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Article

Better recognition of limnic materials at the great group and subgroup levels of the Organic Order of the Canadian System of Soil Classification

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Abstract

In the Canadian System of Soil Classification (CSSC), soils of the Organic order are classified at the great group level primarily based on the dominant organic material in the middle tier. The system recognizes four types of organic horizons: fibric (Of), mesic (Om), humic (Oh), and coprogenous earth (Oco), of which only the latter is not recognized at the great group level of the Organic order. Furthermore, at the subgroup level, Limnic subgroups cannot have terric or hydric layers. This is problematic in soils where the middle tier is dominated by limnic materials, and those which have dominantly limnic materials and have a terric layer. We describe 29 soil profiles in Ontario and Quebec, which are either poorly captured in the CSSC or that cannot be classified into the Organic order based on their diagnostic criteria. Based on an analysis of soil survey information in five provinces across Canada, we estimate 32 057 ha of organic soils which potentially contain limnic deposits. In key vegetable-producing areas of Quebec, large organic deposits in agricultural production are subject to peat subsidence and erosion, resulting in shallower depths to underlying coprogenous earth, which is not a suitable medium for crop production. This can potentially have negative effects on crops when mixed with humic materials in the plow layer. Due to these taxonomic and agronomic considerations, we propose the addition of a new great group, Limnisol, and suggest further integration of limnic materials at the subgroup level for the Humisol, Mesisol, and Fibrisol great groups.

Key words: Canadian System of Soil Classification, soil taxonomy, pedology, organic soils, limnic, coprogenous earth, diatomaceous earth, marl

Résumé

Le Système canadien de classification des sols (SCCS) situe les sols de l'ordre Organique au niveau du grand groupe, essentiellement à cause de la matière organique qui prédomine dans leur étage intermédiaire. Le SCCS reconnaît quatre sortes d'horizon organique : fibrique (Of), mésique (Om), humique (Oh) et terre coprogène (Oco), cette dernière étant la seule à ne pas figurer parmi les grands groupes de l'ordre Organique. Par ailleurs, au niveau du sous-groupe, les sous-groupes limniques ne peuvent posséder de strate terrique ou hydrique, ce qui pose un problème lorsque les matériaux limniques dominent dans l'étage intermédiaire du sol ou quand le sol se compose essentiellement de matériaux limniques mais possède aussi une strate terrique. Les auteurs décrivent le profil de 29 sols de l'Ontario et du Québec que le SCCS saisit mal ou qu'il est impossible de classer dans l'ordre Organique en raison des critères employés pour les diagnostiquer. Après analyse des données pédologiques de cinq provinces canadiennes, les auteurs estiment que 32 057 ha de sols organiques pourraient abriter des dépôts limniques. Dans les principales régions maraîchères du Québec, d'importants dépôts organiques utilisés pour la production agricole pourraient voir la tourbe s'affaisser et s'éroder, ce qui réduirait l'épaisseur de la couche assise sur la terre coprogène, laquelle ne convient pas à l'agriculture. Les cultures pourraient en être affectées négativement, quand les matériaux humiques se mélangeront à la semelle de labour. Compte tenu de ces considérations taxonomiques et agronomiques, les auteurs proposent l'ajout d'un nouveau grand groupe au SCCS, soit celui des lumnisols, et suggèrent qu'on intègre les matériaux limniques aux sous-groupes dans les grands groupes des Humisols, Mésisols et Fibrisols. [Traduit par la Rédaction]

Mots-clés : Système canadien de classification des sols, taxonomie des sols, pédologie, sols organiques, limnique, terre coprogène, terre à diatomées, marne

Introduction

The inclusion of organic soils in Canadian soil taxonomy was first proposed in 1955 by the Subcommittee on Soil Classification of the National Soil Survey Committee (NSSC 1955). A preliminary schema was adopted for field testing in 1960, although it was deemed insufficient and in need of further refinement (NSSC 1960). By 1965, three of the four great groups currently recognized in the Canadian System of Soil Classification (CSSC) (SCWG 1998) were included in the first published approximation, the System of Soil Classification for Canada (CDA 1970). These represented wetland organic soils. The second edition, 4 years later, saw the addition of the Folisol great group, or the upland organic soils (CDA 1974). A detailed description of the evolution of the Organic order of great groups and subgroups is outlined in Kroetsch et al. (2011).

For classification purposes, Organic soils of the Fibrisol, Mesisol, and Humisol great groups have a control section that extends from the surface to a depth of 1.6 m or to a lithic contact, which is divided into three tiers: surface (0–40 cm), middle (40–120 cm), and bottom (120–160 cm; SCWG 1998). The great group classification is based on the dominant material in the middle tier, except when a terric, lithic, or hydric substratum is present within the middle tier, in which case the dominant material in the middle and surface tiers are both considered (SCWG 1998). Organic horizons in wetland organic deposits are designated with the letter O and are further refined with four lowercase suffixes: f (fibric), m (mesic), h (humic), or co (coprogenous). Whereas the first three suffixes refer to the degree of decomposition of the organic material, the fourth suffix, "co", refers to a specific type of limnic deposit, coprogenous earth, or sedimentary peat, which is formed in an aquatic environment from aquatic organisms and fecal material derived from aquatic animals (SCWG 1998; USDA 2015). Gyttja, the Swedish word for slime, is also used to describe coprogenous earth and was first used as a scientific term by von Post (1862). Other types of limnic deposits are also recognized within the Organic order, including diatomaceous earth and marl. These layers are designated as C and Ck horizons, respectively, and are the only two named layers of Organic soils that are not designated with O, L, F, or H. Coprogenous earth can be either organic (>30% organic matter) or inorganic (≤30% organic matter), while diatomaceous earth and marl are inorganic materials primarily composed of siliceous shells of diatoms and shells of aquatic animals and calcium carbonate precipitated in water, respectively (SCWG 1998), making limnic layers an intriguing exception in the Organic order. It should also be noted that for classification purposes, soils with marl or diatomaceous earth >40 cm thick occurring at the surface, or soils with >40 cm of these materials within the upper 80 cm of the control section, are excluded from the Organic order.

Assessment of the mineralogy of limnic materials, and specifically microscopic observations, are limited (Ismail-Meyer et al. 2018). Nonetheless, micromorphological analyses of gyttja have been conducted in Canada. Aquatic plant or animal residues and lacustrine sponge spicules were observed in eutrophic gyttja by Parent et al. (1980) on thin sections of limnic materials in Quebec. The same authors described calcareous gyttja, which contained, amongst other components, identifiable shells, aragonite, and pyrite grains. Calcite is also commonly found in calcareous gyttja in Poland (Jarnuszewski and Meller 2018). In British Columbia, the micromorphological study of various types of gyttja revealed the presence of plant debris, diatoms, and black pyrite grains (Lévesque et al. 1987; Fox and Tarnocai 1990).

In the CSSC, limnic materials in Organic soils are captured at the subgroup level within the Fibrisol, Mesisol, and Humisol great groups. As an example, the Limnic Fibrisol subgroup is defined as:

> "They differ from the Typic Fibrisol by having a limnic layer beneath the surface tier…Limnic Fibrisols may have mesic, humic, or cumulic layers, but do not have terric or hydric layers" (SCWG 1998)

In addition, limnic material may be present in other subgroups, namely the Terric and Hydric subgroups. Limnic materials are not found in the Folisol great group of the Organic order, since these are upland organic soils. At the soil family level, criteria for Organic soils include characteristics of the surface tier, reaction, soil temperature, soil moisture regime, particle-size class of terric layer, limnic material, and depth (SCWG 1998). As such, these soils can be further differentiated to describe the type of limnic material at the soil family level using the terms coprogenous, diatomaceous, or marl. Currently, the recognition of limnic materials is not possible when a soil profile meets the requirements for the Terric subgroup. As an extreme example, Table 1 provides a profile description for a soil that would be classified as a Terric Humisol, with no recognition of the important limnic layer, even though the middle tier consists only of coprogenous earth.

Fundamentally, the recognition of limnic layers in Organic soils in the CSSC is insufficient, especially when dealing with coprogenous materials. This was recognized early in the development of the Organic order by R.E. Smith (Research Branch, Canada Department of Agriculture, Winnipeg, Manitoba) at the Second Meeting of the Eastern Section of the National Soil Survey Committee, but it was acknowledged that it was too early to investigate at that time (CSSC 1971). Two key issues are apparent in the current version of the CSSC (SCWG 1998). First, fibric, mesic, and humic organic materials are recognized as organic horizons (i.e., Of, Om, and Oh) and form the basis for the soil great groups of the Organic order. Despite coprogenous materials being recognized as an organic horizon (i.e., Oco), they are not considered at the great group level. Secondly, although limnic materials are recognized at the subgroup level, they are only captured in deep organic soils where the organic material extends beyond the control section (160 cm). Therefore, in soils with significant limnic deposits and a terric layer within the control section, effectively the limnic materials are ignored. For these reasons, we provide evidence of soils from three study areas in Ontario and Quebec where limnic deposits, primarily coprogenous earth, are not adequately captured by the current CSSC (SCWG 1998), estimate the possible extent of these

Table 1. Profile description of site PTBO18_1246, a Terric Humisol dominated by coprogenous earth based on SCWG (1998).

Horizon	Depth (cm)	Description
Oh	0–34	Black (10YR 2/1 m); very strongly decomposed (vP8); forest peat; neutral (pH 6.9)
Oco	34–148	Greenish gray (5GY 4/1 m); silt loam; massive; moderately calcareous; neutral (pH 7.1)
Cg	148–200	Greenish gray (5GY 5/1 m); silty clay loam; massive, sticky; moderate effervescence; strongly calcareous; mildly alkaline (pH 7.4)

soils, support these taxonomic considerations with soil management implications, and propose revisions to the classification of Organic soils in the CSSC.

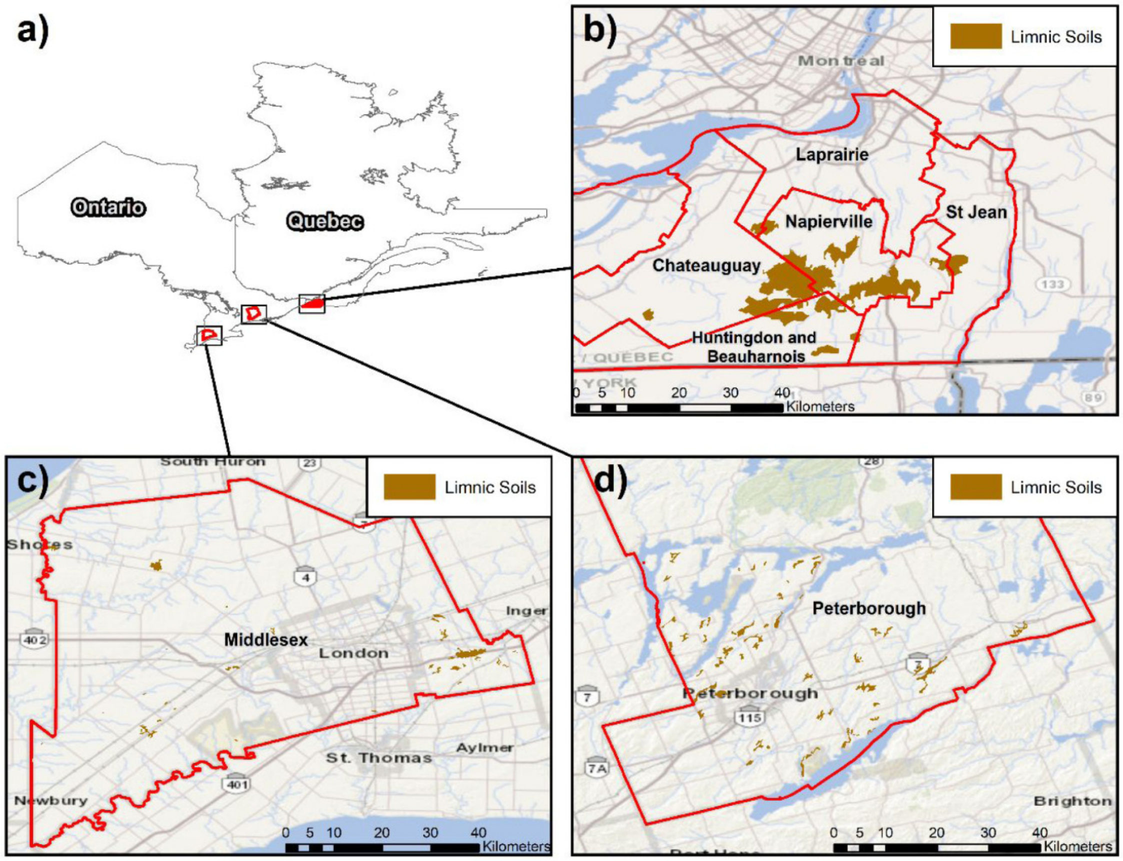
Study areas and approaches

The study includes a field investigation component and a mapping component. For the field investigations, soil profiles from three different regions were collected from existing projects: Middlesex County, Ontario; Peterborough County, Ontario; and the Plain of Montreal, Quebec, which includes Châteauguay, Laprairie, Napierville, and St-Jean counties (Fig. 1). Middlesex County is located in southwestern Ontario and is roughly centered around the city of London, Ontario, located at 42.98°N latitude and 81.25°W longitude (Fig. 1). The organic deposits in this area are sparse and located mainly southeast of London and are described in the Soil Survey of Middlesex County (Hagerty and Kingston 1992). The wetlands in Middlesex County are all classified as swamps dominated by deciduous species (Hagerty and Kingston 1992; National Wetlands Working Group 1997; Ontario Ministry of Natural Resources and Forestry 2019). Peterborough County is located in east central Ontario approximately 140 km northeast of Toronto at 44.46°N latitude, 78.17°W longitude (Fig. 1). Organic soils in the southern portion of the county are distributed mainly as linear depressional features within the drumlinized till plain or in level areas underlain by glaciolacustrine deposits and are described in the Soils of Peterborough County (Gillespie and Acton 1981). Three sites were investigated in Peterborough County, and all three were classified as swamps (National Wetlands Working Group 1997; Ontario Ministry of Natural Resources and Forestry 2019). The Plain of Montreal study area is located approximately 30 km south of the City of Montreal, centered approximately at 45.15°N latitude and 73.62°W longitude (Fig. 1). The organic soils in this area are distributed mainly in five large deposits, which occur across a broad region that transects numerous soil survey reports. These include the Soil Survey of Napierville (Lamontagne et al. 2014), the Soil Survey of Huntingdon and Beauharnois (Mailloux and Godbout 1954), the Soil Survey of St-Jean (Lamontagne et al. 2001), the Soil Survey of Châteauguay (Baril and Mailloux 1950), and the Soil Survey of Laprairie (Lamontagne et al. 2000). The wetlands in this region are classified as treed peatlands (Canards Illimités Canada and Ministère de l'environnement et de la lutte contre les changements climatiques 2019*a*, 2019*b*), which corresponds to swamps in the national system (National Wetlands Working Group 1997), but were also described in the soil surveys as basin bogs or shore swamps (Lamontagne et al. 2000, 2001, 2014). The development of these peatlands can be complex. Due to the presence of limnic materials at the base of the wetlands, and forest peat at the surface, these wetlands likely developed following the trajectory described in Anderson et al. (2003). After deglaciation, large depressions were filled with water and limnic deposits accumulated in the lake bottoms, and terrestrialization of the waterbody began with formation and encroachment of vegetative mats. Following mat development and thickening, larger vegetation, such as shrubs and trees, could be supported, and the process of paludification then became the primary mechanism of peat development.

At each soil inspection, soil profiles were described (Day 1983) and classified as per the CSSC (SCWG 1998). Given that soil profiles were collected under different projects, soil physical and chemical analysis varied considerably. Where available, organic matter content, bulk density, soil pH, calcium carbonate equivalent, cation exchange capacity, total organic carbon, total carbon, total nitrogen, carbon to nitrogen ratio, water content at saturation and field capacity, electrical conductivity, coefficient of linear extensibility (COLE), shrinkage, and hydraulic conductivity are presented. Analyses and method references are provided, by study area, in Table 2.

For the mapping component, we acquired the detailed soil survey (DSS) geodatabase for provinces made available through the Canadian Soil Information Service (CanSIS), and additionally, where available, acquired DSS mapping directly through the provincial authorities (Soil Data Distribution Package, British Columbia; Agricultural Region of Alberta Soil Inventory Database (AGRASID), Alberta; Saskatchewan Soil Information Database (SKSID), Saskatchewan; Soils Agricultural Interpretations Database (SoilAID), Manitoba; Ontario Soil Survey Complex (OSSC), Ontario; Études pédologiques, Quebec). We then searched through all records in the available data sets for descriptions of any soil series classified as a Limnic subgroup of either Humisol, Mesisol, or Fibrisol great groups, and any example soil profiles containing Oco or other limnic horizons (i.e., marl and diatomaceous earth). In addition, soil series known to the authors as containing limnic deposits in shallow organic soils within the study areas that would not be currently recognized as limnic materials were also identified. Polygons within the geodatabases that contained these soils were then extracted to create maps and estimate the potential geographic extent and distribution of these soils in Canada.

Fig. 1. Index map (*a*) showing the location of the Montreal Plain, Middlesex, and Peterborough study areas with respect to Ontario and Quebec, and maps showing organic deposits mapped within the Montreal Plain (*b*), Middlesex County (*c*), and Peterborough County (*d*) study areas that contain limnic materials. Topographic base maps courtesy of the Ontario GeoHub, Ontario Ministry of Natural Resources and Forestry. Map projection: GCS WGS 1984. [Colour online.]



Field observations

Morphological descriptions of soil profiles ($n = 29$) are provided in Table 3. Only one profile is provided from the Middlesex project, three from Peterborough, and 25 from the Plain of Montreal. The profile from Middlesex is unique in that it is the only profile described with diatomaceous earth and marl whereas only two profiles from the Plain of Montreal contained a marl layer. All other profiles contain coprogenous earth. All profiles are classified as Terric subgroups, meaning they have a terric layer at least 30 cm thick below the surface tier. Due to the presence of a terric layer and the absence of a lithic contact in any of the profiles, the control section for all profiles extends from the surface to 160 cm. For classification purposes, when the terric layer is within the middle tier, the dominant material in both the middle and surface tier is given consideration to determine the great group; however, when the terric layer is below the middle tier, only the materials within the middle tier are used to determine the great group. There are 11 profiles classified as Terric Humisols, five as Terric Mesisols, one Terric Mesic Humisol, and 12 profiles that cannot be classified as soils of the Organic order (Table 3).

The thickness of humic, mesic, and limnic materials to be considered for great group classification for each profile was quite variable (Table 3). The average thickness across all profiles was 50.8, 16.4, and 46.8 cm for the humic, mesic, and limnic materials, respectively. All 29 soil profiles had limnic materials as either dominant (11 profiles) or subdominant (18 profiles) within the material to be considered for great group classification (depends on the depth to terric layer), while humic materials were dominant in 13 profiles and subdominant in eight profiles. Mesic materials were less common and were dominant in only five profiles, and subdominant in two profiles.

In total, 28 limnic material samples from the soil profiles were analyzed for various chemical and physical properties (Table 4). Since there were so few marl and diatomaceous earth samples, they were excluded from the analysis, leaving only coprogenous earth materials. Organic matter content ranged from 4.5% to 81.8%, highlighting the fact that coprogenous materials can be either organic or inorganic. Bulk density was below 0.34 g cm^{-3} with the exception of one site; this low bulk density is similar to that of humic organic materials. The mean pH was neutral; however, two sites in the Napierville area were acidic (pH < 5.5). A mean calcium carbonate equivalent of 24.2% for sites in Peterborough suggests the materials there are strongly calcareous; however, it should be noted that two sites in Quebec had

Table 2. Summary of soil properties, units of measurement, and method reference for the Middlesex, Peterborough, and Montreal Plain study areas.

Study area	Soil property	Units	Method
Middlesex County	Organic matter	%	Modified Walkley-Black (McKeague 1978, method 3.613)
	pH—$CaCl_2$		1:2 soil: $CaCl_2$ ratio (McKeague 1978, method 3.11)
	pH—water		1:1 soil: water ratio (McKeague 1978, method 3.13)
	Total organic carbon	%	Calculated from organic matter as TOC = OM/1.724
Peterborough County	Organic matter	%	Calculated from total organic carbon as OM = TOC × 1.724
	Bulk density	g cm^{-3}	Core method
	pH—$CaCl_2$		1:1 soil: $CaCl_2$ (Hendershot et al. 1993)
	pH—water		1:1 soil: H_2O (Hendershot et al. 1993)
	Calcium carbonate equivalent	%	Calculated from inorganic carbon
	Cation exchange capacity	cmol kg^{-1}	Barium chloride method (Rhoades1983)
	Total organic carbon	%	Combustion method, LECO CN-828 carbon analyzer
	Total carbon	%	Combustion method, LECO CN-828 carbon analyzer
	Total nitrogen	%	Combustion method, LECO CN-828 carbon analyzer
Montreal Plain	Organic matter	%	Loss-on-ignition method (MDDELCCQ 2017)
	Bulk density	g cm^{-3}	Core method
	pH—water		1:5 soil: water ratio (CEAEQ 2014)
	Cation exchange capacity	cmol kg^{-1}	Ammonium acetate method (CPVQ 1997)
	Total carbon	%	Combustion method, LECO CN-828 carbon analyzer
	Total nitrogen	%	Combustion method, LECO CN-828 carbon analyzer
	Water content	%	Tension table with glass beads (CPVQ 1997)
	Electrical conductivity	mS cm^{-1}	1:5 soil: water ratio (CEAEQ 2014)
	Coefficient of linear extensibility	cm cm^{-1}	McKeague (1978)
	Shrinkage	m^3 Mg^{-1}	McKeague (1978)
	Hydraulic conductivity	cm h^{-1}	McKeague (1978)

this analysis, and both had no calcium carbonate. This, coupled with the pH results, suggests the biogeochemistry of the environments at the time of deposition was quite different between the Ontario and Quebec locations. Despite differences in the other soil properties, the C:N ratio was within a narrow range (11.6–16.8) across all sites and horizons. Soil electrical conductivity was only measured at some of the sites in Quebec and seemed to indicate the materials were slightly saline; however, the nature of the salinity was not examined. It should be noted that the Quebec study area was once inundated by the Champlain Sea; therefore, saline materials are not surprising. In terms of water retention characteristics, the coprogenous earth had on average 86.4% and 72.8% water content at saturation and at field capacity, respectively, and hydraulic conductivity of 0.0 cm h^{-1}, demonstrating the imperviousness of the material. Two specialized physical analyses, COLE and shrinkage, were determined for only two of the Oco samples. Both parameters are indications of the shrinking potential of the material. COLE was 0.5 cm cm^{-1}, which indicates a 50% reduction in the material and shrinkage was 3.6 m^3 Mg^{-1}, both confirming the potential for major subsidence if the material is allowed to dry.

In addition to the analytical data from this study, data are reproduced from Hamel, Malouin, Ruel et Associés (1972), which has the most detailed information about the coprogenous materials in the peatlands of the Plain of Montreal, with emphasis on their suitability for vegetable crop production (Table 5). These data show close alignment to those collected in this study and provide additional analyses not completed on the more recent sample collection efforts, including the pyrophosphate index, unrubbed fiber, and rubbed fiber content, which are analyses specifically used to determine the level of decomposition of materials in organic soils. Based on their results, the Oco horizons sampled in their study are typically at a medium level of decomposition. Photos of coprogenous materials and soil profiles containing these materials are provided in Fig. 2.

Despite the fact that limnic materials were found to be dominant or subdominant in all of the profiles, based on the current rules for classifying soils of the Organic order in the CSSC, none of these profiles would include the term "limnic" in any of the five recognized taxonomic levels. Twelve of the 29 soil profiles cannot be classified into the Organic order at all, despite the fact they clearly belong there. The reason they cannot be classified as the Organic order is due to a lack of thickness of humic (Oh) or mesic (Om) materials. Based on the key to soil orders, soils of the Organic order must have organic horizons (>17% organic carbon) that extend from the surface to a depth ≥60 cm for fibric materials or a depth ≥40 cm for mesic and humic materials (SCWG 1998). The 12 profiles that cannot be classified do not meet these

Table 3. Soil profile descriptions for soils with limnic layers in the Middlesex, Peterborough, and Montreal Plain study areas.

Profile	Location	Current classification	Revised classification	Horizon	Upper depth (cm)	Lower depth (cm)	Thickness for Great Group Classification (cm)		
							Humic	Mesic	Limnic
OS1	Middlesex County, Ontario	Terric Mesisol	Terric Limnic Mesisol	Om1	0	56	0	55	25
				Om2	56	79			
				Om3	79	95			
				C (diatomaceous)	95	133			
				IICk (marl)	133	+			
DSM045	Peterborough County, Ontario	Terric Humisol	Terric Limnic Humisol	Oh	0	50	50	0	34
				Oco1	50	57			
				Oco2	57	62			
				Oco3	62	84			
				Ckg	84	125			
PTBO18_1246	Peterborough County, Ontario	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Oh	0	34	0	0	80
				Oco	34	148			
				Ckg	148	200			
PTBO18_1305	Peterborough County, Ontario	Terric Humisol	Terric Limnic Humisol	Oh	0	42	42	0	31
				Oco1	42	55			
				Oco2	55	73			
				Cg	73	120			
4-9B-3	Châteauguay County, Quebec	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Ohp	0	27	27	0	49
				Oco	27	76			
				Cg	76	100			
4-1-2	Châteauguay County, Quebec	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Ohp1	0	15	36	0	54
				Ohp2	15	36			
				Oco	36	90			
				Cg	90	120			
4-14-1	Châteauguay County, Quebec	Terric Mesisol	Terric Limnic Mesisol	Ohp1	0	16	6	51	23
				Ohp2	16	46			
				Om1	46	82			
				Om2	82	97			
				Oco	97	120			
				Ck (marl)	120	149			
				IICkg	149	155			
7-10-8	Châteauguay County, Quebec	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Ohp1	0	13	29	0	48
				Ohp2	13	29			
				Oco1	29	54			

Table 3. (*concluded*).

Profile	Location	Current classification	Revised classification	Horizon	Upper depth (cm)	Lower depth (cm)	Thickness for Great Group Classification (cm)		
							Humic	Mesic	Limnic
				Oco2	54	77			
				Cg	77	79			
				IICg	79	110			
1-3-4	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	12	80	0	0
				Ohp2	12	31			
				Oh	31	125			
				Oco	125	153			
				Cg	153	180			
				Ckg	180	200			
11-71-1	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	10	53	0	27
				Ohp2	10	30			
				Oh1	30	48			
				Oh2	48	78			
				Oh3	78	93			
				Oco1	93	115			
				Oco2	115	157			
				Ckg	157	200			
11-75-2	Napierville County, Quebec	**Organic Order (cannot be classified at great group or subgroup level)**	Terric Humic Limnisol	Ohp1	0	15	25	7	48
				Ohp2	15	31			
				Oh1	31	56			
				Oh2	56	65			
				Om	65	72			
				Oco1	72	116			
				Oco2	116	158			
				Cg	158	169			
				IICg	169	180			
				IICkg	180	200			
11-221-1	Napierville County, Quebec	Terric Mesic Humisol	Terric Limnic Humisol	Ohp1	0	18	36	29	30
				Ohp2	18	36			
				Om1	36	49			
				Om2	49	65			
				Oco	65	95			
				Cg	95	101			

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Table 3. (*concluded*).

Profile	Location	Current classification	Revised classification	Horizon	Upper depth (cm)	Lower depth (cm)	Thickness for Great Group Classification (cm)		
							Humic	Mesic	Limnic
				IICkg	101	120			
11-111-1	Napierville County, Quebec	Terric Mesisol	Terric Limnic Mesisol	Ohp1	0	11	17	39	24
				Ohp2	11	32			
				Oh	32	57			
				Om1	57	67			
				Om2	67	96			
				Oco	96	121			
				Cg	121	126			
				IICkg	126	140			
11-8-1	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	33	45	11	25
				Ohp2	33	45			
				Om	45	56			
				Oco1	56	67			
				Oco2	67	81			
				Cg1	81	91			
				Cg2	91	123			
				Cg3	123	127			
11-5-1	Napierville County, Quebec	**Cannot be classified in Organic Order**	Terric Limnic Humisol	Ohp1	0	19	30	0	18
				Ohp2	19	30			
				Oco	30	48			
				Cg	48	56			
				IICkg	56	80			
10-D6-1	St-Jean County, Quebec	Terric Mesisol	Terric Limnic Mesisol	Ohp1	0	10	0	55	25
				Ohp2	10	30			
				Om1	30	55			
				Om2	55	95			
				Oco1	95	126			
				Oco2	126	159			
				Cg	159	185			
5-FON2-1	Châteauguay County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	7	30	21	29
				Ohp2	7	26			
				Ohp3	26	32			

Table 3. (*concluded*).

Profile	Location	Current classification	Revised classification	Horizon	Upper depth (cm)	Lower depth (cm)	Thickness for Great Group Classification (cm)		
							Humic	Mesic	Limnic
				Oh	32	70			
				Om	70	91			
				Oco1	91	110			
				Oco2	110	125			
				Ck (marl)	125	158			
				IICg	158	200			
6-G3-1	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	20	53	0	17
				Ohp2	20	41			
				Oh	41	53			
				Oco	53	70			
				Cg	70	80			
3-JP2-1	Napierville County, Quebec	**Organic Order (cannot be classified at great group or subgroup level)**	Terric Mesic Limnisol	Ohp1	0	8	0	38	42
				Ohp2	8	30			
				Om	30	78			
				Oco1	78	106			
				Oco2	106	119			
				Oco3	119	123			
				Cg	123	132			
				IICg	132	150			
12-5-1	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	6	65	0	15
				Ohp2	6	37			
				Oh1	37	75			
				Oh2	75	105			
				Oco1	105	122			
				Oco2	122	136			
				Cg	136	141			
				IICg	141	150			
13-D2-1	Napierville County, Quebec	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Ohp1	0	21	39	0	59
				Ohp2	21	29			
				Oh	29	39			

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Table 3. (*concluded*).

Profile	Location	Current classification	Revised classification	Horizon	Upper depth (cm)	Lower depth (cm)	Thickness for Great Group Classification (cm)		
							Humic	Mesic	Limnic
				Oco1	39	43			
				Oco2	43	62			
				Oco3	62	98			
				Cg	98	101			
				IICg	101	105			
				IICkg1	105	114			
				IICkg2	114	125			
13-S3-1	Napierville County, Quebec	Terric Mesisol	Terric Limnic Mesisol	Ohp1	0	12	0	46	34
				Ohp2	12	29			
				Om1	29	77			
				Om2	77	86			
				Oco1	86	94			
				Oco2	94	124			
				Oco3	124	156			
				Ckg	156	200			
14-M1-1	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Ohp1	0	10	70	0	10
				Ohp2	10	33			
				Oh1	33	69			
				Oh2	69	85			
				Oh3	85	110			
				Oco	110	130			
				Cg	130	148			
				IICg	148	150			
NP-01	Napierville County, Quebec	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Oh	0	30	30	0	45
				Oco1	30	50			
				Oco2	50	75			
				Ckjg	75	100			
				IICkg	100	120			
				IIICkg	120	150			

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Table 3. (*concluded*).

Profile	Location	Current classification	Revised classification	Horizon	Upper depth (cm)	Lower depth (cm)	Thickness for Great Group Classification (cm)		
							Humic	Mesic	Limnic
				IVCkg	150	210			
NP-03	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Oh1	0	30	80	0	20
				Oh2	30	80			
				Oco	80	100			
				Ckg	100	120			
				IICkg	120	+			
NP-04	Napierville County, Quebec	Terric Humisol	Terric Limnic Humisol	Oh1	0	24	80	0	30
				Oh2	24	80			
				Oco	80	110			
				Cg	110	120			
NP-05	Napierville County, Quebec	**Organic Order (cannot be classified at great group or subgroup level)**	Terric Humic Limnisol	Oh	0	60	20	0	60
				Oco	60	140			
				Cg	140	170			
NP-06	Napierville County, Quebec	**Cannot be classified in Organic Order**	Terric Humic Limnisol	Oh	0	30	30	0	50
				Oco	30	80			
				Cg	80	95			
				IICg	95	120			
01LGGCO00	Châteauguay County, Quebec	**Organic Order (cannot be classified at great group or subgroup level)**	Terric Mesic Limnisol	Ohp	0	16	0	29	51
				Om1	16	37			
				Om2	37	69			
				Oco1	69	83			
				Oco2	83	110			
				Oco3	110	128			
				Ckgj1	128	158			
				Ckgj2	158	230			

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Table 4. Summary of physical and chemical analyses from coprogenous earth horizons from the Peterborough and Montreal Plain study areas.

Soil property	Units	*n*	Minimum	Mean	Maximum	Standard deviation
Organic matter	%	24	4.5	52.1	81.8	25.4
Bulk density	g cm^{-3}	14	0.1	0.3	0.9	0.2
pH (water)		13	4.5	6.4	7.6	1.1
pH ($CaCl_2$)		8	4.0	6.6	7.4	1.2
Calcium carbonate equivalent	%	8	0.0	24.2	69.1	25.4
Cation exchange capacity	cmol kg^{-1}	8	14.4	43.5	113.0	32.9
Total organic carbon	%	8	2.6	13.8	38.6	11.9
Total carbon	%	13	5.2	22.0	41.0	12.3
Total nitrogen	%	13	0.2	1.4	3.3	1.0
Carbon/nitrogen		13	11.6	14.0	16.8	1.6
Water content, 0 kPa	%	8	79.8	86.4	91.5	4.7
Water content, 33 kPa	%	8	58.4	72.8	84.9	9.5
Electrical conductivity	mS cm^{-1}	18	0.7	1.5	3.1	0.6
Coefficient of linear extensibility	cm cm^{-1}	2	0.4	0.5	0.6	0.1
Shrinkage	m^3 Mg^{-1}	2	2.2	3.6	4.9	1.9
Hydraulic conductivity	cm h^{-1}	2	0.0	0.0	0.0	0.0

Table 5. Summary of physical and chemical analyses from coprogenous earth horizons from the Montreal Plain study area reported in Hamel, Malouin, Ruel et Associés (1972).

Soil property	Units	*n*	Minimum	Mean	Maximum	Standard deviation
Organic matter	%	45	9.3	43.7	92.6	22.8
Bulk density	g cm^{-3}	37	0.1	0.1	0.4	0.1
pH ($CaCl_2$)		43	2.2	3.3	6.4	2.9
Total carbon	%	45	3.1	30.7	56.7	13.2
Total nitrogen	%	45	0.2	1.8	3.2	0.8
Pyrophosphate index	%	20	4.9	39.3	140.0	44.1
Unrubbed fiber	%	42	6.0	68.6	100.0	27.7
Rubbed fiber	%	42	1.0	5.3	40.0	7.1

requirements (Om + Oh <40 cm). Furthermore, if these soils were keyed out as Organic order soils by modifying the key to the Organic order, 11 of the profiles could not be classified as a great group within the Organic order because the dominant material in the middle tier, or middle and surface tiers, is limnic material, whereas the key only allows for fibric, mesic, humic, or folic materials to determine the great group. Finally, if the rules at the great group level were ignored, and these soils were keyed into one of the subgroups within the three wetland Organic great groups, the classification would fail to recognize the limnic materials once again because the Terric subgroup takes precedence over the Limnic subgroup.

The extent of soils with limnic materials is not extensive. Based on available information from the provincial and federal soil survey data, we estimated 32 057 ha of organic soils potentially with limnic deposits across Canada in five provinces (Fig. 3). Quebec holds the largest area with 18 111 ha, followed by Ontario (6192 ha), British Columbia (3961ha), Manitoba (3791 ha), and Saskatchewan (2 ha). It is certainly worth noting that these estimates are based on known, mapped soil units, which contain limnic materials, and that additional areas are likely to exist. For example, DSS mapping efforts by the private sector to support project planning in Alberta have mapped limnic deposits near Edmonton, Alberta (Total E&P Canada 2007; Vujnovic et al. 2000), despite the fact the AGRASID database and the CanSIS DSS for Alberta do not contain soils with limnic materials. Agricultural suitability was certainly a key driver for soil survey, and as such organic soils were never surveyed and described as intensively as mineral soils. Proof of this is apparent in many soil survey reports where organic soils were either reported simply as "muck" or "peat" or treated as a "Miscellaneous Mapping Unit" (Gillespie and Wicklund 1971; Hoffman 1974; Hoffman et al. 1963). In such areas, a more detailed survey of organic deposits would likely yield the discovery of additional acreages of organic soils with limnic materials, especially given the fact that these materials have been described in adjacent surveys/projects.

Proposed classification revisions

To address these shortcomings, we propose a series of modifications to the Organic order of the CSSC to be considered for inclusion in the fourth edition (in development):

1. Modifying the Key to Soil Orders to allow for soils with dominantly limnic materials to be included in

Fig. 2. Photos of soil profiles containing limnic horizons and coprogenous materials. Soil profile from Peterborough County (*a*), mixing of coprogenous material into surface plow layer in Napierville County (*b*), layered nature of coprogenous material from Napierville County after air-drying (*c*), close-up of two coprogenous layers from a profile in Peterborough County with the lower layer containing shells (*d*), close-up of layering of dark and light bands in the coprogenous horizon (*e*), sloughing of humic material into the coprogenous layer above an installed tile drain (*f*), soil profile from Peterborough County (*g*) and burgundy colored core of coprogenous material from plain of Montreal area (*h*). Photo credits: D. Saurette (*d*, *g*); R. Deragon (*e*, *f*, *h*); L. Lamontagne (*a*, *b*, *c*). [Colour online.]

the Organic order and including limnic materials to be counted towards the depth requirements for Organic soils.

2. Adding the Limnisol great group to accommodate Organic soils where the middle tier, or middle and surface tiers, are dominantly composed of limnic materials.
3. Adding subgroups under the new Limnisol great group.
4. Further integrating Limnic at the subgroup level in the Fibrisol, Mesisol, and Humisol great groups.

It should be noted that no changes are proposed for the Folisol great group because these are upland organic soils, and limnic deposits only occur in wetland organics since these materials are deposited in standing water. Revised keys to the Organic soil order, great groups, and subgroups are provided in Appendix A, where changes to the keys are denoted by underlined and italic text. In addition to the revisions to the keys, upon acceptance, content will be created to amend Chapter 9: Organic Order, in light of these suggested changes. Furthermore, we propose a slight clarification to the definition of the Middle Tier (SCWG 1998, p. 11):

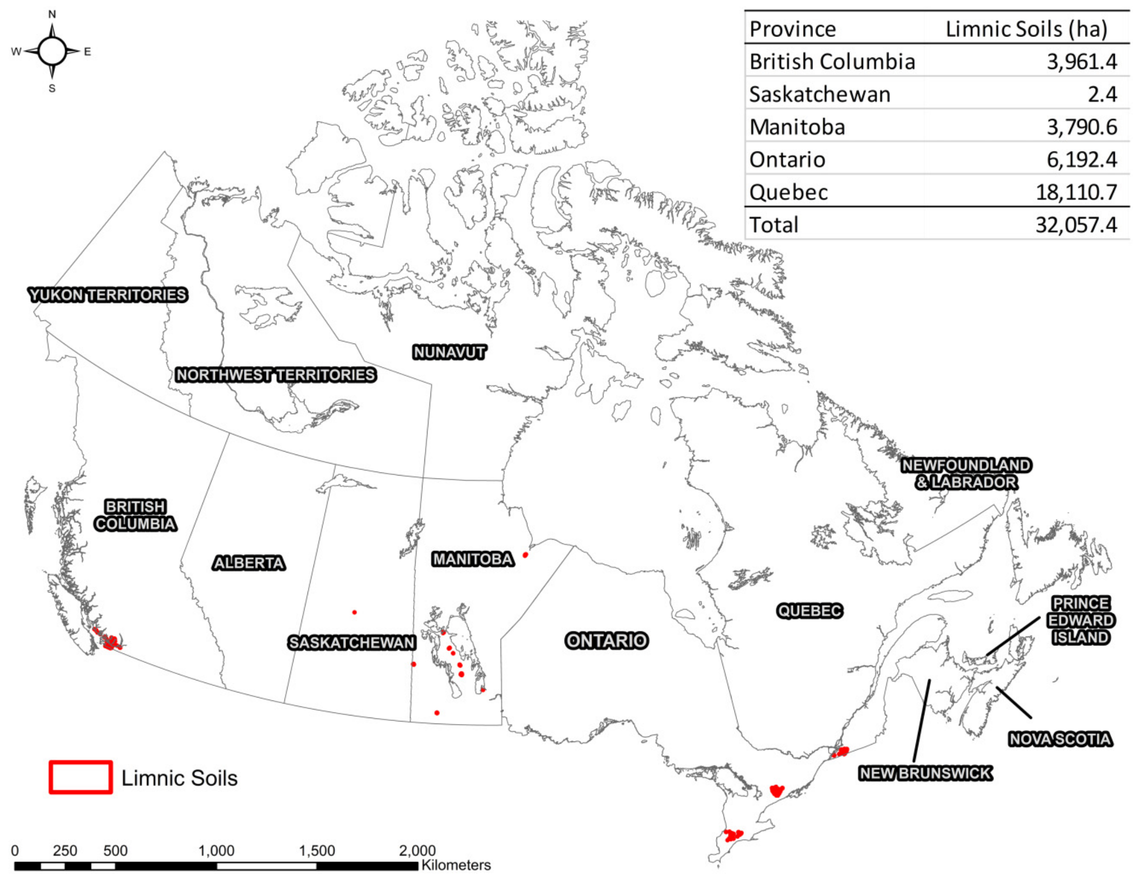
Middle tier: The middle tier is 80 cm thick. It establishes the great group classification if no terric, lithic, or hydric substratum is present *within this tier*. Otherwise, the dominant kind of organic material in this and the surface tier establishes the great group classification. The nature of the subdominant organic material in the middle or bottom tier assists in establishing the subgroup classification.

If these proposed changes were adopted, the resulting classification for all the soil profiles described in this study would change, as outlined in Table 3. In summary, we would have 13 profiles classified as Terric Limnic Humisol, nine profiles as Terric Humic Limnisol, five as Terric Limnic Mesisol, and two as Terric Mesic Limnisol.

Discussion

The CSSC is not the only system that recognizes limnic deposits in organic soils for taxonomic purposes and, likewise, is not the only system that might lack clarity when classifying profiles composed dominantly of limnic materials. In Soil Taxonomy, for instance, the Limnic subgroup

Fig. 3. Map of Canada showing soil polygons where limnic materials have been mapped as per provincial soil survey data, detailed soil surveys from the Canadian Soil Information Service (CanSIS), and the information contained in the Soil Name File of CanSIS. Topographic base map courtesy of the Ontario Ministry of Agriculture, Food and Rural Affairs. Map projection: Canada Lambert Conformal Conic, GCS North American 1983. [Colour online.]



can be applied to each great group within the Histosol order, the equivalent of the Organic order in the CSSC (USDA-NRCS 1999). In Soil Taxonomy, however, the Limnic subgroup appears before the Terric subgroup (the opposite of the sequence in the CSSC), and therefore any Histosol with a limnic layer, or layers, with a total thickness of ≥5 cm, regardless of the presence of a terric layer, is assigned to the Limnic subgroup of the corresponding great group (USDA-NRCS 1999). This, of course, creates the opposite problem faced in the CSSC and does not resolve the issue of accommodating both Terric and Limnic in a combined subgroup. The World Reference Base (WRB) system of soil classification uses two levels to classify soils: the Reference Soil Group (RSG) and Qualifiers, of which the latter are separated into principal and supplementary qualifiers. The principal qualifiers are intended as integral to allow further characterization of a soil, while the supplementary qualifiers are intended to provide additional characterization (IUSS Working Group WRB 2015). Limnic materials are represented only as a supplementary qualifier across many of the RSGs, including the Histosols, whereas “fibric”, “hemic” (mesic), and “sapric” (humic) are designated as principal qualifiers (IUSS Working Group WRB 2015). One difference with the WRB is that “terric” is not used as a qualifier for the Histosol Reference Soil Group.

It should be noted that, in Canada, considerably less research has been conducted to quantify and characterize the properties and origins of coprogenous earth materials as has occurred in Northern European countries such as Finland (Berglund 1996), Sweden (Larsson 1990), Poland (Jarnuszewski and Meller 2018, 2019; Łachacz et al. 2009), and Germany (Schulz et al. 2019). Schulz et al. (2019) classify six types of gyttjas, or coprogenous earth, including detritus, algal, calcareous, sand, silt, and clay gyttjas, differentiated based on their organic matter content, lime ($CaCO_3$) content, and silicate fraction. In Poland, gyttjas, or lake bottom deposits, have been differentiated based on their ash content without $CaCO_3$, organic matter content by loss-on-ignition, and $CaCO_3$ content (Łachacz et al. 2009; Łachacz and Nitkiewicz 2021), which results in a classification triangle that includes 11 different classes, with the sum of the three components adding up to 100. It is evident that more research is needed to better classify the types of coprogenous earth that exist in Canada, and that advanced systems in Europe would provide much insight.

In addition to taxonomic considerations for recognizing limnic materials at a higher taxonomic level, many agricultural considerations would also justify the proposed modifications to the CSSC. Organic soils make up approximately 10% of the Canadian land mass and support important agricultural regions in Canada (Lévesque et al. 1981). A primary example is the Saint-Lawrence plain south of Montreal, which has 145 000 ha of deep organic soils and 24 000 ha of shallow organic soils (Grenon 1988). Specialty crop production in organic soils, focused on root and leafy vegetables, is critically important to the agricultural sector in this region since as early as 1936, with high-value crops destined for markets in Montreal and New York State (McKibbin and Stobbe 1936), generating 50% of agricultural revenues on only 3%–4% of the agricultural land base in the province (Groupe AGÉCO 2007; Parent and Gagné 2010). A significant portion of the organic deposits in the region is underlain by coprogenous earth, and they are at increased risk of being exposed at the surface as a result of subsidence of the peat due to drainage and continued losses of surface organic materials from microbial decomposition (1.25 cm year^{-1}) and wind and water erosion (1.25 cm year^{-1}). Parent et al. (1982) concluded that wind erosion rates could be as high as 4.53 cm year^{-1} in these organic soils when beneficial management practices were not implemented to protect the soils.

Coprogenous materials are reported to have characteristics that could be deleterious to agricultural production. These include being plastic and gelatinous when wet, hard when (irreversibly) dry, saline, and containing potentially high levels of sulfur (Kroetsch et al. 2011). In a detailed assessment of the agricultural potential of organic soils in the Plain of Montreal, Hamel et al. (1972) noted that the underlying gelatinous material (sedimentary peat) made tile drainage very difficult, limited agricultural production when too close to the surface, had negative effects on soil fertility, compromised production once incorporated into the surface peat, and offered very little possibility for continued agricultural production once the overlying peat was gone. They also noted that once dry, the material cracks irreversibly, hardens, and comes apart like thin leaves. The installation of tile drainage is problematic when an irregular limnic layer is present in a field since tiles must sit above the impervious material. Common drainage systems are sometimes inefficient in the presence of such a layer and might require the use of surface drains such as trenches, or complex, multileveled drainage systems. In northeast Poland, many of the extensive gyttja lands have been excluded from agricultural production due to the difficulty in farming them (Łachacz and Nitkiewicz 2021). More recently in Canada, the presence of a coprogenous or mineral layer found close to the surface was found to affect soil's physical and chemical properties in the plain of Montreal (Deragon et al. 2022). For instance, the coprogenous material was found to have salinity levels high enough to reduce crop yields. Crops, particularly high-value vegetable crops, are negatively affected by different levels of salinity. For example, carrots (1.0 mS cm^{-1}), onions (1.2 mS cm^{-1}), celery (1.8 mS cm^{-1}), lettuce (2.0 mS cm^{-1}), and spinach (2.0 mS cm^{-1}) are sensitive and moderately sensitive to soil salinity (Machado and Serralheiro 2017). Possible yield loss can be expected when soil salinity exceeds these thresholds, which was frequent in the study area (Table 4). Water retention, and indirectly gas diffusion, was correlated to the presence of those relatively impervious coprogenous layers. Kroetsch et al. (2011) further support this claim by noting the plasticity and gelatinous appearance of limnic material when wet, and the shrinkage and hydrophobicity of the material when dry. Vegetable roots require sufficient aeration and a growing medium that can store and supply water throughout the growing season, which a limnic layer would fail to deliver. The bearing capacity of these soils can also be problematic for heavy agricultural machinery if a limnic layer is near the soil surface; the consistence is such that machinery can sink dangerously into the limnic material (Hamel et al. 1972).

A more accurate soil classification could provide better information for land transactions. Indeed, a Limnic great group, and better integration at the subgroup level, would add crucial information important to understanding the long-term agricultural potential of an organic soil containing limnic materials. With an average selling price of $63 000 ha^{-1} (2019–2021) in Napierville County, cultivated organic soils are a scarce resource (data extracted and filtered from the Registre financier du Quebec). Inevitably, soils classified as Limnic Terric Humisols or as Terric Limnisols would identify the presence of limnic materials potentially close to the surface and indicate reduced land value, because once exposed or incorporated into the plow layer, thick limnic layers would be an impediment to further agricultural land use (J. Caron, personal communication, 2022). Figure 2*b* shows that dried coprogenous material does not mix well in the surface plow layer. This behavior can affect the seeding operation and can lead to non-uniform germination. While a thin limnic layer could be mixed with the underlying mineral soil to allow cultivation after the depletion of the peat, a thick limnic layer could not be so easily incorporated into the underlying material. Moreover, the underlying mineral soil would likely have fertility issues and undesirable physical properties for specialty crop production, such as low air content. Yield losses could be expected, and therefore land value would decrease. A metric such as the residual maximum peat thickness (MPT)—the thickness of the arable peat layer—has been proposed to estimate the remaining years of production considering average soil loss rates (e.g., 2.5 cm year^{-1}) if no conservation practices are applied (Deragon et al. 2022). Deragon et al. (2022) observed statistically significant changes in chemical and physical properties of peaty layers as a function of the MPT, where soils with an MPT <60 cm showed important signs of soil degradation, while soils with an MPT >60 cm showed fewer signs of degradation. Not only would the MPT reflect the potential of a field, but it would also allow the assessment of economically justifiable soil conservation practices. Wojahn and Illner (1962) determined a critical peat thickness of 80 cm should be maintained over limnic materials due to the possibility of lateral flow of the limnic materials into surface drainage ditches. Therefore, organic soils with limnic layers should not be considered a priority management zone in a soil conservation context, especially if the MPT is less than 60 cm (Deragon et al. 2022) to 80 cm (Husemann 1947; Wojahn and Illner 1962) in thickness.

Recommendations and conclusion

Limnic materials are poorly captured in the CSSC and are even ignored at all five taxonomic levels in some instances, despite the fact these limnic materials can be dominant within a soil pedon. Furthermore, their composition is poorly documented in Canada, and further studies are required to better understand the nature and properties of these materials in the future. Numerous soil profile descriptions were provided from Ontario and Quebec to highlight the deficiencies in the CSSC, and a review of DSSs confirms the potential for over 32 000 ha of organic soils with limnic deposits, which we conclude is likely an underestimate. In addition to taxonomic considerations, we also demonstrate the importance of modifying the CSSC for agronomic and financial reasons, including negative impacts of limnic materials on crop production. Based on our analysis, we recommend the addition of the Limnisol great group to the Organic order, and additional integration of limnic materials at the subgroup level, specifically as it relates to recognizing limnic and terric together. Furthermore, we provide revised keys to the Organic order, its great groups, and subgroups in light of the proposed changes.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Anderson, R.L., Foster, D.R., and Motzkin, G. 2003. Integrating lateral expansion into models of peatland development in temperate New England. J. Ecol. **91**: 68–76. doi:10.1046/j.1365-2745.2003.00740.x.
Baril, R., and Mailloux, A. 1950. Étude pédologique des sols du comté de Châteauguay. Bulletin technique No.2. Division des sols, École Supérieure d'Agriculture. Ministère de l'Agriculture, Ste-Anne-de-la-Pocatière, Québec.
Berglund, K. 1996. Properties of cultivated gyttja soils. Int. Peat J. **6**: 5–23.
Canards Illimités Canada, Ministère de l'environnement et de la lutte contre les changements climatiques. 2019a. Cartohraphie détaillée des milieux humides du territoire de la plaine du Lac-St-Jean (Rapport Technique). Québec, Québec.
Canards Illimités Canada, Ministère de l'environnement et de la lutte contre les changements climatiques. 2019b. Cartographie détaillée des milieux humides des secteurs habités du sud du Québec - territoire de la plaine du Lac-St-Jean - Données géographiques. Québec, Québec.
CDA (Canada Department of Agriculture). 1970. The system of soil classification for Canada., Canada Department of Agriculture, Queen's Printer for Canada, Ottawa, Ontario.
CDA (Canada Department of Agriculture). 1974. The system of soil classification for Canada - Revised. Queen's Printer for Canada, Ottawa, Ontario.

CEAEQ (Centre d'expertise en analyse environnementale du Québec). 2014. Détermination du pH : méthode électrométrique, MA. 100 – pH 1.1, Rév. 3. Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec.

CPVQ (Conseil des Productions Végétales du Québec inc.). 1997. Méthodes d'analyse des propriétés physiques des milieux artificiels, des tourbes et des sols organiques. Courbe de rétention. Québec.

CSSC (Canada Soil Survey Committee). 1971. Canada Soil Survey Committee Second Regional Meeting of the Eastern Section (No. 2). Canada Soil Survey Committee, Fredericton, New Brunswick.

Day, J. 1983. The Canada Soil Information System (CanSIS), Manual for describing soils in the field 1982 Revised (No. 82–85). Land Resource Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario.

Deragon, R., Julien, A.-S., Dessureault-Rompré, J., and Caron, J. 2022. Using cultivated organic soils' depth to form soil conservation management zones. Can. J. Soil Sci. eFirst. doi:10.1139/CJSS-2021-0148.

Fox, C.A., and Tarnocai, C. 1990. The micromorphology of a sedimentary peat deposit from the pacific temperate wetland region of Canada. In: Developments in soil science. *Edited by* L.A. Douglas, Elsevier. San Antonio, Texas. pp. 311–319. doi:10.1016/S0166-2481(08)70343-X.

Gillespie, J.E., and Acton, C.J. 1981. Soils of Peterborough County (No. 45). Ontario Institute of Pedology. Research Branch, Agriculture and Agri-Food Canada. Ontario Ministry of Agriculture and Food. Department of Land Resource Science, University of Guelph., Guelph, Ontario.

Gillespie, J.E., and Wicklund, R.E. 1971. Soils of Halton County. Report No 43 of the Ontario Soil Survey. Soil Research Institute, Research Branch, Agriculture Canada. Ontario Agricultural College, University of Guelph., Guelph, Ontario.

Grenon, L. 1988. Répartition des terres humides dans la plaine du St-Laurent (Cartes de sol). Équipe pédologique du Québec, Agriculture Canada.

Groupe AGÉCO 2007. Portrait et priorités du secteur maraîcher québecois; Rapport final.

Hagerty, T.P., and Kingston, M.S. 1992. The soils of Middlesex County (No. 56). Ontario Centre for Soil Resource Evaluation, Resource Management Branch, Ontario Ministry of Agriculture and Food, Guelph, Ontario.

Hamel, Malouin, Ruel et Associés 1972. Inventaire et étude du potentiel maraîcher des dépôts de sols organiques de la région du sud de Montréal. Préparés pour le Ministère de l'Agriculture et de la colonisation de la province de Québec.

Hendershot, W.H., Lalande, H., and Duquette, M. 1993. Soil reaction and exchangeable acidity, In: Soil sampling and methods of analysis. *Edited by* M.R. Carter, Canadian Society of Soil Science, Lewis Publishers, Boca Raton, FL. pp. 141–142.

Hoffman, D.W. 1974. Soils of Northumberland County. Report No 42 of the Ontario Soil Survey. Soil Research Institute, Research Branch, Agriculture Canada. Ontario Agricultural College, University of Guelph., Guelph, Ontario.

Hoffman, D.W., Matthews, B.C., and Wicklund, R.E. 1963. Soil survey of Wellington County Ontario (Soil Survey No. 35). Research Branch, Canada Department of Agriculture and the Ontario Agricultural College, Guelph, Ontario.

Husemann, C. 1947. Die landwirtschaftliche Bewertung der Moorböden und ihre natürlichen Grundlagen: Ein Beitrag zur Kultivierung und Besiedlung der deutschen Moore. Kinau.

Ismail-Meyer, K., Stolt, M.H., and Lindbo, D.L. 2018. Chapter 17 - Soil Organic matter, In: Interpretation of micromorphological features of soils and regoliths. 2nd ed. *Edited by* G. Stoops, V. Marcelino and F. Mees, Elsevier, Amsterdam, the Netherlands. pp.471–512. doi:10.1016/B978-0-444-63522-8.00017-6.

IUSS Working Group WRB. 2015. World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps. Update 2015. World Soil Resources Reports No. 106. FAO, Rome.

Jarnuszewski, G., and Meller, E. 2018. Morphological and physical properties of dehydrated Holocene carbonate limnic deposits in post-bog areas of NW Poland. J. Ecol. Eng. **19**: 136–142. doi:10.12911/22998993/79412.

Jarnuszewski, G., and Meller, E. 2019. Total content of macroelements and trace elements in Holocene calcareous gyttja from the post-bog area of north-western Poland. Soil Water Res. **14**: 40–46. doi:10.17221/146/2017-SWR.

Kroetsch, D.J., Geng, X., Chang, S.X., and Saurette, D.D. 2011. Organic soils of Canada: part 1. Wetland organic soils. Can. J. Soil Sci. **91**: 807–822. doi:10.4141/cjss10043.

Łachacz, A., and Nitkiewicz, S. 2021. Classification of soils developed from bottom lake deposits in north-eastern Poland. Soil Sci Ann. **72**: 1–14. doi:10.37501/soilsa/140643.

Łachacz, A., Nitkiewicz, M., and Pisarek, W. 2009. Soil conditions and vegetation on gyttja lands in the Masurian Lakeland, In: Contemporary problems of management and environmental protection. pp. 61–94.

Lamontagne, L., Martin, A., and Nolin, M. 2014. Étude pédologique du comté de Napierville (Québec). Laboratoires de pédologie et d'agriculture de précision, Centre de recherche et de développement sur les sols et les grandes cultures, Direction générale des sciences et de la technologie, Agriculture et Agroalimentaire Canada, Sainte-Foy, Québec.

Lamontagne, L., Martin, A., Cossette, J.-M., and Grenon, L. 2000. Étude pédologique du comté de Laprairie (Québec). Bulletin d'extension No. 11. Laboratoires de pédologie et d'agriculture de précision, Centre de recherche et de développement sur les sols et les grandes cultures, Direction générale de la recherche, Agriculture et Agroalimentaire Canada, Sainte-Foy, Québec.

Lamontagne, L., Martin, A., Grenon, L., and Cossette, J.-M. 2001. Étude pédologique du comté de Saint-Jean (Québec). Bulletin d'extension No. 12. Laboratoires de pédologie et d'agriculture de précision, Centre de recherche et de développement sur les sols et les grandes cultures, Direction générale de la recherche, Agriculture et Agroalimentaire Canada, Sainte-Foy, Québec.

Larsson, R. 1990. Behaviour of organic clay and gyttja (No. 38). Swedish Geotechnical Institute, Linköping, Sweden.

Lévesque, M., Dinel, H., Lord, T., and Lortie, G. 1987. The characterization of organic soils developed on peat and limnic materials in British Columbia. Technical Bulletin 1987-5E LRRC Contribution No. 87-06 (No. 1987–5E). Agriculture Canada, Ottawa, Ontario.

Lévesque, M., Morita, H., Schnitzer, M., and Mathur, S. 1981. Les propriétés physiques, chimiques et morphologiques de quelques tourbes du Québec et de l'Ontario. Agriculture Canada, Ottawa, Ontario.

Machado, R.M.A., and Serralheiro, R.P. 2017. Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. Horticulturae, **3**. doi:10.3390/horticulturae3020030.

Mailloux, A., and Godbout, G. 1954. Étude pédologique des sols des comtes de Huntingdon et Beauharnois. Bulletin technique No 4. Division des sols, École Supérieure d'Agriculture. Ministère de l'Agriculture, Ste-Anne-de-la-Pocatière, Québec.

McKeague, J.A.(Editor). 1978. Manual on soil sampling and methods of analysis, 2nd ed. Subcommittee on Methods of Analysis of the Canada Soil Survey Committee, Canadian Society of Soil Science.

McKibbin, R.R., and Stobbe, P.C. 1936. Organic soils of southwestern Quebec. First Report of the Quebec Soil Survey Committee. Dominion of Canada, Department of Agriculture, Ottawa, Ontario.

MDDELCCQ (Ministère du Développement Durable, de l'Environnement et de la Lutte contre les Changements Climatiques du Québec). 2017. Détermination des solides totaux et des solides totaux volatils : méthode gravimétrique, MA. 100 – S.T. 1.1, Rév. 5. Centre d'expertise en analyse environnementale du Québec.

National Wetlands Working Group. 1997. The Canadian wetland classification system. 2nd ed. University of Waterloo, Waterloo, Ontario.

NSSC (National Soil Survey Committee). 1955. Report on the third conference of the National Soil Survey Committee (No. 3). National Soil Survey Committee, Winnipeg, Manitoba.

NSSC (National Soil Survey Committee). 1960. Report on the meeting of the National Soil Survey Committee (No. 4). National Soil Survey Committee, Guelph, Ontario.

Ontario Ministry of Natural Resources and Forestry. 2019. Wetlands. Provincial Mapping Unit, Peterborough, Ontario.

Parent, L.E., and Gagné, G. 2010. Guide de référence en fertilisation (2e édition). Centre de référence en agriculture et agroalimentaire du Québec, Québec.

Parent, L.E., Millette, J.A., and Mehuys, G.R. 1982. Subsidence and erosion of a histosol. Soil Sci. Soc. Am. J. **46**: 404–408. doi:10.2136/sssaj1982.03615995004600020039x.

Parent, L.E., Pauzé, F.J., and Bourbeau, G.A. 1980. Methode nouvelle de preparation de coupes minces des tourbes et des gyttja. Can. J. Soil Sci. **60**: 487–496. doi:10.4141/cjss80-054.

Rhoades, J.D. 1983. Cation exchange capacity. In: Methods of Soil Analysis. Part2. Chemical and Microbiological Properties, American Society of Agronomy. Edited byPage, Miller, and Keeney, Inc. Soil Science Society of Ameroica, Inc. Madison, Wisconsin. pp. 149–157. doi:10.2134/agronmonogr9.2.2ed.c8. PMID: 00654663.

Schulz, C., Meier-Uhlherr, R., Luthardt, V., and Joosten, H. 2019. A toolkit for field identification and ecohydrological interpretation of peatland deposits in Germany. Mires Peat. **24**: 1–20. doi:10.19189/MaP.2019.OMB.StA.1817.

SCWG (Soil Classification Working Group). 1998. The Canadian system of soil classification. 3rd ed. NRC Research Press, Ottawa, Ontario.

Total E&P Canada. 2007. Environmental baseline study: Terrain and soils. Calgary, Alberta.

USDA-NRCS (United States Department of Agriculture - Natural Resources Conservation Service). 1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook #436. 2nd ed. USDA-NRCS, Washington, D.C.

USDA (United States Department of Agriculture). 2015. Glossary of soil survey terms. United States Department of Agriculture.

von Post, H. 1862. Studier ofver nutidens koprogena jordbildningar, gyttja, dy, torf och mylla (Studies on present times coprogenous earth, gyttja, dy, peat and mull) (No. Volume 4 No. 1). Proceedings of the Royal Swedish Academy of Sciences. Royal Swedish Academy of Sciences, Stockholm, Sweden.

Vujnovic, K., Nikiforuk, L., Bentz, J., and Beaudette, P. 2000. Soil and vegetation inventory of Wagner Natural Area, Alberta. Edmonton, Alberta.

Wojahn, E., and Illner, K. 1962. Die standorttypen der niedermoore als grundlage der meliorations planung und projektierung. Wasserwirt Wassertechn, **12**: 139–165.

Appendix A

Revised Keys to Organic Soil Order, Great Groups, and Subgroups

Key to Organic Soil Order—Revised

B. Other soils that either

1. Have organic horizons (more than 17% organic C by weight) *or limnic horizons* that extend from the surface to one of the following:
   a. A depth of 60 cm or more if the surface: layer is fibric material (Of) having a bulk density of < 0.075 g cm^{-3}, *or a depth of 60 cm or more if the fibric material is lessthan 60 cm thick but underlain by limnic material that extends beyond 60 cm*.
   b. A depth of 40 cm or more if the surface layer consists of mesic or humic material (Om or Oh) having a bulk density $\geq$ 0.075 g cm^{-3}, *or a depth of 40 cm or more if the mesic and/or humicmaterial is less than 40 cm thick but underlain by limnic material that extends beyond 40 cm*.
   c. A depth of more than 40 cm if composed of folic materials (L, F, and H), or at least 10 cm if a lithic contact or fragmental materials are present. Folic materials must be more than twice the thickness of a mineral soil layer if the mineral layer is less than 20 cm thick.

   Or
2. Have one or more mineral horizons or layers within 40 cm of the surface in addition to the organic horizons (O) as follows:
   a. If a mineral horizon or layer thinner than 40 cm occurs at the surface, the underlying organic horizon or horizons must have a total thickness of at least 40 cm.
   b. If one or more mineral horizons or layers occur within 40 cm of the surface, the organic material must occupy more than 40 cm of the upper 80 cm of the control section.. **Organic order**

Key to Organic Soil Great Groups–Revised

B.	**Organic order**	
BA.	Organic soils that are formed primarily in upland organic (folic) materials, generally of forest origin, and are rarely saturated with water	**Folisol**
BB.	Other Organic soils that are formed in relatively undecomposed organic materials and have a dominantly fibric middle tier	**Fibrisol**
BC.	Other Organic soils that are formed in organic materials, are in an intermediate stage of decomposition, and have a dominantly mesic middle tier	**Mesisol**
BD.	Other Organic soils that are formed in organic materials, are in an advanced stage of decomposition, and have a dominantly mesic middle tier	**Humisol**
BE.	*Other Organic soils that are formed in limnic materials (coprogenous earth, diatomaceous earth, or marl), and have a dominantly limnic middle tier*	***Limnisol***

Key to Organic Soil Subgroups—Revised

BA.	**Folisol –** No Changes to Folisol Great Group	
BB.	**Fibrisol**	
BBA.	Fibrisols that have a hydric layer	**Hydric Fibrisol**
BBB.	*Other Fibrisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a limnic layer ≥12 cm in thickness within the control section*	***Terric Limnic Fibrisol***
BBC.	Other Fibrisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a humic layer >12 cm in thickness within the control section	**Terric Humic Fibrisol**
BBD.	Other Fibrisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a mesic layer >25 cm in thickness within the control section	**Terric Mesic Fibrisol**
BBE.	Other Fibrisols that have a terric layer at least 30 cm in thickness beneath the surface tier	**Terric Fibrisol**
BBF.	Other Fibrisols that have a limnic layer >5 cm in thickness beneath the surface tier	**Limnic Fibrisol**
BBG.	Other Fibrisols that have more than 5 cm combined thickness of cumulic layer or layers beneath the surface tier	**Cumulic Fibrisol**
BBH.	Other Fibrisols that have a humic layer >12 cm in thickness in the middle or bottom tier	**Humic Fibrisol**
BBI.	Other Fibrisols that have a mesic layer >25 cm in thickness in the middle or bottom tier	**Mesic Fibrisol**
BBJ.	Other Fibrisols	**Typic Fibrisol**
BC	**Mesisol**	
BCA.	Mesisols that have a hydric layer	**Hydric Mesisol**
BCB.	*Other Mesisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a limnic layer ≥12 cm in thickness within the control section*	***Terric* Limnic Mesisol**
BCC.	Other Mesisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a humic layer >25 cm in thickness within the control section	**Terric Humic Mesisol**
BCD.	Other Mesisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a fibric layer >25 cm in thickness within the control section	**Terric Fibric Mesisol**
BCE.	Other Mesisols that have a terric layer at least 30 cm in thickness beneath the .... surface tier	**Terric Mesisol**
BCF.	Other Mesisols that have a limnic layer >5 cm in thickness beneath the surface tier	**Limnic Mesisol**
BCG.	Other Mesisols that have more than 5 cm combined thickness of cumulic layer or layers beneath the surface tier	**Cumulic Mesisol**
BCH.	Other Mesisols that have a humic layer >25 cm in thickness in the middle or ...... bottom tier	**Humic Mesisol**
BCI.	Other Mesisols that have a fibric layer >25 cm in thickness in the middle or .... bottom tier	**Fibric Mesisol**
BCJ.	Other Mesisols	**Typic Mesisol**
BD	**Humisol**	
BDA.	Humisols that have a hydric layer	**Hydric Humisol**
BDB.	*Other Humisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a limnic layer ≥12 cm in thickness within the control section*	***Terric Limnic Humisol***
BDC.	Other Humisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a fibric layer >12 cm in thickness within the control section	**Terric Fibric Humisol**
BDD.	Other Humisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a mesic layer >25 cm in thickness within the control section	**Terric Mesic Humisol**
BDE.	Other Humisols that have a terric layer at least 30 cm in thickness beneath the surface tier	**Terric Humisol**
BDF.	Other Humisols that have a limnic layer >5 cm in thickness beneath the surface tier	**Limnic Humisol**
BDG.	Other Humisols that have more than 5 cm combined thickness of cumulic layer or layers beneath the surface tier	**Cumulic Humisol**
BDH.	Other Humisols that have a fibric layer >12 cm in thickness in the middle or bottom tier	**Fibric Humisol**
BDI.	Other Humisols that have a mesic layer >25 cm in thickness in the middle or bottom tier	**Mesic Humisol**
BDJ.	Other Humisols	**Typic Humisol**

(*concluded*).

BE	*Limnisol*	
BEA.	*Limnisols that have a hydric layer*	***Hydric Limnisol***
BEB.	*Other Limnisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a fibric layer ≥12 cm in thickness within the control section*	***Terric Fibric Limnisol***
BEC.	*Other Limnisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a mesic layer ≥12 cm in thickness within the control section*	***Terric Mesic Limnisol***
BED.	*Other Limnisols that have a terric layer at least 30 cm in thickness beneath the surface tier and a humic layer ≥12 cm in thickness within the control section*	***Terric Humic Limnisol***
BEE.	*Other Limnisols that have a terric layer at least 30 cm in thickness beneath the surface tier*	***TerricLimnisol***
BEF.	*Other Limnisols that have more than 5 cm combined thickness of cumulic layer or layers beneath the surface tier*	***Cumulic Limnisol***
BEG.	*Other Limnisols that have a fibric layer ≥12 cm in thickness in the middle or bottom tier*	***Fibric Limnisol***
BEH.	*Other Limnisols that have a mesic layer ≥12 cm in thickness in the middle or bottom tier*	***Mesic Limnisol***
BEI.	*Other Limnisols that have a humic layer ≥12 cm in thickness in the middle or bottom tier*	***Humic Limnisol***
BEJ.	*Other Limnisols*	***Typic Limnisol***