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Solonetzic Soils of the Prairie Region

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Summary
Soils of the Solonetzic Order account for about 7% of the agricultural land in Western Canada. They are most common in semi-arid regions (the Brown and Dark Brown soil zones) but occur as well in the Aspen Parkland and even under forest. They occur on parent materials containing sodium salts, or in lowland areas influenced by ground water discharge. Solonetzic soils are often referred to as clay-pan soils, in that B horizons are clayey layers that are slowly permeable to water when wet, extremely hard when dry, and difficult for roots to grow through. The clay-pan and generally saline subsoils reduce the productivity of Solonetzic soils. Present-day farming methods such as conservation tillage and a timeliness of field operations are particularly effective at dealing with the soil structural problems characteristic of Solonetzic soils.

Introduction
Soils of the Solonetzic Order must have a solonetzic Bn or Bnt horizon that has a high content of sodium ions in relation to other cations such as magnesium and calcium, that is an exchangeable calcium to sodium ratio of 10 or less[11]. The Bnt horizons are enriched in clay and have columnar or prismatic structures that are slowly permeable when wet and extremely hard when dry. Characteristically, the blocky secondary structure has dark coating of organic matter and clay on the blocky structural units or peds. Most Solonetzic soils have saline C (Csa) horizons with high sodium contents. There are 6 to 8 million hectares of Solonetzic soils in Canada, mainly in Saskatchewan and Alberta with small areas in Manitoba and British Columbia[8]. They are used mainly for arable agriculture, particularly in the more moist Dark Brown and Black soil zones, whereas use as native grazing lands is more common the drier Brown soil zone. There are four great groups in the Solonetzic Order, three representing a sequence of increasingly more developed profiles-Solonetz, Solodized-Solonetz and Solod, and a fourth occurring only on clayey parent materials, Vertic Solonetz. Subgroups are separated based on the colour of the A horizons, and include Brown, Dark Brown, Black, Dark Gray and Gray, more or less corresponding with the soil zones.

Factors of Soil Formation
Climate and Vegetation In Western Canada, Solonetzic soils are most common under grassland in the semi-arid Brown and Dark Brown soil zones where less moisture is available for leaching[2]. There is a considerable small-scale variation in plant communities on Solonetzic soils, ranging from western wheat grass where stronger Solonetzic soil with little Ah horizon (burnout areas) occur to blue grama and spear grasses where Ah horizons are deeper, generally with Solod soils[13]. Solonetzic soils are found as well under forest, although this is considered an unusual occurrence, generally caused by strong upward fluxes of sodium-containing ground water in a moist environment.

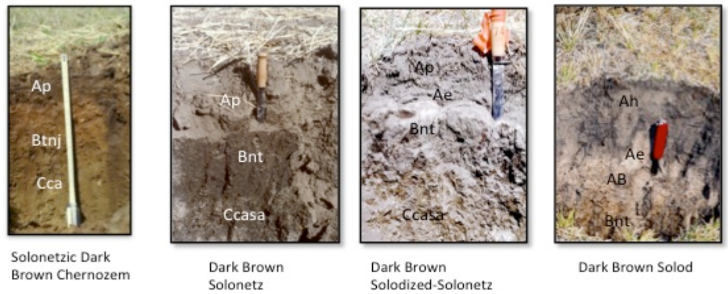

Figure 1 Solonetzic soil profiles

Groundwater is an important soil-forming factor in that Solonetzic soils generally occur in lowland regions adjacent to uplands, under conditions of groundwater discharge. Pawluk[10] wrote "*Solonetz formation in Western Canadian landscapes requires conditions to concentrate and maintain a dominance of sodium salts at the pedon surface, or within the upper part of the pedon, by ground water discharge within the hydrological regime. The water serves as reactant, solvent and transporting agent in the process of salinization."* In Saskatchewan, for example, a broad belt of mixed Solonetzic and Chernozemic soils occur in the Radville to Estevan areas, on the nearly level plain at the base of the Missouri Coteau. Solonetzic soils occur in the Central Butte-Loreburn areas, between the Coteau and the Allan Hills to the northeast. Solonetzic soils occur as well under mixed spruce-aspen vegetation on the level clayey glaciolacustrine plain at the base of Pasquia Hills in east-central Saskatchewan. Similarly, in Alberta, major areas of Solonetzic soils occur running south from Vegreville in the Black to Brooks in the Brown soil zone[8]. This is a region where both ground water discharge and thin glacial deposits containing marine bedrock fragments appear to result in Solonetz formation[13].

Topography is also an important factor in the formation of Solonetzic soils. At the regional level, Solonetzic soils occur in lowland areas with groundwater discharge as discussed above. The kind of Solonetzic profile varies with the local or landscape level topography, often in complex ways that are difficult to explain. Miller and Pawluk[9] (p 207) wrote, "*Topographic position and seasonal fluctuations of soluble salts and exchangeable acidity played a major role in the genesis of soils in the Solonetzic catena*". This may be contrasted with this statement from the Soil Survey Report for the Willow Bunch Lake area in southern Saskatchewan, *"It should be noted that the various series of Solonetzic soils usually form a complex pattern so that the relation between positions in the landscape and kind of soil profile is not as clear as it is with Chernozemic soils"*. The complexity is a result of interactions among several topographic factors that determine the relative balance between downward movement of water and dissolved constituents (leaching) and upward flux of water and sodium due to groundwater discharge.

Classification

The diagnostic horizon for Solonetzic Order soils is the solonetzic B (Bn or Bnt). It is defined as having prismatic or columnar structure that is hard or very hard when dry (a consequence of the clay and sodium content), and a ratio of exchangeable calcium (Ca^{++}) to sodium (Na^{+}) of 10 or less[11]. Despite its use as a criterion, several studies have indicated the imperfect correspondence between the morphology of the Bnt and its Ca/Na ratio, particularly for the Solonetz and Solod great groups[6]. There appears to be, however, a general relation between the morphology of B horizons (determining the classification of the soil in the field) and the degree to which B horizons are affected by Na (Table 1). Sodium concentrations are slightly stronger in the intergrade (Solonetzic Dark Brown Chernozems) than in the orthics, but neither meet the Bnt criterion. The Solods have somewhat higher Na contents, but only a few had

Ca/Na ratios of <10. The Solonetz and particularly the Solodized-Solonetz, with strongly developed Bnt horizons and prominent dark staining (clay and organic matter) on blocky structural units (peds) generally do. These data indicate a reasonably good connection between the morphology of the B horizon and the relative influence of Na, with certain exceptions. The somewhat stronger Na influence for the intergrade (Solonetzic Dark Brown Chernozem, with a Btnj horizon), is consistent with Na dispersion of the clay to favour clay translocation to form the horizon, either in the past or occasionally today, but not enough Na to form a true Solonetz. Only a few of the Solod profles had Ca/Na ratios <10, despite a strong expression of a Bnt morphologically. This too is consistent with a stronger influence of Na in the past[8], or occasional years when higher water tables induce solonization today. The complete or nearly correspondence between morphology and chemistry for the Solodized-Solonetz and Solonetz profiles are consistent with an ongoing role of Na in their formation.

Figure 2 A Vertic Solonetz on clayey glaciolacustrine parent material at the base of the Pasquia Hills in Saskatchewan. Note the concentration of tree roots in the Ahe horizon, and the columnar structure of the Bnt. Slickensides occur at about 1 m depth.

Table 1 The relationship between B horizon morphology, the ratio of exchangeable calcium to sodium, and the soluble sodium % of the horizon

Subgroup (number of reps)	**B horizon morphology**	**Exch. Ca/Na ratio**	**Soluble Na%**
Orthic Dark Brown Chernozem (7)	Bm, prismatic breaking to moderate blocky	>30	28
Solonetzic Dark Brown Chernozem (17)	Btnj, prismatic breaking to strong blocky with faint dark staining on peds	15 to 20	39
Dark Brown Solod (17)	Ae/AB horizon, then Bnt with disintegrating columnar structure, strong dark staining on peds common	15-20, a few <10	45
Dark Brown Solonetz (19)	Bnt, generally strong prismatic, breaking to strong blocky, strong dark staining on peds	8 to 15	65
Dark Brown Solodized-Solonetz (15)	Ae horizon, abrupt boundary to columnar Bnt, breaking to strong blocky, strong dark staining on peds	5 to 10	81

Great Groups are defined based on properties of key horizons that reflect the strength or intensity of the main soil-forming process. Differentiating criteria are based on the presence of certain other horizons in addition to the Bnt horizon.

Great Group	Profile
Solonetz	Ah or Ap, Ae < 2cm, **Bn** or **Bnt**, Csak
Solodized Solonetz	Ah or Ap, **Ae >2cm**, **Bnt**, Csak
Solod	Ah or Ap, Ae, **AB, Bnt**, Csak
Vertic Solonetz	Ah or Ap, **Bnt**, **Css** (slickensides)

Vertic Solonetz soils are any Solonetzic soil that has, in addition to the Bnt horizon, slickenslides at a depth of < 1m from the surface (Figure 2). These soils are intergrades between Solonetzic and Vertisolic soils, in that they have some of the diagnostic features of both orders.

Subgroups of the Great Groups of Solonetzic soils are based on the colour of the surface horizons. The colour criteria are exactly as for the great groups in the Chernozemic Order. In addition, the modifier *gleyed* may be added to all the subgroup names where indications of imperfect drainage are evident in the subsoil. There is an Alkaline Solonetz subgroup, but no equivalents in the other great groups. Alkaline Solonetz soils are weakly developed soils (only a Bn horizon) that are typical of drier areas.

The USDA Soil Taxonomy has no 'Solonetzic' Order or suborder[12]. Bnt horizons are referred to as 'natric' horizons. The presence of a natric horizon is diagnostic for great groups in the Mollisol (like Chernozemic), Alfisol (like Luvisolic) , and Aridisol (soils of arid regions) orders. For example, a soil in the northern Great Plains with a mollic epipedon and a natric B, is Mollisol Order, Cryoll Suborder and Natricryoll Great Group. The soil would be a Dark Brown Solonetz by the Canadian classification.

Soil-Forming Processes

The formation (genesis) of Solonetzic soils remains not as well understood as the soils of other orders. This statement from the Canadian soil classification[11], **"***Solonetzic soils are thought to have developed from parent materials that were more or less uniformly salinized with salts high in sodium. Leaching of salts by descending rainwater presumably results in deflocculation of the sodium-saturated colloids. The peptized colloids are apparently carried downward…*" with its several conditional statements underlined for emphasis.

The genesis of Solonetzic soils is best explained by complex interactions among parent material, topography, the ground water regime and time. The three classical soil-forming processes of salinization, solonization and solodization describe the genesis of Solonetzic soils[8, 10].

Salinization includes the many processes by which soluble salts accumulate at or near the landscape surface. Salinization may be a consequence of simply high salt contents in parent materials or weathering reactions producing salts, but it is unlikely that this explains the salt accumulation in W. Canadian soils. In virtually all instances the salt levels sufficient to result in saline or Solonetzic (where Na salts are dominant) soils are a result of localized concentrations of salts due to ground water flows (ie. ground water discharge).

Solonization is a transfer process in the development of Solonetzic soils. While salinization sets the stage for the development of Solonetzic soils, certain conditions must be met before they develop. Salt accumulations must contain a significant component of Na salts, and there must be a net change in environmental conditions to favour gradual removal of the soluble salts due to dissolution and transfer by water percolation. After excess salts are removed from the soil, exchangeable Na causes a dispersion of the humic (organic) and mineral colloids, making it possible for them to move downwards and accumulate to form the clayey, Na-influenced Bnt horizon. The dispersive effect of the Na appears to be most effective when the salt content is moderate and Na cations occupy 10 to 15% of the exchange complex.

Solodization is the term that describes the progressive changes that result first in the development of eluviated (Ae) horizons just above the Bnt, and gradually the breakdown of the upper Bnt, and the formation of thick Ae and AB horizons. AB horizons are transitional between Ae and Bnt horizons and result from the disintegration of the Bnt. The Ae horizons develop first because of the strong weathering conditions that result from sporadic saturation of the soil immediately above the slowly permeable Bnt, resulting in more acidic conditions[1, 8]. Weathering is strongest in the voids between the prismatic structures in the Bnt, resulting in eluviation of clay from those areas, the grayish colour, and the eventual formation of the round-topped columnar Bnt characteristic of the Solodized-Solonetz great group. With time, and probably related to much stronger leaching or a reduction in the influence of upwards fluxes in maintaining sodium concentrations in the Bnt, the Bnt breaks down to form the AB horizons that are typical of the Solod great group.

Despite general concurrence that Solonetz—Solodized-Solonetz—Solod is a time-dependent genetic sequence, questions remain concerning the details of the relationship. All three may occur in the same landscape and are presumably of similar age, indicating that additional factors are involved. One possible explanation for the inconsistent correspondence between B horizon morphology and Na content, as discussed earlier, is that the former is a more static aspect of soils, a consequence of centuries of soil processes, reflecting an average, long-term condition. On the other hand, the content of exchangeable cations especially Na is a more dynamic property, changing in response to seasonal, annual and perhaps decadal differences in precipitation and their influence on the balance between upward and downward fluxes of water in the soil. The upwards flux of water and Na ions is maintained by capillary flow through the fine pores, whereas the downward flux or leaching results from gravitational water flow through the large pores[10]. The downwards flux depends on the water available, as influenced by precipitation and landscape. Precipitation varies from year to year, and the net flux will likewise vary. During periods of above average precipitation there will be a strong flux downwards, moving soluble components to greater depth. During dry periods, there will be less water moving down and stronger upwards flux due to evaporation from the soil surface, moving soluble materials back towards the surface. Changes in soluble cations will result in changes in adsorbed cations through exchange processes.

Landscape influences water distribution, with convex upper slopes such a knolls and shoulders losing water, with gains in concave areas particularly in lower slopes or depressions[1]. Downward flux will be stronger in areas receiving extra water, and less in those areas losing water by runoff. In higher parts of the landscape with a longer distance to the water table, capillary rise will not reach the upper part of the soil profile. The result is that soluble components, particularly Na, will be less involved in soil formation, resulting in Chernozemic soils[7]. In lower areas where the capillary fringe reaches at least into the B horizon, sodium will be involved in soil formation, and Solonetzic soils are likely to occur. On level to very gently inclined surfaces that gain no extra water from areas upslope, typical Solonetz profiles (Ah/Bnt/Csa) are most common. In concave areas that receive additional water from upslope, the downward flux will be stronger, and more strongly developed soils such as Solodized-Solonetz (Ah/Ae/Bnt/Csa) are likely to occur. Solodized-Solonetz profiles are common, for example, in level areas right at the foot of runoff-shedding slopes. Distinctly depressional areas have a stronger flux downward due to extra water, and even deeper Solod (Ah/Ae/AB/Bnt/Cca/Csa) soils.

The distribution of Solonetzic soils within landscapes is quite complex, pointing to the many factors which influence their occurrence - the salt and sodium content of parent materials, the strength of leaching as related to landscape and the redistribution of water, the relative depth to water tables (or relative influence of artesian pressure), the strength of leaching as related to landscape, and the depth to water tables.

Management

Solonetzic soils sometimes referred to as burn-out soils, recognizing that crops growing on them often ‘burn’ out- that is they wither and mature early as they run out of moisture in periods of drought and high temperatures. Poor stands are related to the thin Ap horizons, the tough Bnt or clay-pan horizon, and saline subsoil at shallow depth.

Measurements made in five farmers' fields illustrate well the yield differences for different kinds of soil profiles, and an interesting differential effect related to moisture[3, 4]. The 1975 crops were seeded on summer fallow as was the general custom. The 1976 crop was seeded on the same fields, described then as stubble cropping, with moderate addition of fertilizer. Rainfall was less in 1975, particularly in the critical period of late June, July and early August. The low moisture supplies perhaps made worse by hot temperatures in July and early August resulted in much lower yields on the Solonetz and Solodized-Solonetz soils, the soils with the toughest and shallowest Bnt horizons and saline C horizons (Table 2) . The generally higher yield on the Chernozemic profiles and the Solod appeared to be related to the good nutrient supply, especially nitrogen, and the uptake of water from greater depths. Protein contents of grain were not measured in 1975.

Table 2. Yield (kg/ha) of wheat grown on different Solonetzic and Chernozemic soils in a dry (1975) and moist (1976) year.

Subgroup profile	**Mean yield, 1975**	**Mean yield, 1976**
Orthic Dark Brown Chernozem (Bm horizon)	2372 +/-202	1439 +/-114
Solonetzic Dark Brown Chernozem (Btnj horizon)	2294 +/-145	1461 +/-120
Dark Brown Solod (Ae/AB/Bnt)	1981 +/-149	2052 +/-110
Dark Brown Solonetz (Bnt)	1750 +/-159	1385 +/-87
Dark Brown Solodized-Solonetz (Ae/Bnt horizon)	1297 +/- 156	1916 +/-104

The next year, 1976, had more rainfall, evenly distributed through the generally cool growing season. Interestingly, the lowest yields were on the Chernozemic profiles, probably because of insufficient nutrients especially nitrogen (Table 2). The yields on the Solod and Solodized-Solonetz were highest, and correlated with the thickness of the A (Ap/Ae and AB) horizons. Protein contents of the grain were surprisingly high (up to 18%) even where yields were good, with a strong statistical relationship between nitrate in the Bnt and C horizons (0 to 90 cm depth) and protein content. The moisture use curves indicated use of moisture from the subsoil to 60 cm depth. My conclusion was that that the timely rains and somewhat cooler temperatures during the summer had permitted the growth of roots into the Bnt and saline C horizons, making use of the very high nitrate contents, to build protein. The importance of late season uptake of nitrogen to protein content has been reported by others.

These data are consistent with what many observe. Solonetzic soils most adversely reduce yields during dry years, when highly variable stands are evident on lands with mixed Solonetzic and Chernozemic soils (Figure 3). With adequate moisture, however, the stands are much more uniform and the Solonetzic soils may even out-yield the Chernozems. Crops growing on fields of Solonetzic or mixed Solonetzic and Chernozemic soils are quite variable in drought years, with growth related strongly to the depth to, and toughness of, the solonetzic B horizon, and the depth to salts in the subsoil. The poorest stands occur on soils with thin Ap horizons, extremely tough Bnt horizons, and strongly saline C horizons right below the Bnt. Mixed Solonetzic and Chernozemic soils quite often result in uneven crop stands.

Figure 3 Variable crop stands on Solonetzic soils in the Weyburn area. The poor stands are mainly on Solodized-Solonetz soils, the taller and greener stands on deep Solods or Solonetzic Dark Brown Chernozems.

Deep plowing (60 cm depth) or deep-ripping to disrupt the Bnt horizons and bring calcium salts (namely gypsum, calcium sulphate which is much more soluble than carbonate) to the surface has been used to improve Solonetzic soils. The calcium is to exchange with Na ions adsorbed to clay in the Bnt material, and improve soil structure. Breaking up the clay-pan or Bnt improves water transmission and fosters deeper rooting. Deep ploughing increased wheat yields by 0.34 to 0.40 tonnes per hectare in a trial on two fields west of Weyburn on Trossachs soil[5]. Deep ploughing is time-consuming and expensive because of high energy costs, and has not been adopted generally.

Conservation (no-till) tillage, particularly the elimination of tilled summer fallow, appears to be working well on Solonetzic soils. Fields in tilled fallow generally have poorly structured Ap horizons, because of low organic matter and, probably, the concentration of Na at the soil surface as water moves upwards, driven by evaporation from the bare soil. Maintaining a surface mulch of residues and gradually increasing organic matter is likely to increase water entry and storage, thereby increasing yields. In addition, tillage is best done when soils are moderately moist. Timely tillage operations are more likely with large machinery used today.

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