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Prairie Wetland Soils: Gleysolic and Organic

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Summary

Gleysolic and Organic soils are collectively referred to as “wetland soils”. They are found in wet low-lying or level landscape positions. Gleysolic soils are found throughout the agricultural Prairies, in association with Chernozemic and Luvisolic soils. In semi-arid regions, they are frequently tilled in dry years and can be very productive due to their relatively high levels of soil moisture and nutrients. In the Prairie Provinces, Organic soils tend to be mostly associated with the Boreal transition zones at the northern and eastern perimeter of the Prairies. With proper management, these can also provide productive agricultural land, particularly for forages.

Introduction

Soils of the Gleysolic and Organic orders are collectively referred to as “wetland soils”. Soil maps of the agricultural region of the Canadian Prairies seldom have areas mapped as dominantly Gleysolic[8] or Organic[9]; however, these soils are found throughout the region wherever climate and/or topography have led to persistent water-saturated conditions. Gleysols are mineral soils with colors that reflect intermittent or prolonged anaerobic (i.e., saturated, low oxygen) conditions (Fig. 1A). Organic soils reflect permanent anaerobic conditions, which lead to soils that are made up of variably decomposed plant residues, mostly from water-tolerant (i.e., hydrophytic) vegetation (Fig. 1B).

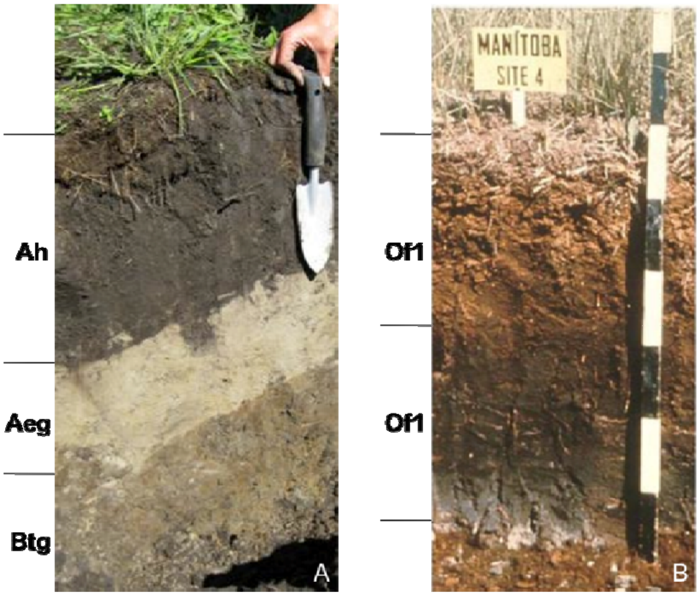

Figure 1: A) Humic Luvic Gleysol, Saskatchewan and B) Typic Fibrisol (Organic), Manitoba[7].

Of the some 100,000,000 ha covered by the Canada Land Inventory (CLI) in the Prairie Provinces[12], Gleysolic soils occupy less than 15% of the Prairie ecoregions and up to 40% in the Mid-Boreal (boreal = “northern”) Upland (Alberta) and Interlake Plain (Manitoba) ecoregions[12]. Up to 12% of the CLI coverage area is classified as Organic, primarily within the Boreal Plains ecoregions[12, 13]. Although these wetland soils may be minor inclusions in terms of their spatial distribution, in semi-arid landscapes they can be important contributors to a field’s overall agricultural productivity. In more humid regions of the Prairies, where drainage is required in order for these soils to be arable, wetlands may be a source of land-use conflict.

Factors of Formation

The Gleysolic and Organic Orders are readily distinguished from each other by their primary *parent material*: the Gleysolic order develops in mineral parent material (<30% organic matter by weight) and the Organic order develops in organic parent material (>30% organic matter by weight)[31]. In addition, Gleysols are more likely to develop in finer-textured parent materials (i.e., clay-dominated) because of slower drainage. Given the importance of water redistribution in the formation of both orders, their location within the overall soil landscape is governed by *topography* and *climate*. Gleysolic soils are found throughout the Prairies in depressions where topography results in the accumulation of standing water for several weeks or months of each year and/or a very shallow *groundwater* table[5]. In particular, for the climate to favor the formation of Organic soils, there must be an excess of precipitation over evaporation[10], so they are rare in the semi-arid Prairie, but more common at the northern and eastern fringes of the Prairies and along the northeastern shore of Lake Winnipeg[36]. Organic soils tend to be constrained to floodplains, river valleys, and the Boreal Plains ecoregions; they are commonly referred to as peat, muck, bog or fen soils[31]. The natural *vegetation* associated with wetland soils is tolerant of water-saturated conditions, which includes grasses, sedges, mosses, and willow. The relative dominance of grasses and sedges versus mosses can influence the pH of Organic soils, affecting their suitability for agriculture.

For the Boreal Plains, the *time* since deglaciation is shorter than for the Prairie ecoregions, and hence these soils are quite young (<8000 years)[17]. The relative youthfulness and the cooler climate lead to the dominance of the less-decomposed Great Groups of the Organic order (i.e., Fibrisols and Mesisols). In more recent times (i.e., since settlement), *human activity* has greatly transformed the soils and vegetation within and surrounding wetland soils, making humans an important soil-forming (or soil changing) factor. Tillage redistribution has resulted in the accumulation of organic-matter and nutrient-rich topsoil in those low-lying depressions typically occupied by Gleysols, thickening the A horizons[28]. Artificial drainage of wetlands to facilitate agricultural production is increasingly common in the sub-humid portions of the Prairies, and the transition to a more aerobic (oxygen-rich) system increases the rate of organic matter decomposition, microbial community activity, and nutrient cycling (discussed further below).

Processes of Formation

The key process contributing to the formation of Gleysolic soils is *gleization*, referring to the effects of reduction-oxidation (redox). Glacially derived parent material associated with most Prairie Gleysolic soils is rich in iron, and to a lesser extent, manganese. Prolonged water-saturation (typically during the spring and early summer) leads to *reducing* conditions: the iron and manganese are reduced (i.e., gain electrons), transformed into a more mobile form, and transported in the soil solution. The reduction of iron contributes to the characteristic dull blue-gray (or “gley”) color of Gleysolic soils. When the soil dries out (i.e., becomes aerobic in late summer or fall), the iron is oxidized and forms concentrated reddish or brown spots, typically in large pores or root channels that dry out first.

In Gleysolic soils, where the dominant direction of water movement is downwards, dispersed clays can be carried down through the profile in solution through a process called *lessivage*. The clays are deposited at depth, resulting in a clay-depleted layer near the surface and a clay-enriched layer at depth, which can form a barrier to downward water movement. This is most notable in Luvic Gleysols, with the term “Luvic” referring to the clay transfer (a.k.a. *eluviation* and *illuviation*). Where the dominant direction of water movement is upwards (i.e., discharge from the groundwater table), calcium carbonate or other salts in solution may be deposited in the soil (i.e., *calcification*). However, the pH required for gleization is lower than that required for calcification, so if both processes are observed in the same soil profile, this probably reflects two separate time periods of soil formation[5]. Organic soils arise through the process of *paludification*, which refers to an accumulation of partially decomposed organic matter (i.e., peat) under persistent anaerobic conditions. In saturated soils, microbial decomposition of organic matter is very slow, so the net balance between accumulation and decomposition favors development of thick layers of organic matter or peat.

Typical Soil Landscapes

Throughout the Prairie Pothole Region, small ephemeral wetlands (a.k.a., depressions, sloughs, potholes) are concentrated in low-lying landscape positions where water ponds during spring snow melt. The hummocky and undulating glacial deposits characteristic of the region are scattered with depressions where standing water persists well into late spring or early summer. In Saskatchewan, the number of wetlands has been estimated in excess of 1.5 million, but over 80% of these cover less than one hectare[19]. Soils vary significantly with small changes in topography. In Saskatchewan, these soils have been mapped as associations to reflect the range of soils present in a small area. For example, the Weyburn association is dominated by Orthic Dark Brown Chernozemic soils (*see* Chapter 3) developed on glacial till, but the typical hummocky soil landscape would include Regosols, Rego Chernozems, or Calcareous Chernozems on the convex (water-shedding) positions, Orthic Chernozems on the level or midslope positions, and Gleyed and/or Eluviated Chernozems or Gleysols in the depressions. The soil types within a depression reflect the shape of the depression, which influences the redistribution of water: the most concave portions of a given depression - where standing water will persist the longest - will exhibit the most strongly gleyed profiles[5]. True Organic soils are generally constrained to large wetland areas underlain by water-deposited sediments, such as the sedge peatlands of Muskeg Lake Cree Nation in central Saskatchewan.

As mentioned, Organic soils are more common in the Boreal Plains ecozone where local climate inhibits rapid decomposition of organic matter inputs[39]. Throughout this region, compared to the semi-arid Prairies, annual precipitation is 100-200 mm greater, evapotranspiration is lower (reflecting lower wind speeds and cooler temperatures) and organic matter inputs are higher. Organic soils are dominant in portions of the Peace River district of northwestern Alberta, the Boreal Transition zone of central Saskatchewan (e.g., around Prince Albert), and the Interlake Plain between Lake Winnipeg and Lake Manitoba in Manitoba[13]. Gleysols and Organic soils commonly occur together in the landscape, with Gleysols found in shallower depressions or on the perimeter of larger wetlands that are dominated by Organic soils. In the transitional area between dominantly Gleysolic and dominantly Organic, soils not having sufficient peat accumulation to meet the classification criteria for the Organic order are often described as peaty-phase Gleysols; essentially Gleysolic soils with a thin accumulation of peat materials at the surface. Soil surveys from the Peace River region in Alberta refer to two dominant Organic series. Both are characterized by level and depressional topography, but are differentiated from each other by the origin of their peat materials: the Eaglesham soils are derived from grass and sedge residues in varying stages of decomposition, whereas the Kenzie soils are derived from much coarser plant material, dominated by sphagnum moss[26]. Of the region's mineral wetland soils, the Enilda series are an example of the peaty-phase Gleysols, and are commonly found in association with both Eaglesham and High Prairie (Gleyed Black and Gleyed Dark Gray Chernozemic) soils on the broad flood plains of the region[25].

Throughout the Boreal Plains, Organic soils are found in association with Black and Dark Gray Chernozems, Luvisols, and Brunisols. These soils develop in the thick glacial deposits that overlie the contact between the Precambrian Shield and the sedimentary bedrock of the Prairies. For example, the Roseau River is a tributary to the Red River in the southeastern portion of the Interlake Plain ecoregion of Manitoba; its eastern basin is underlain by Precambrian Shield[23]. The eastern-most portion of the watershed is 35-40% Organic soils. The most significant Organic series in the area include Baynham (Typic Mesisols on deep forest peat: 4318 ha), Katamik (Typic Mesisols on deep fen or forest-fen peat: 3611 ha), and Okno (Terric Mesisols, thin forest peat over fine lacustrine deposits: 3600 ha). In the western-most portion of the watershed, where the Roseau joins the Red River (near Emerson and Dominion City), the proportion of Organic soils decreases to 0% and Rego Black Chernozems and Humic Gleysols on lacustrine clay are the dominant soils.

Agricultural Properties and Capability

Given the wide range of climate, topography, vegetation, and soil textures associated with Gleysolic and Organic soils, it is unsurprising that there is also a wide range of agricultural properties associated with these soils. Generally, they are associated with higher soil moisture and soil organic matter contents and good nutrient availability. But there are also management considerations associated with their status as “wetland soils” that require careful evaluation of the risks and benefits when used for agricultural production.

Ducks Unlimited estimates that more than 70% of Prairie wetlands have been converted to agriculture[11]. Chief among the advantages of Gleysols in the semi-arid Prairie climate is the greater moisture content associated with their landscape position and/or parent material. Organic soils have not been as extensively developed for agriculture in the Canadian Prairies as they have in warmer climates. The wet conditions that resulted in the accumulation of peat layers means the soil takes longer to warm in the spring, further shortening an already brief growing season and limiting the types of crops that can be grown. In other areas, such as southern Ontario and Quebec and portions of the Midwest and Southern US, Organic soils are used extensively for vegetable production.

The primary risk or limitation associated with both of these orders is the probability of flooding in wet years. Increasingly, producers in wetter regions of the Prairies are turning to artificial drainage to reduce this risk for their Gleysolic and/or Gleyed Chernozemic soils. For Organic soils, drainage to manage the depth to the water table is essential for agricultural production. Although the original soil capability classification system of the Canada Land Inventory did not classify Organic soils, a system has been developed regionally, and is outlined in the Roseau River soil survey[23]. Organic soils are known to subside (i.e., decrease in thickness) following drainage for agriculture, reflecting the loss of buoyancy from the decrease in moisture content and the oxidation or decomposition of the organic materials[27]. The capability classification therefore assumes that even under optimum management, soils will subside 2 to 5 cm annually. Optimum Organic soils for agricultural production – uncommon in the Canadian Prairies – would be deep and level (i.e., easier to drain) with neutral to slightly acidic pH, minimal coarse wood fragments, and mild climate (mean annual soil temperature: 8-15°C)[23].

However, some questions do remain regarding the potential impacts of drainage on downstream water quality and the long-term effects of drainage on the soil properties of the drained areas. These questions, although beyond the scope of this review, are increasingly the source of land-use conflict in the southeastern Prairies where drainage is becoming more common; it is estimated that up to 90% of wetlands in the eastern Prairie Pothole Region (including southeastern Saskatchewan, southern Manitoba, and portions of the USA) have been drained[20]. Studies examining the effects of drainage on mineral soil properties (i.e., in addition to the intended effect of lowering the water table) are relatively few in number, and have been based in Russia[21], France[15], and southeastern USA[18]. After reviewing the limited literature available, the French research group determined that subsurface drainage would increase the variability of soil properties over short distances, including an increase in leaching and transfer of clays and changes in iron and manganese dynamics[24]. Changes in color (such as increased iron oxide or rust-colored spots under drier conditions) and increased structure (i.e., individual particles binding together into larger aggregates or clods) were observed in some gleyed soils within 30 years of drainage[15, 18]. The increase in structure reflects increased faunal activity (earthworms, etc.) under less saturated conditions, increased movement of clay (i.e., lessivage) with greater vertical water movement, and the effects of more frequent wet-dry cycles on shrink-swell clays.

In terms of the impacts of drainage on nutrient dynamics, a study in southern Sweden found increased N mineralization rates (3 times higher), reduced denitrification rates (5 times lower), and increased available K[34]. However, a study in the St. Denis National Wildlife Area (east of Saskatoon, SK) and the Manitoba Zero Till Research Association (near Brandon, MB) also found that tilling wetland soils reduced total carbon and cation exchange capacity, and reduced the sorption of several herbicides, including 2,4-D, trifluralin, and atrazine, increasing the risk of unintended herbicide impact[40], such as contamination of groundwater. This suggests that some of the perceived productivity associated with these soils is rapidly exhausted after drainage, resulting in a long-term loss of biodiversity in exchange for short-term agricultural productivity.

Additional risks of drainage include loss of carbon stores due to more rapid decomposition under better-aerated conditions (created both by drainage and tillage). In the St. Denis National Wildlife Area, soils in uncultivated and native wetlands (i.e., Gleysols and the associated Chernozems) had more than double the organic C storage of cultivated wetlands[3]. Non-drained peatlands, although a sink for CO_2, are also a significant source of methane, so after the difference in global warming potential between these two gases is factored in, non-agricultural Organic soils are neither a net source or sink for CO_2 [30]. In contrast, one study found that drained peatlands in Norway produced a total annual C loss of 1.8 to 2 million tons of CO_2[16]. These results from Norway, and results from other areas of Europe where Organic soils are commonly used for agriculture, suggest that to minimize greenhouse gas emissions, these soils should not be tilled [22].

As an alternative to drainage, producers can consider either completely converting the wetland to grassland or pasture or including forage crops such as clover and alfalfa in their long-term crop rotations[2]. In the Peace River district of Alberta, non-drained Gleysolic soils (i.e., Goose and Prestville series) are limited to improved pasture. However, some producers have noted that by growing oats or forages such as alsike clover for several consecutive years, drainage is ultimately improved (likely reflecting a lowering of the water table) and grains can then be produced[25]. Similarly, models of land use and climate change effects on water levels for a wetland in South Dakota showed that under a wetter climate, wetlands in unmanaged grassland would have the lowest water levels, whereas managed (grazed or cut) grassland or cropland would have the highest wetland water levels[37]. In the St. Denis National Wildlife Area, the introduction of a brome grass (*Bromus inermis*) and alfalfa (*Medicago sativa*) mixture increased the upland snow trapping during the winter months and the snowmelt infiltration in the spring such that within a few years, all small wetlands within the area seeded to grass had dried out and have remained dry in the years since[33]. This reflects an increase in macroporosity from 0.01% to 0.04% of the total soil volume and in both saturated (four-fold increase) and unsaturated (up to three-fold increase) hydraulic conductivity[6].

Given the risks and limitations of drainage, and recent emphasis on recognizing the value of ecosystem services, there has been significant interest in wetland restoration. In the semi-arid to sub-humid Prairies, one of the key considerations is the inherent importance of wetlands to regional hydrology. Although the period of time each year where the surface water is “connected” to the groundwater is mostly limited to springtime[32], wetlands provide an important source of groundwater recharge in wet years[38]. Other key ecosystem services provided by wetlands include flood protection, water filtration/purification, waterfowl breeding grounds, and (as mentioned above) carbon storage[35].

A recent study of the Broughton’s Creek watershed in southern Manitoba indicated that wetland restoration would reduce total annual phosphorus (P) export from that watershed by 79 to 785 kg/yr and total nitrogen (N) by 423 to 4,219 kg/yr [41]. In contrast, the previously mentioned study from Sweden found that re-wetting a formerly drained wetland significantly increased denitrification loss and extractable P [34], highlighting the need to develop careful restoration plans. In a study of restored wetlands in central New York state, even 55 years after restoration, surface soils had less than 50% of their original levels of organic matter and cation exchange capacity, suggesting the need for strategies to “jump-start” soil development in restoration[1].

In those landscapes where wetlands have not been drained or have been restored, maintaining vegetative buffers between the wetland and the cultivated uplands can ensure the continued effectiveness of the wetlands. Where cultivation occurs immediately adjacent to wetlands, there is P loading, increased organic matter throughout the profile (through tillage deposition and translocation within the soil), and increased nitrate levels[14]. In contrast, in a comparison of buffered and non-buffered wetlands in South Dakota, researchers found lower N and P levels in the buffered wetlands. In addition, they determined that where the buffer vegetation could be cut annually for hay, the buffers were economically viable as well[29]. Regular cutting can actually increase the effectiveness of buffers by increasing plant demand[4].

Conclusion

Gleysolic and Organic soils make up a relatively small portion of the agricultural land of the Prairie Provinces; despite their small area, they provide a number of important ecological services. Wetland soils can be very productive, but economic benefits associated with drainage and cultivation must be carefully evaluated against environmental risks and other production limitations (soil temperature, flooding etc.) when deciding how to best manage the land.

Gleysolic and Organic soils in other soil classification systems

Table 1: Correlation between Canadian System of Soil Classification (to the Great Group level) and other commonly used classification systems[31].

Canadian System of Soil Classification	U.S. Soil Taxonomy	World Reference Base
Organic Order	Histosols	Histosol
Fibrisol	Fibrists	
Mesisol	Hemists	
Humisol	Saprists	
Gleysolic Order	*Aqu-* suborders*	Gleysol, Planosol
Humic Gleysol	Aquolls, Humaquepts	Mollic, Umbric, or Calcic Gleysol
Gleysol	Aquents, Fluvents, Aquepts	Eutric or Dystric Gleysol
Luvic Gleysol	Argialbolls, Argiaquolls, Aqualfs	Planosol

*Applied to the following equivalent orders: Mollisols (Chernozems), Inceptisols (Brunisols), Entisols (Regosols), Alfisols (Luvisols)

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