated Black: Malmo silt loam	Ah	20	*8*	6.1	16.09	1.1	0.18	0.14	0.12	0.14	0.42	177	0
	Ae	15	*6*	6.2	4.12	1.0	0.05	0.07	0.14	0.10	0.18	114	5
	Bt	51	*20*	7.6	1.72	2.4	0.10	0.35	1.03	0.01	1.35	15	14
	Ck	—	—	7.7	1.23	2.8	0.05	0.28	1.18	0.01	1.38	0	14

*Explanation of horizon suffixes
e—leached
h—humus accumulation
k—contains significant amounts of carbonate
n—contains significant amounts of sodium
s—contains significant amounts of salt
t—clay accumulation
†— indicates that there are no data.

described above. For example, it is almost certain that there was repeated leaching and recharging with salts from the groundwater. However, for practical purposes the above description will suffice.

Natural productivity

At least six characteristics of Solonetzic soils adversely affect their productivity and create special management problems for the farmer.

- The hard, compact B horizon limits the penetration of water, air, and roots. Rainwater often remains on the surface and is lost by evaporation. The roots tend to concentrate in the surface horizon and, as a result, crops on Solonetzic soils do not withstand long periods of drought as well as crops on the more permeable non-Solonetzic soils.
- The high salt content in the subsoil affects plant growth by limiting the availability of water to the plants and preventing the roots from penetrating to lower depths.
- The light-colored Ae horizon contains little organic matter and has a platy structure. The soil in this horizon crusts readily.
- The particular chemical composition of these soils appears to affect the uptake of plant nutrients by the roots. The potassium content of plants grown on these soils is generally low but can be greatly increased when nitrogen fertilizers are applied.
- Nitrogen is commonly a limiting factor in crop production. Most of the nitrogen present in any soil is derived from previous plant growth. Plant growth was limited on Solonetzic soils during their development and this accounts for the shallowness of the surface horizon and the low organic nitrogen content.
- The soluble sodium content of the surface layer of many Solonetz soils changes as the water table rises or falls and as soil water evaporates. Soluble sodium affects the soil structure and management practices such as seedbed preparation.

Because the severity of each of the above characteristics may vary over short distances, there is considerable variation in the growth of crops and time of their maturity. As a result, most crops grown on Solonetzic soils are patchy (Fig. 3). Solonetzic soils in their natural state are unproductive. The productivity of two Solonetz soils and a field-associated, loam textured Black soil of a different order is shown in Table 2.

Shallow groundwater

In certain areas of Solonetzic soils, saline groundwater occasionally occurs within 1 m (*3 ft*) of the surface. The function of the groundwater in soil development is not fully understood. However, it is

Fig. 3. *Upper*: Wheat on a Brown Solonetz soil area. *Lower*: Hay on a Black Solonetz soil area. Notice the variability in growth in both areas.

Table 2. Dry matter yield and root penetration of hay grown in 1958 and 1959 on three soils of the Solonetzic complex at Vegreville, Alta.

Soil	Dry matter yield of hay 1958 kg/ha	1958 *lb/ac*	1959 kg/ha	1959 *lb/ac*	Root penetration cm	Root penetration *in.*
Black Solonetz: Duagh silt loam	756	*675*	936	*836*	20–23	*8–9*
Black Solonetz: Thin Duagh silt loam	246	*220*	836	*746*	18–20	*7–8*
Eluviated Black: Malmo silt loam	2516	*2246*	4303	*3842*	40–46	*16–18*

known that it readily rises within the soils. In order to prevent the upward movement of salt-bearing groundwater in such areas, surface water must be removed by either drainage or transpiration rather than by evaporation.

The great variability in the groundwater quality and level within a given Solonetzic soil complex has been studied at Vegreville. Batteries of piezometers were installed in a very thin Solonetz (Duagh) soil, a Solonetz (Duagh) soil, and an Eluviated Black (Malmo) soil, which all occur within a radius of about 37 m (*120 ft*) (Fig. 4). The depth to

Fig. 4. A nest of piezometers used for measurement of the groundwater table at the Vegreville substation.

Table 3. Depth to groundwater and sodium content in piezometers 305 cm (*120 in.*) deep after installation in October, 1965

Soil	Depth to water			Date of reading	Na content		Date of reading
	Reading	cm	*in.*		Reading	meq/litre	
Malmo silt loam	Minimum	60	*24*	May 1967	Highest	120.0	Aug. 1966
	Average	190	*75*	1966–72	Average	38.0	1966–72
	Maximum	270	*106*	Apr. 1972	Lowest	0.5	May 1971
Duagh silt loam	Minimum	35	*14*	Sept. 1966	Highest	250.0	Aug. 1966
	Average	170	*67*	1966–72	Average	170.0	1966–72
	Maximum	205	*81*	May 1966	Lowest	126.0	Feb. 1971

water and its sodium content fluctuated greatly (Table 3) and these factors did not appear to be related to the season or local climate. The less productive the soil, the greater the rise of the water in the deep piezometers relative to the rise of water in the shallower piezometers, and the less the seasonal fluctuations of the water levels in general. The chemistry of the groundwater varied greatly with piezometer depth (Table 4) and probably reflected the chemistry of the soil material (Table 5) through which the water had moved before entering the piezometer. No relationship was found between the surface elevation of the land and the existing soil condition.

Special problems

Solonetzic soils also present problems in construction. Special construction techniques are necessary because salt corrodes metal surfaces and makes ordinary cement deteriorate. Solonetzic soils contain a substantial amount of salt, which causes the soil to erode easily and places certain demands on the building of roads and other earthen structures. The slow transmission of water that is characteristic of these soils suggests, among other things, that they are inferior as a site for sewage disposal.

CLIMATE

Solonetzic soils occur under a wide range of climatic conditions. The Solonetzic Soil Substation at Vegreville is located in the Black soil zone, which is one of the moister regions. During the 18 years from 1958 to 1975, the average total annual precipitation at Vegreville was 392 mm (*15.42 in.*) with a low of 285 mm (*11.21 in.*) in 1966 and a high of 554 mm (*21.83 in.*) in 1973; the longtime (70-year) average for the area is about 432 mm (*17 in.*). The rainfall from April 1 to September 1 for this 18-year period averaged 265 mm (*10.43 in.*), with a low of 167 mm (*6.58 in.*) in 1958 and a high of 410 mm (*16.13 in.*) in 1973. The killing frost-free period, above $-1.7°C$ (*29°F*), averaged about 111 days, varying from 128 days in 1958 to 83 days in 1974.

Table 4. Chemistry of the groundwaters of a Solonetzic soil complex

Soil	Piezometer depth		Groundwater sampled Nov. 1971						Groundwater sampled May 1972					
			EC*	Constituent (meq/litre)					EC*	Constituent (meq/litre)				
	cm	*in.*	(mmhos/cm)	Na	Ca	Mg	K	Total	(mmhos/cm)	Na	Ca	Mg	K	Total
Malmo silt loam	305	*120*	0.3	0.8	0.3	0.3	0.21	1.6	0.3	1.4	0.3	0.2	0.33	2.2
	460	*181*	3.1	24.0	4.1	2.0	0.17	30.3	2.5	19.0	0.6	1.4	0.22	21.2
	610	*240*	3.6	29.0	1.6	0.9	0.21	31.7	3.6	29.0	0.7	1.1	0.34	31.1
Duagh silt loam	230	*90*	30.0	197.0	8.1	32.0	0.45	237.6	—†	—	—	—	—	—
	305	*120*	21.0	143.0	4.3	24.0	0.39	171.7	22.0	145.0	2.8	26.0	0.58	174.4
	460	*181*	16.0	96.0	8.6	8.5	0.38	113.5	14.0	84.0	4.3	8.0	0.47	96.8
	610	*240*	5.5	43.0	1.7	1.9	0.20	46.8	4.6	37.0	0.7	1.9	0.26	39.9
Thin Duagh silt loam	305	*120*	—	—	—	—	—	—	22.0	142.0	5.0	23.0	0.51	170.5
	460	*181*	30.0	153.0	0.3	0.3	0.40	154.0	24.0	117.0	0.6	0.5	0.63	118.7
	610	*240*	2.6	22.0	0.8	0.3	0.12	23.2	2.4	21.0	0.3	0.3	0.19	21.8

*Electrical conductivity.

† — indicates that there are no data.

Table 5. Quantity of various cations extractable with 1.0 N ammonium acetate (ph 6.5) from soil samples procured from piezometer sites

Soil	Sample depth		Color	Extractable cations (meq/100 g)			
	cm	*in.*		Na	Ca	Mg	K
Malmo silt loam	90	*35*	Brown	5.3	84.8	7.0	0.8
	150	*59*	Brown	3.4	36.0	4.2	0.6
	305	*120*	Brown	8.5	17.0	7.8	1.1
	460	*181*	Gray	8.7	15.0	4.2	1.1
	490*	*193**	Black	14.0	17.0	5.2	1.2
	610	*240*	Gray	14.8	15.0	2.4	1.4
Duagh silt loam	90	*35*	Brown	18.4	39.0	12.4	0.8
	150	*59*	Brown	17.6	15.0	8.8	1.0
	305	*120*	Gray	8.4	10.0	3.0	1.2
	460	*181*	Gray	12.4	10.0	2.4	1.2
	610	*240*	Black	15.2	13.0	3.0	1.3
Thin Duagh silt loam	90	*35*	Brown	11.6	28.0	8.6	0.5
	150	*59*	Brown	10.0	23.0	7.8	0.6
	305	*120*	Brown	6.8	18.0	5.2	0.5
	460*	*181**	Gray	11.2	11.0	6.4	0.9
	610	*240*	Gray	11.6	16.0	5.8	1.0

*Very hard layers occurred at a depth of 490 cm (*193 in.*) in the Malmo soil and at a depth of 377 cm (*146 in.*) in the very thin Duagh soil. A somewhat similar but softer layer was encountered at a depth of 610 cm (*240 in.*) in the Duagh silt loam. Samples of these materials were very difficult to filter and the extracts were highly colored. This appeared to be a layer of carbonaceous shale.

The frost-free period above 0°C averaged about 87 days. Solonetzic soils in the Dark Brown and Brown soil zones are in a low-moisture region, but the climate has a rather long frost-free period. For example, the average annual precipitation at Brooks, Alta., is 305 mm (*12 in.*) and at Weyburn, Sask., it is about 406 mm (*16 in.*); the frost-free period at Brooks is 120 days and at Weyburn 100 days.

MANAGEMENT

Large quantities of soluble salts in the profile of these soils poses management problems. These salts move vertically. Management practices must minimize the upward movement of salts to prevent a buildup of salt in the A horizon (Fig. 5).

Drainage

Surface drainage, where practical and economical, is very valuable. Water does not readily move into these soils so if it is not drained from the surface it tends to evaporate where it lies, leaving a residue of salt. The removal of subsurface water by ditch or tile drainage is not generally practical because of the very slow movement of water within Solonetzic soils.

Fig. 5. Salt accumulation on the soil surface in a Solonetzic area.

Tillage practices

The main purpose of tillage is to prepare a fine, firm seedbed and to reduce surface crusting. The exact operations required to achieve these conditions vary greatly from year to year. In general, the soils tend to be mellower if they are worked during cool weather or when they are moderately dry. Working them during hot weather or when they are wet causes them to bake into cinder-like structures. These relationships must be kept in mind during all tillage operations on these soils.

Working the soil to a depth greater than 10–15 cm (*4–6 in.*) but less than 45 cm (*18 in.*) has not appreciably increased yields, and some practices, such as 36-cm (*14-in.*) plowing, have created problems in seedbed preparation. Bringing the hard B horizon to the surface has given no significant increase in yield, and has increased soil baking and crusting. The practice of deep plowing is discussed later in this publication.

Seeding

For successful seeding, the seed must be placed in firm contact with moist soil. This is essential for all crops sown on these soils. On normal soils, rains after seeding may prove beneficial for seedling emergence, but on Solonetzic soils the rains are more likely to prevent emergence

Fig. 6. Crusting of Solonetzic soils caused by heavy rain and rapid drying before the emergence of cereal crops.

because they cause a crust to form on the soil surface (Fig. 6). The main objective is to create conditions favorable to rapid seedling emergence.

A successful seeding method followed at the Solonetzic Soil Substation at Vegreville has been to drill the cereal crops and bromegrass down to moist soil with a press drill, and then to cross-drill alfalfa down to moist soil before the grain crops emerge. The packing done in the first operation prevents excessive penetration in the second. Although this method has been successful, other methods may be used as long as they fulfill the requirements of seed placement and soil packing. Broadcast seeding of forage crops has rarely proved successful for establishment of a stand.

A new hay stand on strongly developed Solonetz soils may have bare patches. Breaking the entire area for reseeding provides little benefit; the same patches that were bare after the first seeding are likely to be bare after the second one. Seed may be drilled into the bare patches when the soil is firm enough to carry the equipment, yet soft enough to allow penetration. This practice usually gives some seedling establishment in these patches and eliminates the expense of reseeding the whole area.

Crops

Usually, crops and varieties that are adapted to the normal soils of a district can be successfully grown on the Solonetzic soils of the same district.

Forage crops improve the tilth of Solonetzic soils, and their inclusion in a cropping system is desirable. Seven grasses were compared at Vegreville for 5 years (Table 6). Bromegrass, intermediate wheatgrass, and creeping red fescue gave about equal average yields over the 5 years. Intermediate wheatgrass gave higher yields than bromegrass in the seeding year, but considerably lower yields in the 4th and 5th years after seeding. Crested wheatgrass, reed canarygrass, meadow fescue, and timothy gave adequate but lower production than the other three grasses.

More recent 3-year studies have shown that bromegrass outyields western wheatgrass, tall wheatgrass, and Altai wild ryegrass (Table 7). The slender wheatgrass cultivar Revenue outyielded bromegrass, but its

Table 6. Five-year average dry matter yield of seven grass species grown on fertilized Duagh silt loam at Vegreville, Alta.

Species	Average yield of dry matter kg/ha	*lb/ac*
Bromegrass	4010	*3580*
Intermediate wheatgrass	3990	*3560*
Crested wheatgrass	3430	*3060*
Reed canarygrass	3380	*3020*
Meadow fescue	3380	*3020*
Timothy	3610	*3220*
Creeping red fescue	3920	*3500*

Table 7. Three-year average dry matter yields of grasses and alfalfa grown for hay on fertilized Duagh silt loam at Vegreville, Alta.

Species	Average yield of dry matter kg/ha	*lb/ac*
Carlton bromegrass	3725	*3326*
Magna bromegrass	3883	*3467*
Manchar bromegrass	3781	*3376*
Western wheatgrass	3135	*2799*
Revenue slender wheatgrass	4444	*3968*
Orbit tall wheatgrass	2717	*2426*
Altai wild ryegrass	2600	*2321*
Rambler alfalfa	4375	*3906*
Beaver alfalfa	4049	*3615*
Roamer alfalfa	3744	*3343*
Drylander alfalfa	4580	*4089*

best yields were produced in the first 2 years after seeding. In the 3rd year it yielded less than bromegrass. There was little difference in the productivity of Carlton, Magna, and Manchar bromegrasses.

Alfalfa can be readily established on these soils and is generally more productive than other legumes. The cultivars Rambler and Drylander outyielded Beaver and Roamer. The contribution alfalfa makes to the total yield is determined by the severity of the Solonetzic condition. On the more productive Solonetzic soils it yields well, but on the less productive phases, the plants are spindly and unproductive. It is suggested that a small amount of alfalfa may be seeded, because it may contribute slightly to the yield of the 1st-year hay, but it is also suggested that fertilization should be aimed at increasing the yield of bromegrass rather than alfalfa.

Cereal crops harvested as green feed during the 3 years from 1972 to 1974 produced an average dry matter yield of 5345 kg/ha (*4772 lb/ac*) as compared with an average dry hay yield of 4003 kg/ha (*3574 lb/ac*) at Vegreville. These yields are composites of fallow and stubble wheat, oats, and barley for green feed and of 1st- to 3rd-year hay crops for hay. In general, 1974 had the highest yielding green feed crop and 1972 had the lowest yielding. The hay was a mixture of bromegrass and alfalfa.

Seeding rates may be obtained from the Alberta Farm Guide or other publications on cereal, hay, and pasture crops.

Cropping systems

In general, the cropping system adapted to the non-Solonetzic soils of the district is also suitable for the Solonetzic soils. However, this general rule is modified by three considerations. First, the most strongly developed Solonetzic soils should be seeded to grass because of the high cost of seedbed preparation and the likelihood of crop loss caused by the difficulty of preparing a proper seedbed and the possibility of crusting. Second, rather strongly developed Solonetzic soils should be farmed with a cropping system that includes forage crops, because such crops have a mellowing effect on the soil. Third, weakly developed Solonetzic soils may be successfully used to grow cereals exclusively, provided the crop residue is left in the field. The cropping system that is used depends largely on the soil condition.

Solonetzic soils occur under a wide range of climatic conditions, and climate influences crop selection; for example, forage crops are generally more suited to areas of reasonably high precipitation. The results of using various cropping systems for 16 years on fairly strongly developed Solonetzic soil at Vegreville are worthy of consideration. The four cropping systems and their results follow.

Continuous wheat

The average gross yearly revenue from continuous wheat was $200/tillable ha (*$81/tillable ac*) averaged over the rotation. In this system, returns varied more from year to year than in any other system studied. The highest revenue since the system was started in 1959 was $326/ha (*$132/ac*) in 1971. The best returns were obtained in moderately dry years. The weed control problem required special attention. The soil was difficult to work for the first few years, but it has improved in recent years.

Fallow–wheat

The rotation of fallow followed by wheat, which uses only half the land in crop each year, grossed about $49/ha (*$20/ac*) less than continuous wheat each year. The average gross revenue varied little from year to year. This rotation system minimized weed problems.

Fallow–wheat–barley

With two-thirds of the land in crop, the fallow—wheat—barley system produced an average annual gross revenue of $195/ha (*$79/ac*). This system had a greater variability in returns that the fallow—wheat system because of the greater susceptibility of the stubble crops to weather conditions. This rotation system offers an excellent combination of weed control, soil conditioning, and productivity.

Wheat–oats–barley–hay–hay–hay and break

A 6-year rotation of wheat followed by oats, barley, hay, hay, and hay and break produced average annual returns of $158/ha (*$64/ac*) with a fairly high variability. The variability was caused by the marked susceptibility of forage crops to drought. This was an easily managed system, well suited to mellowing the hard, Solonetzic soils.

In the rotation studies, crops were valued at $130, $100, and $60/tonne (*$3.54, $2.18, and $0.93/bu*) for wheat, barley, and oats respectively, and $33/tonne (*$0.015/lb*) for hay. Crops have been fertilized since 1961 as follows: fallow crops with ammonium phosphate (11-48-0) at 67 kg/ha (*60 lb/ac*); stubble and continuous crops with ammonium nitrate-phosphate (26-13-0) at 90 kg/ha (*80 lb/ac*); and hay crops with ammonium nitrate (34-0-0) at 224 kg/ha (*200 lb/ac*).

FERTILITY

Solonetzic soils generally contain less nitrogen and release less nitrogen to the growing crop than do associated non-Solonetzic soils. The small amount of nitrogen in a unit volume of soil is not the only problem. Often, Solonetzic areas have less than half as much topsoil as other soil areas, and almost all the released nitrogen comes from this topsoil layer.

Although the scarcity of nitrogen is the main limitation to crop production, available phosphorus or potassium may also be lacking on a particular soil. None of the many Solonetzic soils studied have been found deficient in potassium, but their nutrient contents are extremely variable and such deficiencies may occur.

Cereal crops

With cereal crops on fallow, the use of fertilizers such as ammonium phosphate (11-48-0) at 67 kg/ha (*60 lb/ac*) and ammonium nitrate-phosphate (23-23-0) at 78 kg/ha (*70 lb/ac*) has been profitable at Vegreville. With crops on stubble and crops on breaking, the application of ammonium nitrate-phosphate (26-13-0) at 90 kg/ha (*80 lb/ac*) has been profitable. As nutrient requirements may vary from place to place, soil analysis will be helpful in designing a fertilizer program.

Forage crops

Forage crops on Solonetzic soils usually respond very well to nitrogen fertilizer (Fig. 7). At Vegreville, after ammonium nitrate

Fig. 7. Increased production on a 20-year-old stand of brome hay by the liberal use of ammonium nitrate fertilizer.

(34-0-0) at 224 kg/ha (*200 lb/ac*) was applied every year for 14 years, the average annual dry matter yield of bromegrass was 2681 kg/ha (*2394 lb/ac*), as compared with 1156 kg/ha (*1032 lb/ac*) when no fertilizer was used. In studies conducted for 3 years on various Solonetzic soil types throughout Alberta, similar results with bromegrass were common (Table 8). In the Brown soil zone the lack of moisture restricted crop response. At some locations, even in the Black soil zone, the Solonetzic condition was so severe that it restricted plant stand and consequently crop response. Applications of phosphorus and potassium on Solonetzic soil types have not given profitable responses in hay crops.

Bromegrass fertilized with ammonium nitrate (34-0-0) on Duagh silt loam contained more nitrogen and potassium and less sodium, aluminum, and iron than unfertilized bromegrass (Table 9). After 5 years of fertilization, the amount of salt in the A horizon was half that in unfertilized areas, twice as many roots had developed, and the soil was mellower (Table 10).

Supplemental irrigation of forage crops

In the Brown soil zone where the lack of moisture restricted crop response to nitrogen in some years, a study was conducted to measure the effect of supplemental water combined with fertilizer on yield of bromegrass (Table 11). During the 6 years from 1969 to 1974, the application of 7.6 cm (*3.0 in.*) of water a year, in addition to ammonium nitrate (34-0-0) fertilizer at a rate of 448 kg/ha (*400 lb/ac*), resulted in yields of 1210 kg/ha (*1080 lb/ac*) more dry matter per year than applications of fertilizer alone; but in 1974, a year of greater natural precipitation, there was no benefit. The use of supplemental water without fertilizer did not significantly increase production on

Table 8. Three-year average dry matter yields of bromegrass on eight Solonetzic soils after annual applications of ammonium nitrate at 224 kg/ha (*200 lb/ac*) as compared with the yield on unfertilized plots

		Dry matter yield of bromegrass			
		Unfertilized plots		Fertilized plots	
Location	Soil	kg/ha	*lb/ac*	kg/ha	*lb/ac*
Kavanagh	Kavanagh loam	1987	*1774*	3684	*3289*
Ryley	Thin Camrose loam	1771	*1581*	3703	*3306*
Bruce	Torlea loam	2035	*1817*	4465	*3987*
Camrose	Camrose loam	1648	*1471*	3537	*3158*
Chipman	Whitford loam	1337	*1194*	3407	*3042*
Halkirk	Halkirk loam	1365	*1219*	4359	*3892*
Halkirk	Torlea loam	1219	*1088*	3646	*3255*
Coronation	Hemaruka loam	1214	*1084*	2445	*2183*

Table 9. Effect of annual applications of ammonium nitrate at 448 kg/ha (*400 lb/ac*) as compared with no fertilizer application on the average chemical composition of bromegrass grown on Duagh silt loam, Vegreville, Alta., from 1962 to 1965

Treatment	N %	NO_3-N %	P %	K %	S %	Na %	Ca %	Mg %	Cl %	Al %	Fe %	Cu ppm	Mn ppm
Unfertilized	1.64	0.10	0.18	1.60	0.26	0.11	0.36	0.18	0.15	0.05	0.03	21	158
Fertilized	2.57	0.26	0.13	2.11	0.20	0.03	0.31	0.14	0.13	0.01	0.01	18	111

Table 10. Effect of annual fertilizer applications of ammonium nitrate at 896 kg/ha (*800 lb/ac*) for 5 years on bromegrass growth and various properties of the A horizon of Duagh silt loam at Vegreville, Alta.

Factor measured	Unfertilized	Fertilized
Average dry matter crop yield (kg/ha)	1504	6773**
(*lb/ac*)	*1343*	*6047***
A horizon soil contents		
Plant roots (dry matter) (kg/ha)	6608	12096**
(*lb/ac*)	*5900*	*10800***
Soluble sodium (meq/100 g)	1.24	0.75**
Exchangeable sodium (meq/100 g)	3.84	1.85**
Exchangeable sodium (% of exch. bases)	17.34	8.92**
Exchangeable calcium (% of exch. bases)	47.81	61.04**
Soil hardness (unconfined strength) (kg/cm^2) (*$tons/ft^2$*)	1.45	0.66*

*Significant at the 5% level.
**Significant at the 1% level.

Table 11. Effect of modified irrigation and fertilization of Solonetzic soils on dry matter yield of bromegrass on two separate farms near Coronation, Alta., in the Dark Brown soil zone

	Dry matter yields of bromegrass							
	Hemaruka loam (SE-26-36-11-W4)				Halkirk loam (SE-28-33-11-W4)			
	1974		1969–74 av.		1974		1972–74 av.	
Treatment*	kg/ha	*lb/ac*	kg/ha	*lb/ac*	kg/ha	*lb/ac*	kg/ha	*lb/ac*
Dryland, unfertilized (control)	1980	*1768*	1568	*1400*	1347	*1203*	1279	*1142*
Dryland, fertilized	3515	*3138*	2906	*2595*	4739	*4231*	5316	*4746*
Irrigated, unfertilized	2279	*2035*	2129	*1901*	1329	*1187*	1169	*1044*
Irrigated, fertilized	3581	*3197*	4115	*3674*	3616	*3229*	3965	*3540*

*Fertilizer treatments were ammonium nitrate (34-0-0) at 448 kg/ha (*400 lb/ac*) applied annually to dryland in the fall and irrigated land in early spring. Irrigated land received 7.6 cm (*3.0 in.*) of water annually in early spring.

Hemaruka loam or Halkirk loam. Additional water in some years can cause losses, such as those recorded for Halkirk loam, because of waterlogging in soils with a very low rate of water penetration.

Sources of nitrogen for grass

Ammonium nitrate (34-0-0), ammonium sulfate (21-0-0), and urea (45-0-0) applied to provide nitrogen at a rate of 112 kg/ha (*100 lb/ac*) annually were compared for 12 years at Vegreville as fertilizers for bromegrass (Table 12). All these fertilizers were equally effective in increasing yield in all years except the drought year, 1966, when urea was less effective than the others. In the 10 years from 1963 to 1972, the average recovery of nitrogen was 42% for ammonium nitrate, 40% for ammonium sulfate, and 34% for urea. Ammonium sulfate caused an undesirable increase in soil acidity from pH 5.6 to pH 3.9 during the 10 years. Laboratory study has shown that ammonium nitrate substantially increases the rate of penetration of water into these soils (Table 13), but urea does not. Ammonium nitrate is the most desirable nitrogen fertilizer readily available for fertilizing grass on Solonetzic soils, even though it also increased acidity.

Calcium compounds

Agricultural limestone has proven beneficial to some Solonetzic soils, improving both productivity and physical properties in greenhouse and field experiments. Limestone has greater value on Solonetzic soils with surface layers that have pH levels below 6.0, than on

Table 12. Effect of annual applications of nitrogen fertilizers at 112 kg/ha (*100 lb/ac*) on the dry matter yield of bromegrass grown on Duagh silt loam at Vegreville, Alta.

	Average dry matter yield				
	1963–67		1963–74		Soil pH
Fertilizer treatment	kg/ha	*lb/ac*	kg/ha	*lb/ac*	1972
No fertilizer	1606	*1434*	1295	*1156*	5.6
Ammonium nitrate	3985	*3558*	3274	*2923*	4.7
Ammonium sulfate	3881	*3465*	3039	*2713*	3.9
Urea	3660	*3268*	3018	*2695*	4.9

Table 13. Laboratory results of the effect of ammonium nitrate on water movement in Duagh silt loam at Vegreville, Alta.

Soil horizon	Treatment	Infiltration rate (mm/h)
A	Water	0.12
	0.06 N ammonium nitrate	7.08
B	Water	0.10
	0.06 N ammonium nitrate	2.78

Solonetzic soils that have higher pH levels in the surface layers. There have been three problems connected with its use: it has generally been fairly costly and is not readily available in Western Canada; the hard B horizon still presents a barrier to increased productivity; and it is very slowly soluble. Farmers with acid Solonetzic soils who wish to test this material should have a lime requirement test conducted at the Provincial Soils and Feed Testing Laboratory.

Gypsum has proved beneficial to some Solonetzic soils, especially in improving the physical properties of the soil. The same problems have been associated with its use as with limestone, and also it does not correct acidity.

Several years of research at Coronation, Alta., have indicated that gypsum may be fairly effective in improving the soil and its productivity when combined with nitrogen fertilizers (Table 14). The calcium had penetrated the columns of the B horizon and mellowed them. However, those results were obtained on only one soil at one rate of application and a final interpretation will only be possible when results are available from studies now in progress on several Solonetzic soils. Farmers whose land is located on Solonetzic soils with a pH level of 6.0 or greater, and who have ready access to a fertilizer plant where large quantities of gypsum are produced as a by-product, may wish to test this method of soil improvement on a small area. It is obvious that the rate applied in the study at Coronation was considerably greater than required because a large amount accumulated in the C horizon, where it is not needed.

DEEP PLOWING OF SOLONETZIC SOILS

Deep plowing might best be described as mixing the soil horizons. The soil is plowed to a depth of more than 40 cm (*16 in.*), but it is not inverted as it might be with ordinary plowing. The A, B, and C horizons are mixed by deep plowing. These horizons of Solonetzic soils are respectively the top soil, the hard layer beneath it, and the lime-salt layer beneath the hard layer. Deep plowing mixes them in nearly equal proportions.

Preliminary studies

Mixing the A and C horizons of Duagh silt loam caused a 10-fold increase in the growth of wheat in the greenhouse when compared with the growth of wheat on the A horizon soil alone. Plowing this Solonetzic soil at Vegreville to a depth of 60 cm (*24 in.*) could draw 27–40 tonnes/ha (*12–18 tons/ac*) of gypsum and 45–67 tonnes/ha (*20–30 tons/ac*) of calcium carbonate up into the low-calcium A and B

Table 14. Effect of surface-applied gypsum on average dry matter yield and chemical composition of bromegrass and on exchangeable calcium in A, B, and C horizons of Hemaruka loam at Coronation, Alta.

Annual treatment* with nitrogen		Annual treatment with gypsum		Bromegrass 1971–74 av. yield		Bromegrass chemical composition, 1974						Soil exchangeable Ca (meq/100 g)		
						N	P	K	Na	Ca	Mg			
kg/ha	*lb/ac*	t/ha	*tons/ac*	kg/ha	*lb/ac*	%	%	%	%	%	%	A	B	C
0	*0*	0	*0*	2162	*1930*	1.03	0.09	1.00	0.07	0.43	0.10	–†	–	–
152	*136*	0	*0*	4045	*3612*	1.40	0.07	1.13	0.05	0.33	0.10	5.18	3.20	10.52
152	*136*	4.5	*2*	4919	*4392*	0.91	0.07	1.26	0.04	0.56	0.08	9.59	7.63	28.40

*All plots irrigated annually with 7.6 cm (*3.0 in.*) of water early in spring.
†– indicates that there are no data.

horizons. Plowing offers a far more economical way of supplying the needed calcium to these soils than any alternative source of supply (Fig. 8).

In early field trials at Vegreville, the soil was dug to a depth of 60 cm (*24 in.*) and then mixed and replaced. Subsequent wheat and barley crops grown successsively after digging showed a yield increase caused by the digging and soil horizon mixing. Both wheat and barley crop yields increased about 33% over a period of 6 years.

Field studies

Field experiments have been conducted in Alberta at Chipman, Coronation, Enchant, Fleet, Halkirk, Hanna, Lamont, Leduc, Legal, Vegreville, and Viking. A specially built plow was used at all locations (Fig. 9).

Because of the difficulty in averaging yields of various crops, we have calculated and averaged the gross financial returns to interpret the results of deep plowing studies (Table 15). The increased value of crop production derived from deep plowing alone varied from about $10/ha (*$4/ac*) annually on one site at Vegreville to $111/ha (*$45/ac*) annually on a site at Coronation. The highest increase for 1 year, $171/ha (*$69/ac*), occurred at Chipman on Duagh silt loam.

At Vegreville, deep plowing had little beneficial effect on the yield of cereal crops grown from 1960 to 1965 because management practices had been discovered that permitted the production of good cereal crops on normally tilled Duagh silt loam. These practices

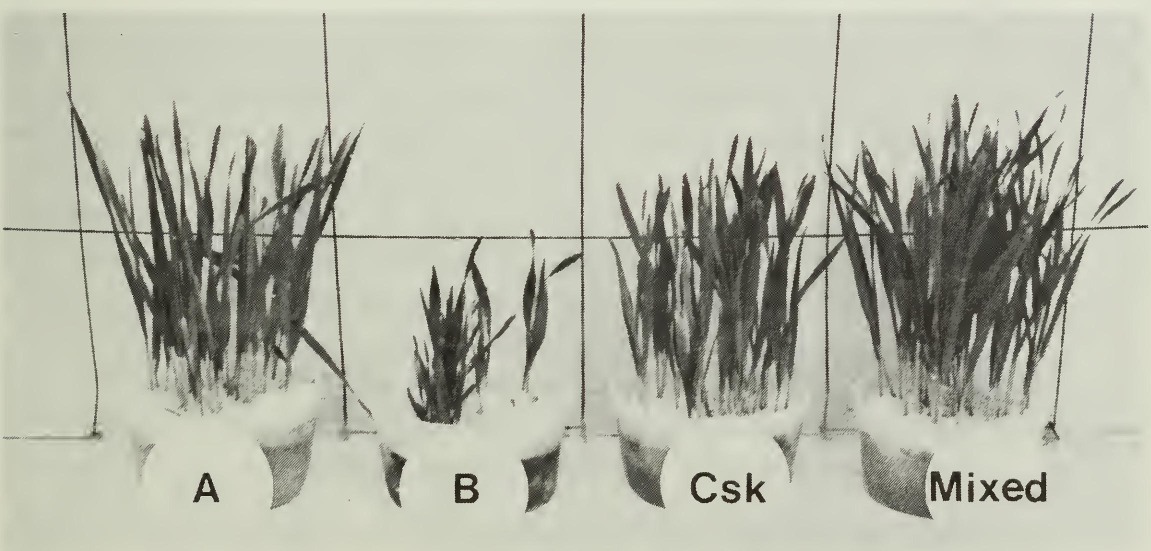

Fig. 8. Greenhouse pot tests show barley growth on soil samples from various horizons of a Solonetzic soil and on a 1:1:1 mixture of the horizons. The results suggest one of the effects of deep plowing where the horizons are mixed.

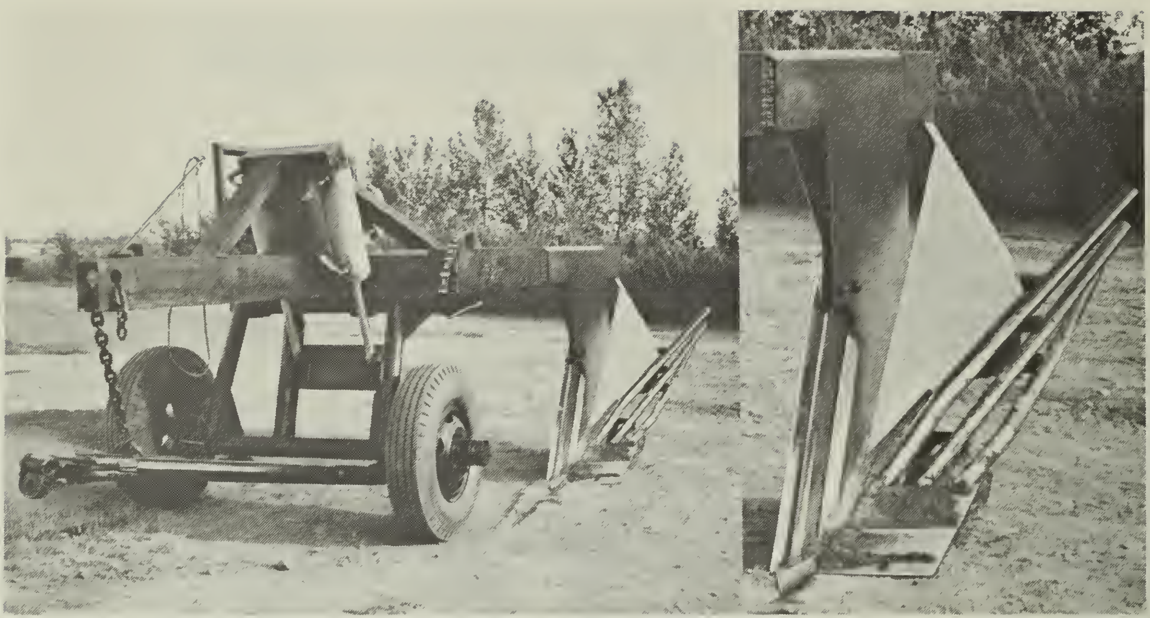

Fig. 9. Plow manufactured in 1967 and capable of thoroughly mixing the soil where buried stones or boulders are likely to be encountered.

included surface drainage, seedbed preparation, careful seeding, and the judicious use of fertilizer.

The beneficial effect of deep plowing was reflected in the hay crops grown in the 4 years from 1966 to 1969. The hay crop yield was increased from 2100 kg/ha (*1875 lb/ac*) annually on normally cultivated soil to 3284 kg/ha (*2932 lb/ac*) on the deep-plowed soil. The increase was largely a result of the improved growth of alfalfa, which could not be achieved on normally plowed soil by improved management.

A 6-year study was conducted at Coronation to determine the effect of deep plowing and the application of fertilizer in water on crop response. Under dryland conditions, deep plowing increased the dry matter yield of forage to about 2094 kg/ha (*1870 lb/ac*) from an average of about 1568 kg/ha (*1400 lb/ac*) annually on normally plowed soil. Where water was applied at the rate of 7.6 cm (*3.0 in.*) a year, deep plowing increased the dry matter yield from about 2130 kg/ha (*1900 lb/ac*) to about 3700 kg/ha (*3300 lb/ac*) annually. Where both the normally plowed area and the deep-plowed site were watered and fertilized, the average annual dry matter yields were about 4145 kg/ha (*3700 lb/ac*) and 5150 kg/ha (*4600 lb/ac*) respectively.

Reasons for beneficial effects

Variability in the response to deep plowing exists among the sites studied. The reasons for this variability have been examined. Most soil scientists have attributed the beneficial effect of deep plowing almost

Table 15. Effect of deep plowing on the productivity of various Solonetzic soils in Alberta, as indicated by the gross annual returns from the various treatments

					Av. gross annual return, $/ha (*$/ac*)*			
					Normally plowed soils		Deep-plowed soils	
Location	Soil	Site no.	No. of crop yr	Crops†	No fert.	Fert.‡	No fert.	Fert.‡
Chipman	Duagh silt loam	1	5	BG1, H4	84 (*34*)	178 (*72*)	133 (*54*)	193 (*78*)
		2	1	B1	143 (*58*)	222 (*90*)	314 (*127*)	487 (*197*)
Coronation	Hemaruka loam	1	5	B2, H3	109 (*44*)	131 (*53*)	126 (*51*)	124 (*50*)
		2	7	B1, H6	64 (*26*)	143 (*58*)	101 (*41*)	190 (*77*)
		3	6	H6	52 (*21*)	96 (*39*)	69 (*28*)	128 (*52*)
		4	2	B2	74 (*30*)	– (–)	185 (*75*)	– (–)
		5	1	W1	168 (*68*)	– (–)	215 (*87*)	– (–)
Enchant §	Hemaruka loam		1	W1	217 (*88*)	230 (*93*)	249 (*101*)	301 (*122*)
Fleet	Halkirk loam		1	H1	54 (*22*)	91 (*37*)	121 (*49*)	136 (*55*)
Halkirk	Halkirk loam		2	O1, H1	74 (*30*)	– (–)	124 (*50*)	– (–)
Hanna	Sunnynook loam		2	OG1	89 (*36*)	– (–)	153 (*62*)	– (–)
Lamont	Duagh silt loam		3	B1, H2	35 (*14*)	94 (*38*)	79 (*32*)	131 (*53*)
Leduc	Kavanagh loam	1	6	B1, H5	47 (*19*)	111 (*45*)	89 (*36*)	156 (*63*)
		2	4	OBW4	116 (*47*)	170 (*69*)	175 (*71*)	198 (*80*)
Legal	Camrose loam		3	BG1, H2	40 (*16*)	121 (*49*)	124 (*50*)	227 (*92*)
Vegreville	Duagh silt loam	1	6	B1, H5	62 (*25*)	94 (*38*)	72 (*29*)	146 (*59*)
		2	11	W3, B2, O2, H4	175 (*71*)	– (–)	205 (*83*)	– (–)
Viking	Torlea loam		3	B1, H2	52 (*21*)	52 (*21*)	119 (*48*)	128 (*52*)

Wheat, barley, and oats were valued at $130, $100, and $60 a tonne ($3.54, $2.18, and $0.93 a bushel*) respectively. Hay and green feed were each valued at $33 a tonne (*$0.015 a lb*).

†BG1, H4 means barley as green feed for 1 yr and hay for 4 yr; B1 means barley for 1 yr; B2, H3 means barley for 2 yr and hay for 3 yr; OG1 means oats as green feed for 1 yr; OBW4 means oats, barley, wheat mixture for 4 yr; and W3, B2, O2, H4 means wheat for 3 yr, barley for 2 yr, oats for 2 yr, and hay for 4 yr.

‡Crops fertilized annually with a blanket application of N at 158 kg/ha (*141 lb/ac*); P_2O_5 at 137 kg/ha (*122 lb/ac*), and K_2O at 168 kg/ha (*150 lb/ac*) except at Coronation site 3 where the application was 34-0-0 at 448 kg/ha (*400 lb/ac*). These data for the effect of fertilizers are given to illustrate the similarity between the effects of plant nutrition and deep plowing. The treatments were not intended to be economical, but to assure adequate nutrition. The same crop response can be achieved at most locations with much lower levels of fertilizer than those applied. The costs of fertilizers and management practices are not included in calculations of dollars returns for this reason.

§Irrigated crops.

entirely to the leaching of salt out of the upper layers of soil after deep plowing. Contrary to those opinions, our studies have shown that the leaching of sodium after soil mixing is nutritionally unnecessary. Greenhouse studies have shown that under conditions of adequate moisture, leaching actually decreases the beneficial effects of soil horizon mixing on plant growth. Field studies have shown that increased crop growth results after deep plowing regardless of whether or not leaching of sodium occurs (Table 16). A great deal of sodium leached from the upper layers of soil at Vegreville, where the increased returns from deep plowing averaged only about $10/ha (*$4/ac*) annually. By contrast, very little leaching occurred at Leduc or Chipman but the increased returns from deep plowing were generally greater.

Field, greenhouse, and laboratory studies have shown that deep plowing has much the same effect on crop production as a dressing of nitrogen fertilizer. This effect was probably caused by an increase in soil pH that resulted from the introduction of calcium carbonate into the A horizon from the C horizon. The nearly neutral pH level of the mixed soil horizons favors the activity of microbes, especially those associated with soil and legume nitrogen, much more than does the generally low pH level of the A horizon of these soils.

Another beneficial effect of deep plowing on Solonetzic soils is the increased availability of moisture, which results in increased root activity in the soil depth below the A horizon. Studies have shown that fertilized crops or crops grown after deep plowing remove more moisture to a greater soil depth than unfertilized crops or crops that

Table 16. Sodium content of soil measured by saturation extract methods (1972) after deep plowing of Solonetzic soil at various locations

Location	Soil	Year plowed	Depth*		Soluble sodium (meq/100 g)	
			cm	*in.*	Normally plowed	Deep plowed
Chipman	Duagh silt loam	1966	0–9	*0–3.5*	2.99	4.82
			9–25	*3.5–10*	5.21	7.20
Coronation	Hemaruka loam	1967	0–15	*0–6*	2.41†	1.08†
			15–30	*6–12*	4.90†	5.89†
Leduc	Kavanagh loam	1966	0–9	*0–3.5*	1.34	1.80
			9–25	*3.5–10*	3.49	2.89
Vegreville	Duagh silt loam	1959	0–13	*0–5*	2.84	0.84
			13–25	*5–10*	7.05	2.37
Viking	Torlea loam	1966	0–9	*0–3.5*	2.84	0.96
			9–25	*3.5–10*	6.32	2.34

*Depth refers to the depth of the A and B horizons of unplowed soil and comparable depths in the deep-plowed soil.
†Soluble sodium measured in 1:5 soil-to-water extracts.

were grown on normally plowed soil. This additional effect of either fertilizing or plowing is common and indicates that plants grown on unfertilized or normally plowed Solonetzic soil do not have the vigor for adequate root penetration. The hard B horizon is a physical barrier to root penetration, but because irrigation without fertilization can decrease productivity, adequate plant nutrition is the main barrier to productivity, and availability of water is a secondary barrier.

Calcium-to-sodium ratio

Although the leaching of sodium may not be a critical factor in plant nutrition, the results of every study indicate that it helps to improve the physical properties of the soil. Sodium destroys the physical properties of the soil, whereas calcium improves them. Ideally, the ratio of exchangeable calcium to sodium in a soil should be greater than 10:1. Although the ratio of calcium to sodium is important, leaching even a non-Solonetzic soil with very dilute solutions of sodium salts severely impedes the subsequent entry of water into the soil. The presence of sodium increases the hardness of the soil and the soil loses its mellowness. With a calcium-to-sodium ratio of less than 4:1, preparing a seedbed is almost impossible. These problems are very severe in Solonetzic soils because of their fine textures. When the calcium content of the upper layers of soil was increased and sodium was subsequently leached, deep-plowed Duagh silt loam at Vegreville had a greater quantity of water-stable aggregates, a lower breaking strength, and a higher infiltration rate than Duagh silt loam that was not deep plowed.

Duration of beneficial effects

It is impossible at present to predict accurately how long the beneficial effects of deep plowing will last. The beneficial effect on productivity and soil condition has persisted at Vegreville on Duagh silt loam for 16 years and is apparent at several other locations 9 years after plowing. There is no evidence to suggest that the soils are reverting to their original condition.

Predicting benefits from deep plowing

A simple diagnostic method of predicting the degree of response to deep plowing is being sought. No such method has been found. However, it was established for the soils studied that the less productive the B horizon, or the greater the resistance to root penetration, the more responsive the soil was to deep plowing. For example, the B horizon of Duagh silt loam was as productive as the A horizon and the percentage yield increase from deep plowing was somewhat less than at other locations. Cereal crops were not very responsive to deep plowing at Vegreville, but were more responsive at several other locations, including Leduc. The yields of crops on both deep-plowed and normally plowed areas were dependent on the adaptation of the crops grown, seasonal conditions, and the original productivity of the test site.

Depth of plowing

The depth of plowing required to achieve the benefits possible depends largely on the thickness of the various soil horizons. The plow should penetrate the C horizon to a depth that will provide about a 1:1:1 mixture of the A, B, and C horizon soils. A soil with A and B horizons that are both about 15 cm (*6 in.*) deep should be plowed to a depth of about 45 cm (*18 in.*). In general the plowing should be 40–60 cm (*16–24 in.*) deep. Plowing to a depth of more than 15 cm (*6 in.*) but less than 40 cm (*16 in.*) can damage the soil. If the plowing draws little or no C horizon up into the A and B horizons, the soil becomes hard and unproductive. Deep plowing to a depth of 36 cm (*14 in.*) at Vegreville caused a 5-year average annual loss of about $12/ha (*$5/ac*). Problems can also be caused by plowing too deep. A large plow was built and used for several studies. A tendency to plow too deep with this machine brought up too much of the C horizon and diluted the original A horizon. A reinforced regular breaking plow (Fig. 10) is now used, except where many buried stones could destroy the plow. In

Fig. 10. Regular breaking plow that has been modified and reinforced and is capable of plowing to a 56-cm (*22-in*) depth.

general, buried stones are not a problem on water-deposited (lacustrine) soils, but they are a problem on glacial-deposited (till) soils.

Preparing an adequate seedbed in the first year after plowing is sometimes difficult. However, the tilth of the soil gradually improves and becomes mellow with time and cropping. Research is currently under way in cooperation with the Alberta Department of Agriculture to find a plow design that will allow more of the natural topsoil to remain on the surface and to determine if this will make seedbed preparation easier.

Cost of deep plowing

Measuring the cost of plowing is difficult, because the areas plowed were generally small and required a great deal of turning. However, in 1972, studies in cooperation with the Alberta Department of Agriculture attempted to determine the operating costs. Using a large plow and a D-8 Caterpillar tractor near Hanna, and plowing to a depth of 56–61 cm (*22–24 in.*) cost $49/ha (*$20/ac*). Using a reinforced breaking plow and a 108.2-kW (*145-hp*) four-wheel-drive tractor at Leduc, plowing to a depth of 46 cm (*18 in.*) cost $42/ha (*$17/ac*) (Fig. 11). At Chipman the operating cost of plowing 2- and 4-ha (*5- and 10-ac*) areas was about $37/ha (*$15/ac*) using similar farm tractors with

Fig. 11. Deep plowing a Solonetzic soil to a depth of 50 cm (*20 in.*) using a four-wheel-drive tractor.

tractor rental rates of $10/h. The costs varied widely and have increased with inflation.

Alternative methods of mixing the soil horizons

Chiseling to a 56-cm (*22-in.*) depth has been studied as an alternative to deep plowing. A 15-year average annual return of $74/ha (*$30/ac*) was obtained from hay fertilized with ammonium nitrate (34-0-0) at 224 kg/ha (*200 lb/ac*) per year after chiseling. This return may be compared with $67/ha (*$27/ac*) from fertilized hay on Duagh silt loam that was not chiseled. Where fertilizer was not applied, the annual returns were $22/ha (*$9/ac*) on soil that was not chiseled and $27/ha (*$11/ac*) on chiseled areas.

A slip plow, which elevates a slice of soil, was built from an old blade implement. It increased crop yields but required as much power to pull as the plow. A method of soil horizon mixing to compete with the plow has not yet been found.

IRRIGATION OF SOLONETZIC SOILS

There are large areas of Solonetzic soils within the irrigation districts in Alberta that have been considered nonirrigable, because of their potential for salinization. Studies have been started in cooperation with the Alberta Department of Agriculture to determine whether or not they could be irrigated successfully. It is almost certain on the basis of studies conducted elsewhere and a general knowledge of the soil that flood irrigation would not be successful. The present studies deal with the possibility of using sprinkler irrigation in combination with soil improvement practices developed for dryland conditions. Two of these practices are deep plowing and the use of nitrogen fertilizers.

At Enchant in southern Alberta, a study was conducted using the following treatments: irrigation alone; irrigation and nitrogen fertilization; irrigation and deep plowing; and irrigation, nitrogen fertilization, and deep plowing. Water was applied throughout the growing season to meet the requirements gauged by soil-moisture tensiometers. Ammonium nitrate-phosphate (34-17-0) fertilizer at 336 kg/ha (*300 lb/ac*) was applied annually in the spring with a fertilizer spreader and disced into the soil. The 2-year average dry matter yields of alfalfa from irrigation alone; from irrigation and nitrogen fertilizer; from irrigation and deep plowing; and from irrigation, nitrogen fertilizer, and deep plowing were 4298, 5095, 5488, and 6489 kg/ha (*3838, 4549, 4900, and 5794 lb/ac*) a year respectively. No stand could be established on the nonirrigated areas. Although these results are promising from a crop yield standpoint, the irrigation of Solonetzic soils should still be considered extremely hazardous. The potential for salinization is great and the studies must be conducted for at least 3 years to properly assess the probable long-term effect of applied water on salt distribution.

SUMMARY

Solonetzic soils are characterized by a thin layer of topsoil, or A horizon, underlain by a massive, columnar, structured B horizon, which in turn is underlain by a lime-salt layer, or C horizon. The C horizon often begins at 30–48 cm (*12–18 in.*) below the soil surface. The following practices have been found helpful in increasing the productivity of these soils.

- Provide surface drainage.
- Till when the soil is dry enough not to be plastic, yet not so dry as to be baked into a hard, cinder-like condition.
- Till to the depth of the A horizon, except where deep plowing is undertaken to improve the soil.
- Seed early in the season and drill to moisture, if possible. Avoid seeding fine grass and legume seeds too deep.
- On Solonetzic soils, seed crops that are commonly grown on geographically associated non-Solonetzic soils except alfalfa, which is not productive on thin Solonetzic soils.
- Solonetzic soils with more than about a 15-cm (*6-in.*) depth of topsoil may be straight grain farmed. Soils with less than 15 cm (*6 in.*), and more than 7.5 cm (*3 in.*) should be farmed with a grain–grass cropping system. Solonetzic soils with less than 7.5 cm (*3 in.*) of topsoil are best used for the production of fertilized grass.
- Solonetzic soils are generally deficient in nitrogen and the use of such high-nitrogen fertilizers as 26-13-0 for cereal crops and 34-0-0 for grass crops is recommended. Soil testing will help in identifying other possible nutrient deficiencies and in planning a fertilizer program.
- Avoid fertilizers containing sulfur.
- Stimulate crop production by using nitrogen fertilizers that improve the soil.
- Deep plowing is an improvement practice that has proven to be generally effective. In some cases, seedbed problems have been encountered because of the low calcium-to-sodium ratio of the lime-salt layer. Plow to a depth that draws a significant quantity of the lime-salt horizon into the upper soil layers.

- Solonetzic soils are often acid in the surface horizon and applying limestone together with nitrogen fertilizers corrects the acidity and improves the pH level of the soil.
- Gypsum used alone is harmful to crop production, but when used in combination with ammonium nitrate was found to improve a very hard Solonetzic soil at Coronation, Alta.
- Solonetzic soils are generally nonirrigable, but studies are under way to find a method of irrigation that will prove successful on a long-term basis.

ACKNOWLEDGMENTS

I acknowledge the help of my original coauthor, the late Mr. W. E. Bowser; my colleagues at the University of Alberta, the Alberta Research Council, the Province of Alberta, and Agriculture Canada; and the many private farmers who allowed the use of their land and facilities. Without this cooperation, it would have been impossible to conduct the great number of experiments that provided the background information for this publication. I further acknowledge the editorial assistance of Mr. I. W. Cowan, technician, and the dedicated work of the Vegreville staff.

R. R. Cairns

CONVERSION FACTORS FOR METRIC SYSTEM

Imperial units	Approximate conversion factor	Results in:	
LINEAR			
inch	x 25	**millimetre**	**(mm)**
foot	x 30	**centimetre**	**(cm)**
yard	x 0.9	**metre**	**(m)**
mile	x 1.6	**kilometre**	**(km)**
AREA			
square inch	x 6.5	**square centimetre**	**(cm^2)**
square foot	x 0.09	**square metre**	**(m^2)**
acre	x 0.40	**hectare**	**(ha)**
VOLUME			
cubic inch	x 16	**cubic centimetre**	**(cm^3)**
cubic foot	x 28	**cubic decimetre**	**(dm^3)**
cubic yard	x 0.8	**cubic metre**	**(m^3)**
fluid ounce	x 28	**millilitre**	**(ml)**
pint	x 0.57	**litre**	**(ℓ)**
quart	x 1.1	**litre**	**(ℓ)**
gallon	x 4.5	**litre**	**(ℓ)**
WEIGHT			
ounce	x 28	**gram**	**(g)**
pound	x 0.45	**kilogram**	**(kg)**
short ton (2000 lb)	x 0.9	**tonne**	**(t)**
TEMPERATURE			
degrees Fahrenheit	(°F-32) x 0.56 or (°F-32) x 5/9	**degrees Celsius**	**(°C)**
PRESSURE			
pounds per square inch	x 6.9	**kilopascal**	**(kPa)**
POWER			
horsepower	x 746	**watt**	**(W)**
	x 0.75	**kilowatt**	**(kW)**
SPEED			
feet per second	x 0.30	**metres per second**	**(m/s)**
miles per hour	x 1.6	**kilometres per hour**	**(km/h)**
AGRICULTURE			
gallons per acre	x 11.23	**litres per hectare**	**(ℓ/ha)**
quarts per acre	x 2.8	**litres per hectare**	**(ℓ/ha)**
pints per acre	x 1.4	**litres per hectare**	**(ℓ/ha)**
fluid ounces per acre	x 70	**millilitres per hectare**	**(ml/ha)**
tons per acre	x 2.24	**tonnes per hectare**	**(t/ha)**
pounds per acre	x 1.12	**kilograms per hectare**	**(kg/ha)**
ounces per acre	x 70	**grams per hectare**	**(g/ha)**
plants per acre	x 2.47	**plants per hectare**	**(plants/ha)**