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Gray Luvisols are polygenetic

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Abstract

With respect to the pedosphere, human activities in the last 100 years have been the major driver of soil change. Despite human activities being one of the main soil forming factors recognized by soil scientists (in addition to climate, organisms, parent material, relief, groundwater, and time), the Canadian System of Soil Classification (CSSC) emphasizes soil as a natural body. We argue human agricultural activities are direct and indirect drivers of significant changes to the carbon balance and cycling in A horizons of Gray Luvisolic soils in western Canada, resulting in changes to A horizon carbon stocks, structure, and micromorphology. Evidence from scientific literature, in-field soil profile observations, and the National Pedon Database are presented in support of our argument. We propose a polygenetic, two-stage model of Gray Luvisol soil formation. The first stage is dominated by the climate forcing of the Holocene, resulting in a relatively stable boreal forest ecosystem including perturbations from natural and human-induced wildfire and other disturbances. The second stage is dominated by direct, human-driven disturbances such as cultivation, release of exotic fauna (earthworms), and indirect human-driven disturbances associated with anthropogenic climate change. Further, we propose modest amendments to the CSSC to reflect a polygenetic model of soil genesis in Gray Luvisolic soils that preserve the balance between observation and interpretation inherent in the system.

Key words: soil genesis, soil classification, Luvisol, cultivation, bioturbation, Anthropocene

Introduction

There is scientific consensus that human activities have been the main driver of global, environmental change since the industrial revolution, termed the Anthropocene Epoch (Rockstrom et al. 2009). With respect to the pedosphere, human activities in the last 100 years are also the major driver of soil change (Richter 2020; Richter and Yaalon 2012; Richter 2007). Early pedological investigations and theory development focussed on natural processes leading to the formation of *virgin soils* (sic; Richter 2007). Perhaps the most well-known model of soil formation is that of Jenny (1941) based on the soil forming factors of climate, relief, organisms, parent geological material, and time. While Jenny recognized the influence of human activities on the soil forming factors (Jenny 1941; Amundson and Jenny 1991), Ellis (1938) is perhaps the earliest example to explicitly include human activity (and groundwater) as a soil forming factor based on his observations of soil profiles in native and agricultural ecosystems in Manitoba. On page 1 of the Canadian System of Soil Classification, third edition (CSSC), acknowledgement of human activity as a soil forming factor is conspicuously missing: "From the time of the first surveys Canadian pedologists were influenced by the concept of the soil as a natural body integrating the accumulative effects of climate and vegetation acting on surficial materials" (Soil Classification Working Group 1998; emphasis added). The modal concept of many soil orders in the CSSC was apparently intended to reflect the natural ecosystems under which the majority of pedogenesis had occurred.

Since the Neolithic, human agricultural activities, especially tillage, have altered soils from their natural state. A major theme in the soil science literature over the last 50–70 years has been the effects of management on soil properties and processes (e.g., Bronick and Lal 2005; Van Oost et al. 2006; Richter 2007). In western Canada, the relatively recent introduction of agriculture at the beginning of the 20th century has provided an opportunity to document human agricultural-induced changes to soil properties. In the Dark Gray and Gray soil zones of Alberta, forested land continues to be converted to agricultural land use with the area of cultivated land increasing from ∼7.5 to ∼10.5 M acres (3.0–4.3 M ha) between 1971 and 1991—150 000 acres per year (Bentley et al. 1971; Hamley 1992). More recent estimates of the rates of land conversion are not available.

While the last glaciation completely extirpated native earthworms, European species are now invading the northern United States and Canada, an invasion facilitated by human activities (Cameron et al. 2007). Reported in Alberta for the first time in the 1980s, exotic earthworms are responsible for many changes in forest soil properties (Lejoly et al. 2021).

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In agricultural soils, because of the similarities between bioturbation and tillage, it is however more difficult to separate the impacts of earthworm activity from those of management, although they both are a consequence of human activities in this case.

In 1929, the University of Alberta Breton Plots near Breton, AB, were established on Gray and Dark Gray Luvisolic soils with the initiation of the Classical Plots experiment by Ben Flesher (landowner) and Dr. Frank Wyatt (Department of Soil Science, University of Alberta). This experiment is still in operation today and compares two rotations—wheat–fallow (WF); 5 year cereal–forage (WOBHH; wheat–oats–barley–hay–hay)—and eight fertility treatments. Another long-term experiment, the Hendrigan Plots, established later in 1980 by Dr. Bill McGill and his colleagues (Ross et al. 2008), compares a continuous grain, continuous forage, and 8 year cereal–forage–pulse rotation. The results of these experiments have reported significant agricultural management-driven changes to soil properties and processes, especially in the A horizon. Moreover, the extraction of environmental DNA from archival soil samples confirmed the presence of invasive earthworms in the Hendrigan Plots in 1985 (Jackson et al. 2017), suggesting further, indirect human effects. The results from the long-term experiments at Breton illustrate the action of human activity as a soil forming factor.

In this paper, we argue that human agricultural activities are direct and indirect drivers of significant changes to the A horizons of Gray Luvisolic soils in western Canada, supporting a polygenetic model of Gray Luvisol soil formation. We use three lines of evidence in developing our argument.

- A summary of the relevant literature from the Breton Plots and western Canada showing the impacts of direct and indirect human activity on Gray Luvisol biogeochemistry and micromorphology.
- Cultivated and uncultivated soil profile descriptions from the Breton Plots.
- A query of the National Pedon Database (NPDB) to show that changes driven by agricultural management are widespread.

We further propose modest amendments to the CSSC (Soil Classification Working Group 1998) consistent with a polygenetic model of Gray Luvisol formation.

Methods

Literature review

Google Scholar, the Breton Plots bibliography, and digital publication archive (available upon request) were queried for literature summarizing properties of and processes in cultivated and uncultivated Gray Luvisols in western Canada. From the search results, we selected publications documenting Gray Luvisol pedogenesis and those containing relevant information to address our main objectives.

Profile descriptions

In August 2021, soil color, texture, and structure of surface horizons from selected plots in the Breton Classical Plots (established 1930) and Hendrigan Plots (established 1980) (Dyck et al. 2012), and the adjacent Bentley Forest Preserve were described according to Watson (2007) and Watson and Pennock (2016). Small monoliths were excavated from the plots for photographs and the pit face was photographed in the forested site. Photographs were cropped and the “mist” filter was applied (to improve the contrast between horizons) in Microsoft Paint 3D.

National Pedon Database

Soil data from the NPDB (Agriculture and Agri-Food Canada 2016) were filtered to include only the Gray Luvisol and the Dark Gray Chernozem great groups. All available subgroups for Gray Luvisols and Dark Gray Chernozems were included in the analysis. Cultivated versus uncultivated Luvisols were then separated based on the land use category. Sites with land use values of cropland, improved pasture, built up, or mines and quarries were included in the cultivated category. All other land uses were included in the uncultivated category. Natural grazing was excluded from both categories. All examples of Dark Gray Chernozems were cultivated. The databases were then subset to only include A horizon data, and A horizon structures were reclassified as either platy or nonplaty due to a lack of statistical power to assess the large number of the many nonplaty structural classes separately.

Statistical analysis

In this section, the term Gray Luvisols includes all subgroups of the Gray Luvisolic great group except Dark Gray Luvisols and Gleyed Dark Gray Luvisols, which are referred to as Dark Gray Luvisols. To examine the influence of cultivation on Luvisolic A horizon structure, χ^2 tests were performed using R (R Core Team 2018) based on the frequency of platy versus nonplaty A horizon structures. Horizons with depths less than 5 cm were removed for this analysis. The proportion of platy versus nonplaty structures were compared with pairwise comparisons between the following: (*i*) cultivated and uncultivated Gray Luvisols, (*ii*) cultivated Dark Gray Luvisols and cultivated Gray Luvisols, (*iii*) uncultivated Dark Gray Luvisols and uncultivated Gray Luvisols, (*iv*) cultivated and uncultivated Dark Gray Luvisols, and (*v*) cultivated and uncultivated Gray Luvisols (excluding the Dark Gray subgroup), and Dark Gray Chernozems.

Summary statistics—minimum, 25th percentile, median, 75th percentile, and maximum values—for average A horizon soil organic carbon (SOC; %), total nitrogen (%), carbon to nitrogen ratio, cation exchange capacity (meq 100 g^{-1}), sand content (%), clay content (%), and pH were calculated. For these properties, A horizons of all depths were used. To start, weighted average values of each property were calculated using A horizon depths as weights. Topsoil depth was also calculated as the sum of all A horizon thicknesses for each pedon. Of note, was that the cultivated Gray Luvisols had significantly more sand than their uncultivated counterparts,

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and a significant negative correlation existed between SOC and sand content in the data set. Therefore, for the purposes of calculating and comparing summary statistics for each soil parameter by soil type, the other soil types were subsampled to ensure all Luvisolic and Chernozemic subgroups had similar sand contents. To subsample, data bins were created based on the percentiles (20th, 40th, 60th, and 80th percentiles) of sand content. The soil types other than cultivated Luvisols were then subsampled such that they had the same proportion of sand content bins.

Results

Literature review

Two related themes in the literature regarding differences in Gray Luvisolic A horizons in cultivated and forested ecosystems, demonstrating the pedologically significant changes resulting from agriculture and bioturbation, are (*i*) carbon balance of the A horizon and (*ii*) changes to A horizon structure and micromorphology (i.e., microstructure).

A summary of SOC stocks from the Breton Plots is presented in Table 1. The land where the Breton Plots are now located was deforested and converted to agriculture around 1920. Although SOC stocks were not quantified when the land was cleared or when the agricultural plots were established (1930), archived samples from 1936 and 1938 were reanalyzed by Izaurralde et al. (2001) and are assumed to be close to the SOC levels in the Ap horizon (0–15 cm) when long-term experiments at the Breton Plots were established: 24–27 Mg ha^{-1} (Table 1). Soil carbon stocks of the Ahe/Ae horizons under forest were not documented until 1979 and 1981 when samples were collected in the forest preserve north of the agricultural plots (Howitt and Pawluk 1985; Izaurralde et al. 2001). Izaurralde et al. (2001) assumed SOC stocks in the forest preserve measured in 1979 were representative of stocks in 1920 and estimated that conversion of the land to agricultural management resulted in 57% loss of carbon from the LFH, Ahe, and Ae horizons through mineralization, burning, or LFH removal.

The SOC stocks in the Ap horizon in 1936 and 1938 were apparently about 10 Mg ha^{-1} greater than the Ahe/Ae horizons under forest - more than can be accounted for by the 15% increase in bulk density following cultivation (Table 1), suggesting that some organic carbon from the LFH was mixed into the Ap horizon during land clearing and (or) changes to the carbon balance of the A horizon following cultivation. Based on the results reported in Table 1, consistent increases in Ap SOC stocks from 1936/1938 through 2008 are apparent in Check, NPKS, and manure treatments of the 5 year, cereal–forage rotation, and the manure treatment of the WF rotation of the Classical Plots experiment. These increases in SOC between 1938 and 1990 are likely attributable to increased carbon inputs in the form of manure and below-ground root inputs. Above-ground crop residues were removed with harvest between 1929 and 2000 (Grant et al. 2001; 2020). The added effect of reincorporating above-ground crop residues to the plots is reflected in the 2008 and 2013 estimates (Grant et al. 2020).

Initially, average SOC stocks in the top 15 cm of the Hendrigan Plots (1979; Table 1)—29 Mg ha^{-1}—were comparable to the 1979 levels in the Check treatment in the 5 year rotation and manure treatment of the WF rotation of the Classical Plots. From 1940 to 1964, the Hendrigan Plots area—before its establishment in 1979—was in a cereal–forage rotation like the Classical Plots. From 1964 to 1980, annual cereal crops were grown with minimal fertilizer (Wani et al. 1994). Therefore, like the Classical Plots, the change in soil carbon balance following cultivation and the response of the carbon balance to crop rotation, fertilizer and manure inputs is apparent in the Hendrigan Plots.

Table 2 summarizes Luvisol SOC stocks from other sites in Western Canada reported in the literature. Ellert and Bettany (1995) compared the LFH and Ae SOC stocks in forested Orthic Gray Luvisols to the Ap SOC stocks in nearby cultivated fields. Their observations indicated a change in the distribution of SOC within the profile, but no significant change in total surface SOC stocks following conversion to agriculture, even when quantifying SOC stocks in equivalent soil masses. The SOC stocks in the LFH and Ae horizons in two forested sites were essentially equivalent to the Ap horizon carbon stocks in recently cultivated sites, suggesting most of the carbon from the LFH was incorporated into the Ap horizon during forest clearing operations.

These results suggest that Luvisolic A horizons under boreal forest stands (Ahe, Ae) and under agricultural management (Ap) have significantly different carbon inputs and soil carbon balances. There is also evidence to suggest that increased earthworm activity in forested Luvisolic soils has altered the soil carbon balance of the mineral A horizons in the last 30–40 years. Lejoly et al. (2021) sampled pedons in the forest preserve at the Breton Plots showing significant evidence of earthworm activity (Ahu horizons) and these pedons have a markedly different soil carbon distributions compared to the forested pedons sampled by Izaurralde et al. (2001) and Howitt and Pawluk (1985). Lejoly reported SOC stocks of 3.3 Mg ha^{-1} in the LFH (4 cm thick) and 35.3 Mg ha^{-1} in the top 10 cm of mineral soil, compared to the 1979 and 1981 estimates of 43 and 40 Mg ha^{-1} in the LFH (10 and 8 cm thick) and 17 and 14 Mg ha^{-1} in the top 18 and 17 cm of mineral soil, respectively. Under forest, earthworms are mixing carbon from the LFH horizon into underlying A horizons. Earthworms have also been observed to be active in the agricultural plots at Breton (Pawluk 1980). Despite these well-documented examples, the effect of agricultural management and bioturbation on the carbon balance of Gray Luvisols is not represented in the CSSC. While Lavkulich and Arocena (2011) covered potential changes in nutrient availability and compaction from cultivation of Luvisolic soils, they do not mention cultivation-induced changes to the carbon balance or changes because of bioturbation.

Micromorphology

Micromorphometric investigations on forested and cultivated Luvisolic soils carried out by Pawluk (1980) at the Breton Plots and Martin et al. (1987) at sites near Winfield, AB are summarized in this section. An explanation of micromor-

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Table 1. Summary of SOC stocks and C:N ratios in surface horizons/layers of forested and cultivated soils with consistent long-term management at the University of Alberta Breton Plots.

	Year of measurement							
	1936/1938[*]	1979[*]	1981[†]	1990[*]	2003[‡]	2008[‡]	2013[‡]	2019/2020[§]
Location/ treatment (depth, cm)	SOC Mg/ha (depth, cm), C:N							
Forested LFH	—	43 (10–0), 28:1	40 (8–0), 23:1	—	—	—	—	3.3 (4–0)
Forested Ahe/Ae	—	17 (0–18), 17:1	13 (0–17), 15:1	—	—	—	—	35.3 (0–10)
WF–Check (0–15)[‖]	27, 11:1	23, 10:1	—	18, 10:1	18, 5:1	18, 6:1	19, 5:1	—
WF–NPKS (0–15)[‖]	—	25, 10:1	—	22, 10:1	22, 7:1	25, 8:1	23, 8:1	—
WF–Manure (0–15)[‖]	—	30, 10:1	—	32, 10:1	34, 11:1	38, 13:1	38, 14:1	—
5 year (WOBHH)–Check (0–15)[‖]	24, 11:1	30, 11:1	—	30, 11:1	32, 9:1	35, 10:1	32, 9:1	35[*], 9:1
5 year (WOBHH)–NPKS (0–15)[‖]	—	33, 11:1	—	34, 11:1	37, 10:1	38, 10:1	38, 10:1	—
5 year (WOBHH)–Manure (0–15)[‖]	—	41, 11:1	—	44, 11:1	45, 13:1	49, 13:1	47, 15:1	—
Continuous Grain (0–15)[‖]	—	29, 11:1	—	—	—	39, 12:1	—	44[*], 9:1
8 year (0–15)[‖]	—	32, 12:1	—	—	—	55, 11:1	—	65[*], 10:1
Continuous Forage (0–15)[‖]	—	29, 11:1	—	—	—	68, 12:1	—	69[*], 10:1

Note: SOC, soil organic carbon; WF, wheat–fallow; WOBHH, wheat–oats–barley–hay–hay.

[*] Reported in Izaurralde et al. (2001).

[†] Calculated with SOC concentrations reported in Howitt and Pawluk (1985) and bulk densities for equivalent horizons reported in Izaurralde et al. (2001).

[‡] Unpublished data from the Breton Plots Database; 2013 measurements also reported in Dyck and Puurveen (2020).

[§] Forested measurements: Lejoly et al. (2021); cultivated measurements: Sorenson et al. (2020).

[‖] WF and 5 year (WOBHH) are the two rotations of the Classical Plots, established in 1930; Continuous Grain, 8 year and Continuous Forage are the rotations of the Hendrigan Plots; detailed information on long-term management can be found in Dyck et al. (2012).

Table 2. Comparison of published surface SOC stocks in forested and cultivated Gray Luvisols in Western Canada.

	Horizon			
	LFH	Ae	LFH + Ae	Ap
Source, site	SOC Mg/ha (depth, cm), C:N			
Ellert and Bettany 1995, Forest 1	35, 18:1	11, 12:1	46 (0–18)	—
Ellert and Bettany 1995, Forest 2	43, 21:1	15, 12:1	58 (0–32)	—
Ellert and Bettany 1995, Recently cleared	—	—	—	56 (0–15), 18:1
Ellert and Bettany 1995, Pasture	—	—	—	53 (0–18), 12:1
Ellert and Bettany 1995, WF 1	—	—	—	43 (0–15), 12:1
Ellert and Bettany 1995, WF 2	—	—	—	46 (0–16), 13:1
Landi et al. 2003	45 (5–0)	11 (0–32)	56 (0–37)	—
Tarnocai. 1997	—	—	49 (0–30)	—
Shaw et al. 2008	28	—	—	—

Note: SOC, soil organic carbon.

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phometric fabrics is included in Table S1. The detailed descriptions in the following paragraphs describe differences in surface horizon fabrics in Gray Luvisols under forest and under agricultural management. Specifically, the accommodated fragmic and fragmoidic fabrics in forested Ahe and Ae horizons were not present or only occasionally present in Ap horizons dominated by unaccommodated (matri)granic and (matri)granoidic fabrics.

Fabrics of LFH (4–0 cm), Ahe (0–2 cm), Ae (4–18 cm), and AB (18–22 cm) horizons of an Orthic Dark Gray Luvisol in the forest preserve at the Breton Plots were described by Pawluk (1980). The LFH exhibited a mor humus form and undecomposed litter was observed in the L horizon. Phyto-humigranic and granoidic humigranic fabrics were observed in the F and H horizons, respectively. Evidence of bioturbation in the form of fecal materials was observed in the Ahe horizon which exhibited a mull humus form with a primarily mullgranic fabric. There was no evidence of bioturbation in the Ae horizon which exhibited a banded matrifragmoidic fabric and a silasepic plasma. The fabric of the AB horizon was matrifragmoidic intergrading to vughy porphyric units separated by horizontal joint planes with zones of silasepic and skelsepic plasma.

Fabrics of LFH (10–0 cm), Ahe (0–4 cm), and Ae (4–18 cm) horizons of an undisturbed Orthic Gray Luvisol under forest vegetation near Winfield, AB were comparable to the example from the Breton Plots. LFH fabrics were humiphytogranic, humi-granoidic, and mull-phyto-humigranic, respectively. The Ahe horizon was observed to have significant components of granic/granoidic and banded fragmoidic porphoric to vughy porphoric fabrics. In the Ae horizon, the fabric was observed to be isobanded vughy porphyric.

Luvisolic Ap horizons, 18 cm thick on average, from the fertilized, unfertilized, and manured treatments from WF and cereal–forage rotations of the Breton Classical Plots shared similar fabrics (Pawluk 1980). Modal Ap horizon fabrics were observed to be matrigranic, matrigranoidic porphyric, and vughy porphyric sequences with some finer granic and granoidic fabrics associated with bioturbation. Humigranic fabrics were associated with pedotubules in localized zones of decaying organic matter. Some differences in fabrics observed were attributable to management. Finer, smaller scale fabric units, attributable to less stable aggregation and lower organic matter, were more prevalent in samples from the WF rotation than the cereal–forage rotation (Pawluk 1980). For both rotations, in treatments with higher levels of organic matter that had received chemical fertilizer or manure, some weakly developed mull-matrigranic fabric units were observed.

In two cultivated Luvisol pedons in forage stands near Winfield, AB, primary fabrics of the Ap horizons were much like those observed at the Breton Plots with additional features and secondary fabrics. In the first Ap horizon (0–20 cm), under a 3-year-old forage stand, humi-matrigranic to granoidic, and fragmic-fragmoidic to vughy porphyric fabrics were observed. In the second Ap horizon (0–11 cm), from a field with a 50-year-old forage stand, humi-mull-phyto-matricgranic/matrigranoidic porphyric and weakly banded vughy porphyric/vughy porphyric fabric sequences were observed.

All soils observed at Breton and Winfield had evidence of faunal activity in the form of bioturbation features in pedotubules and fecal pellets. At Breton (Pawluk 1980) these features were associated with Collembola (springtails), Acari (mites), Diplopoda (millipedes), Enchytraeidae (pot worms), and Lumbricidae (earthworms). At Winfield (Martin et al. 1987), these features were associated with Oribatida (mites), Collembola (spring tails), and Enchytraeidae (pot worms), but there was no evidence of organo–mineral complexes associated with earthworm activity.

The Bt horizons of the forested and cultivated soils exhibited matrifragmic and fragmoidic fabrics, respectively.

Profile descriptions

A summary of shallow profile descriptions from the Bentley Forest Preserve and long-term rotations at the Breton Plots are presented in Table 3. Photographs of selected profiles are presented in Fig. 1.

A summary of the profile descriptions for undisturbed and cultivated profiles observed by Pawluk (1980), Howitt and Pawluk (1985), and Martin et al. (1987) is presented in Table 4. In the forested profiles at Breton and Winfield observed by Pawluk and Martin, Ahe horizon structure was reported to be weak platy to granular (Table 4). The Ahe horizon thickness was 2 and 4 cm at Breton and Winfield, respectively. More recently, Lejoly et al. (2021) reported the presence of an 8 cm thick Ahu horizon with granular structure underlying the LFH horizon at Breton (Table 3). A third pedon in the forest preserve at the Breton plots was observed to have a 13 cm thick Ahu horizon underlying the LFH horizon.

The Ae horizons described by Pawluk (1980) and Martin et al. (1987) had weak or moderate platy structures and were 12 and 14 cm thick. Lejoly et al. (2021) reported Ahe horizons that were 2–3 cm thick with platy structures. The third pedon in the forest preserve had a 25 cm thick Ahe horizon with platy structure (Table 3).

The cultivated Ap horizons described by Martin et al. (1987) had fine, granular to weak platy structure (Table 4). At Breton, the thickness of Ap horizons in cultivated plots observed in 2021, varied between 9 and 12 cm with coarse or medium, primary granular structure and fine, secondary granular structure (Table 3). Ap horizons were underlain by either Ahe horizons with coarse, platy primary structure in the WF and continuous forage rotations, or AB horizons with coarse subangular blocky primary structure in the 5 year and 8 year rotations (Table 3).

National Pedon Database

In this section, the term Gray Luvisols includes all subgroups of the Gray Luvisolic great group except Dark Gray Luvisols and Gleyed Dark Gray Luvisols, which are referred to as Dark Gray Luvisols. Based on the χ^2 test, there were significant differences in the proportions of platy versus nonplaty A-horizon structures by soil type (Table 5). Cultivated Gray Luvisols had a weakly associated relative increase in the proportion of nonplaty structures compared to their unculti-

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Table 3. Recent Breton Plots soil profile descriptions (2020 and 2021).

Site	Profile/ Classification	Horizon	Depth (cm)	Color[*]	Texture	Primary structure	Secondary structure
Breton Plots					**Bentley Forest Preserve**		
	1. Dark Gray Luvisol[†]	LFH	7–0	—	—	—	—
		Ahu	0–6	10 YR 4/2	Clay Loam	Coarse granular	—
		Ahe	6–8	10 YR 5/2	Silty Clay Loam	Medium platy	—
		Bt	8+	10 YR 6/2	Clay Loam	Medium angular blocky	—
	2. Dark Gray Luvisol[†]	LFH	5–0	—	—	—	—
		Ahu	0–8	10 YR 4/2	Clay Loam	Coarse granular	—
		Ahe	8–11	10 YR 5/2	Silty Clay Loam	Medium platy	—
		Bt	11+	10 YR 6/2	Clay Loam	Medium angular blocky	—
	3. Dark Gray Luvisol[†]	LFH	3–0	—	—	—	—
		Ahu	0–13	2.5 Y 3/2	Clay Loam	Fine subangular blocky	—
		Ahe	13–38	2.5 Y 5/3	Silty Clay Loam	Medium platy	—
		Bt	38–85+	2.5 Y 4/3	Silty Clay	Medium/fine angular blocky	—
Breton Classical Plots					**Cultivated, 5 year WOBHH rotation**		
	Check (plot D5)	Ap	0–11	10YR 3/2	Loam	Coarse granular	Fine granular
	Orthic Dark Gray Chernozem[‡]	AB	11–15	10YR 3/2	Loam	Coarse subangular blocky	Medium platy
		Btgj	15+	10YR 4/2	Sandy Clay	Coarse subangular blocky	Fine subangular blocky
	NPKS (plot D3)	Ap	0–10	10YR 3/2	Loam	Coarse granular	Fine granular
	Orthic Dark Gray Chernozem[‡]	AB	10–15	10YR 3/2	Loam	Coarse subangular blocky	Medium platy
		Bt	15+	10YR 4/2	Sandy Clay Loam	Coarse subangular blocky	Fine subangular blocky
					Cultivated, WF rotation		
	Check (plot E5)	Ap	0–9	10YR 4/3	Loam	Medium granular	Fine granular
	Dark Gray Luvisol[‡]	Ahe	9–19	10YR 4/2	Loam	Coarse platy	Medium subangular blocky
		Bt	19 +	10YR 4/4	Sandy Clay Loam	Medium subangular blocky	Fine subangular blocky
	NPKS (plot E3)	Ap	0–12	10YR 4/3	Loam	Medium granular	Fine granular
	Dark Gray Luvisol[‡]	Ahe	12–22	10YR 3/2	Loam	Coarse platy	Medium subangular blocky
		Bt	22+	10YR 4/3	Sandy Clay	Medium subangular blocky	Fine subangular blocky
Breton Hendrigan Plots					**Continuous Forage**		
	Plot C14	Turf	3–0	—	—	—	—
	Orthic Dark Gray Chernozem[‡]	Ap	0–10	10YR 3/2	Loam	Coarse granular	Fine granular
		Ahe	10–18	10YR 3/2	Loam	Coarse platy	Medium subangular blocky
		Bt	18+	10YR 4/3	Sandy Clay Loam	Coarse subangular blocky	Fine subangular blocky
					8 year agroecological cereal–forage–pulse		
	Plot C16	Ap	0–10	10YR 3/2	Loam	Coarse granular	Fine granular
	Orthic Dark Gray Chernozem[‡]	AB	10–18	10YR 3/2	Loam	Coarse subangular blocky	Medium platy
		Bt	18+	10YR 4/2	Sandy Clay Loam	Coarse subangular blocky	Fine subangular blocky

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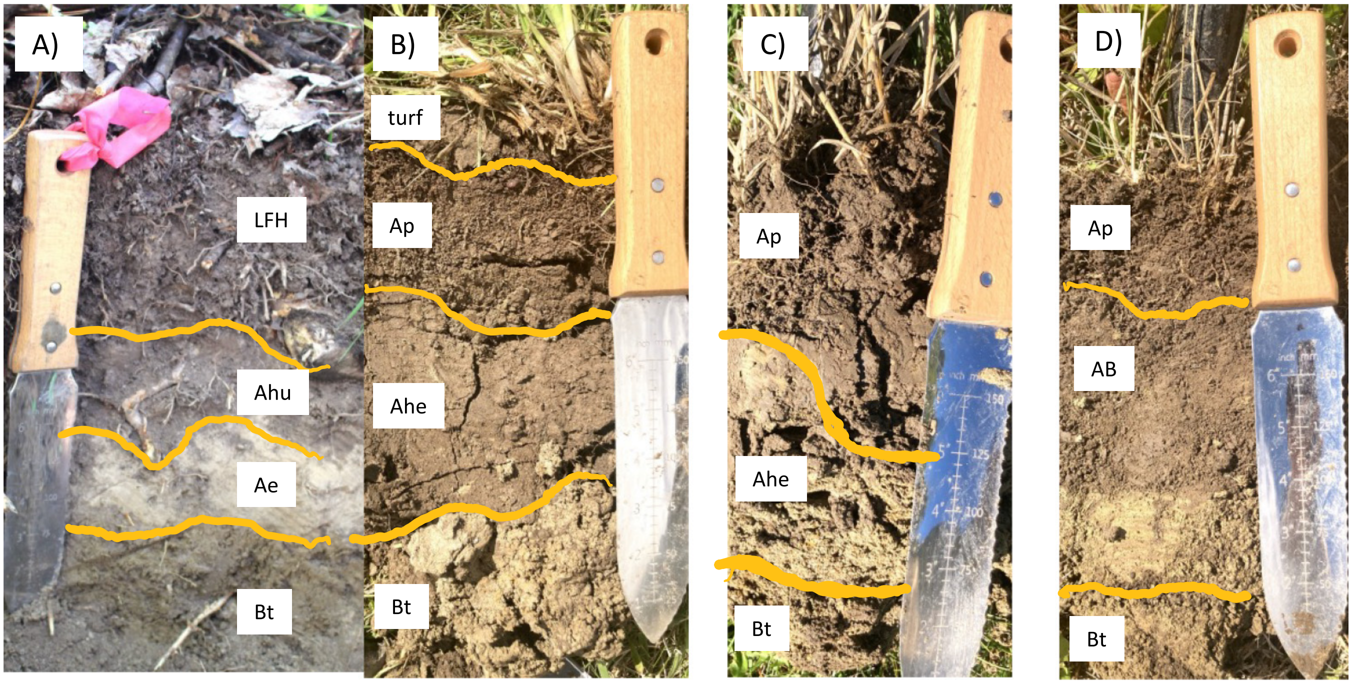
Table 3. (*concluded*).

Site	Profile/ Classification	Horizon	Depth (cm)	Color*	Texture	Primary structure	Secondary structure
				Continuous grain (cereal)			
	Plot C17	Ap	0–9	10YR 4/3	Loam	Medium granular	—
	Dark Gray Luvisol	AB	9–18	10YR 3/2	Loam	Coarse subangular blocky	Medium platy
		Bt	18+	10YR 4/3	Sandy Clay	Medium subangular blocky	Fine subangular blocky

*Munsell color on moist soil, except for profiles 1 and 2 from Bentley Forest Preserve which were on dry soil.
†Chernozemic A horizons are Ah, Ahe, or Ap by definition (p. 61; Soil Classification Working Group 1988).
‡Chernozemic A horizons must be one color value darker than the C horizon (p. 62; Soil Classification Working Group 1988); although not directly observed, moist C horizon color was assumed to be 10YR 4/3 (moist) as observed by Martin et al. (1987).

Fig. 1. Photographs of selected profiles from Table 3. (A) Forest Preserve, profile 1; (B) Continuous Forage, plot C14; (C) WF NPKS, plot E3; and (D) 8 year Agroecological, plot C16.



vated counterparts ($\chi^2 = 2.58$, $p = 0.10$). Cultivated Gray Luvisols were similar to cultivated Dark Gray Luvisols ($\chi^2 = 0$, $p = 1$), with very similar proportions of platy versus nonplaty structures. Cultivated and uncultivated Dark Gray Luvisols were similar as well ($\chi^2 = 0$, $p = 1$). As expected, the uncultivated Gray Luvisols were significantly different from the uncultivated Dark Gray Luvisols in terms of the proportion of A-horizon structures ($\chi^2 = 24.46$, $p < 0.001$). The cultivated Dark Gray Luvisols had relatively more nonplaty structures compared to uncultivated Gray Luvisol subgroups. Both cultivated ($\chi^2 = 19.86$, $p < 0.001$) and uncultivated ($\chi^2 = 16.31$, $p < 0.001$) Gray Luvisols were different in terms of platy structure frequency compared to Dark Gray Chernozems, but these differences were not apparent between Dark Gray Luvisols and Dark Gray Chernozems (Table 5).

With respect to the summary statistics, after adjusting the data to account for the differences in sand content, uncultivated Gray Luvisols had the thinnest median topsoil depths compared to the other soil types (Table 6). Uncultivated Gray Luvisols had the lowest median SOC and total nitrogen values with Dark Gray Chernozems having the highest (Table 6). Cultivation of Gray Luvisols was also associated with lower median carbon to nitrogen ratios on average. The Gray Luvisols had lower median cation exchange capacity compared to the Dark Gray Luvisols and Chernozems. While the cultivated Gray Luvisols had lower cation exchange capacity than uncultivated Gray Luvisols, this is likely due to their lower on average clay contents in the data set (Table 6). Cultivated Gray Luvisols were also associated with a higher median soil pH compared to uncultivated Gray Luvisols.

Discussion

The examples presented in this paper are in line with Richter and Yaalon's (2012) observation that soils are "archival products of pedogenic processes that range widely

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Table 4. Forested and cultivated Gray Luvisol profile descriptions reported in Pawluk (1980), Howitt and Pawluk (1985), and Martin et al. (1987)

Reference	Profile/ Classification	Horizon	Depth (cm)	Color	Primary structure	Secondary structure
			Breton Plots Bentley Forest Preserve			
Pawluk (1980)	Forested	LFH	4–0	—	—	—
	Orthic Gray Luvisol	Ahe	0–2	10YR 4/2 m	Platy/granular	—
		Ae1	2–6	10YR 4/3 m	Platy	—
		Ae2	6–14	10YR 5/3 m	Platy	—
		AB	14–18	10YR 5/4 m	Platy-blocky	—
Howitt and Pawluk (1985)	Forested	LFH	8–0	—	—	—
	Orthic Gray Luvisol	Ahe	0–3	10YR 4/2 m	Medium platy	Fine granular
		Ae1	3–8	10YR 5/2 m	Medium platy	—
		Ae2	8–13	10YR 5/2 m	Medium platy	—
		AB	13–17	10YR 5/4 m	Coarse platy	Medium blocky
			Winfield, AB			
Martin et al. (1987)	Forested	LFH	10–0	—	—	—
	Orthic Gray Luvisol	Ahe	0–4	10YR 4/2 m	Granular	Weak platy
		Ae	4–18	10YR 7/1 m	Moderate, fine platy	—
		AB	18–25	10YR 4/3 m	Moderate subangular blocky	Weak platy
	Forage; 3 years since cultivation Dark Gray Luvisol*	Ap	0–20	10YR 4/2 d	Fine granular	—
	Forage; 49 years since cultivation	Turf	3–0	—	—	—
	Dark Gray Luvisol*	Ap	0–11	10YR 6/2–10YR 5/1 d	Weak, coarse platy	Fine granular

Note: d, dry; m, moist.
*Chernozemic A horizons are one color value darker than the C horizon (p. 62; Soil Classification Working Group 1988); although Ap horizon colors are dry it was assumed not to be darker than the observed moist C horizon color 10YR 4/3 (moist) as in Martin et al. (1987).

Table 5. A-horizon soil structure frequency for cultivated Luvisols, uncultivated Luvisols, and Dark Gray Chernozems in the National Pedon Soil Database.

Soil structure	Cultivated Gray Luvisol	Uncultivated Gray Luvisol	Cultivated Dark Gray Luvisol	Uncultivated Dark Gray Luvisol	Dark Gray Chernozem
Not Platy	10	98	102	256	175
Platy	4	162	21	47	26

Note: Cultivated and uncultivated Gray Luvisols includes all subgroups of the Gray Luvisolic great group except Dark Gray Luvisols and Gleyed Dark Gray Luvisols, which are included in the uncultivated and cultivated Dark Gray Luvisol categories. All Dark Gray Chernozem examples are cultivated.

over time". We therefore propose a polygenetic model of Gray Luvisol pedogenesis. The simplest expression of the proposed model is that there are two stages of pedogenesis in Gray Luvisols, but we recognize there are likely more than these two. The first stage is dominated by the climate of the Holocene, resulting in a relatively stable boreal forest ecosystem including relatively minor perturbations from climate cycles, natural and human-induced wildfire and other disturbances. Presumably this first stage is the assumed model in the current CSSC. The second stage is dominated by direct, human-driven disturbances such as cultivation, release of exotic fauna (earthworms), and indirect human-driven disturbances associated with anthropogenic climate change such as increased frequency and severity of wildfires. Specifically, the cultivation of large areas of Gray Luvisolic soils in western Canada starting in the early 20th century, and the human-facilitated earthworm invasion represent the start of the second stage of Luvisol pedogenesis, archived in the A horizons of both cultivated and forested Luvisols.

We recognize that modification of A horizons by agricultural management and earthworm invasion is not exclusive to the Luvisolic order. With respect to the extent of earthworms, the only sampling effort for Gray Luvisols specifically was done by Lejoly et al. (2021) and all three sites sampled in Alberta were invaded by earthworms. At a larger scale, there is no estimate for each soil type, but 9% of the boreal forest of northeast Alberta was invaded in 2009, and it is expected to reach 49% by 2059 (Cameron and Bayne 2009). In comparison, in Alaska, 50% of the low human-impact sites sampled by Saltmarsh et al. (2016) were invaded. Compared to other soil types, A horizons of Gray Luvisols are potentially more affected by earthworm invasion compared to other orders because they form de novo organo–mineral complexes (Lejoly et al. 2021).

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Table 6. Topsoil depth, soil organic carbon, total nitrogen, carbon to nitrogen ratio, cation exchange capacity, sand content, clay content, and pH as a function of soil type (Cultivated Luvisol, Dark Gray Chernozem, and uncultivated Luvisol).

	Minimum	25th percentile	Median	75th percentile	Maximum	No. of observations
			Topsoil depth (cm)			
Uncultivated Gray Luvisol	3	10	14	24	46	52
Cultivated Gray Luvisol	8	20	21	27	35	7
Cultivated Dark Gray Luvisol	15	26	38	44	56	10
Uncultivated Dark Gray Luvisol	5	13	20	30	64	24
Dark Gray Chernozem	8	14	18	25	74	78
			Soil organic carbon (%)			
Uncultivated Gray Luvisol	0.14	0.42	1.01	1.53	9.00	52
Cultivated Gray Luvisol	0.20	0.60	1.34	1.97	9.00	7
Cultivated Dark Gray Luvisol	0.50	1.04	1.24	1.69	2.28	10
Uncultivated Dark Gray Luvisol	0.34	1.30	1.84	2.93	9.00	24
Dark Gray Chernozem	0.47	1.67	2.86	4.32	20.85	78
			Total nitrogen (%)			
Uncultivated Gray Luvisol	0.02	0.03	0.07	0.10	0.83	52
Cultivated Gray Luvisol	0.03	0.14	0.18	0.40	0.87	7
Cultivated Dark Gray Luvisol	0.04	0.10	0.14	0.20	0.57	10
Uncultivated Dark Gray Luvisol	0.03	0.10	0.18	0.23	0.93	24
Dark Gray Chernozem	0.01	0.14	0.22	0.32	1.38	78
			Carbon to nitrogen ratio			
Uncultivated Gray Luvisol	0.56	11.00	13.44	17.79	150.00	52
Cultivated Gray Luvisol	0.23	5.69	11.62	13.96	41.28	7
Cultivated Dark Gray Luvisol	2.20	9.11	10.32	11.60	24.00	10
Uncultivated Dark Gray Luvisol	0.37	11.31	12.66	16.20	20.56	24
Dark Gray Chernozem	2.67	11.96	13.25	15.08	132.00	78
			Cation exchange capacity (meq 100 g^{-1})			
Uncultivated Gray Luvisol	1.86	5.35	10.69	17.68	52.93	52
Cultivated Gray Luvisol	3.29	4.94	6.9	116.82	29.34	7
Cultivated Dark Gray Luvisol	5.17	10.26	14.26	17.48	29.63	10
Uncultivated Dark Gray Luvisol	3.69	11.70	13.70	21.80	36.80	24
Dark Gray Chernozem	6.8	15.02	23.30	32.21	104.80	78
			Sand content (%)			
Uncultivated Gray Luvisol	2.45	26.00	60.60	73.88	93.00	52
Cultivated Gray Luvisol	20.38	33.17	71.54	90.46	91.29	7
Cultivated Dark Gray Luvisol	22.67	33.68	58.90	77.47	88.42	10
Uncultivated Dark Gray Luvisol	4.00	27.25	62.50	76.06	92.57	24
Dark Gray Chernozem	8.00	26.25	64.92	78.58	91.00	78
			Clay content (%)			
Uncultivated Gray Luvisol	0.00	5.95	10.00	19.73	65.55	52
Cultivated Gray Luvisol	3.20	4.21	6.79	30.48	45.13	7
Cultivated Dark Gray Luvisol	4.00	8.57	9.60	22.06	23.46	10
Uncultivated Dark Gray Luvisol	4.18	10.37	13.13	18.05	50.00	24
Dark Gray Chernozem	4.00	9.00	19.50	27.84	60.00	78
			pH			
Uncultivated Gray Luvisol	3.80	4.59	5.34	6.02	7.50	52
Cultivated Gray Luvisol	4.52	5.33	6.09	6.72	7.12	7
Cultivated Dark Gray Luvisol	6.20	6.32	6.73	7.10	7.50	10
Uncultivated Dark Gray Luvisol	5.46	6.20	6.50	7.00	7.40	24
Dark Gray Chernozem	5.53	6.59	7.20	7.47	7.80	78

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Cultivation (tillage) and increased bioturbation in cultivated and forested Luvisols have resulted in the loss of significant amounts of soil carbon from the forest floor (LFH) or transfer from the LFH into the underlying A horizons, resulting in increased topsoil depth and pH (Tables 1, 2, and 6). Granular structure was more common in cultivated Gray Luvisols and platy structure was more common in forested Gray Luvisols (Table 5). Conversion of land from forest to agriculture has resulted in the complete loss of the LFH through oxidation and physical mixing into the Ap horizon through tillage and bioturbation. The shift to annual grains and perennial forages has fundamentally changed the magnitude and frequency of above- and below-ground carbon inputs into surface horizons (Izarraulde et al. 2001; Grant et al. 2001). The overall result of these processes has been the transformation of LFH, Ahe, Ae surface horizons with distinct boundaries, highly contrasting levels of SOC, and fragmoidic fabrics to a much more homogeneous Ap horizon with higher levels of SOC than their forested Ahe/Ae counterparts as expressed by the presence of granular structures and granoidic fabrics (Tables 1, 2, and 3; Pawluk 1980; Martin et al. 1987). While not observed directly, the apparent shift to granular structure is likley a result of tillage-driven mixing and greater organo–mineral complexes formed by earthworms reworking greater below-ground carbon inputs from fibrous root systems of annual grain and perennial forage crops.

In the boreal forest, invasion and propagation of exotic fauna coupled with climate change, has significantly increased bioturbation-driven incorporation of organic carbon from the LFH into underlying mineral horizons over and above activity from native fauna alone. The apparent result of these processes is the presence of Ahu horizons in the boreal forest (Table 3; Lejoly et al. 2021), a horizon traditionally reserved for the mixed hardwood forests of southern Ontario. These changes appear to be progressing surprisingly quickly in the forest preserve at the Breton Plots given the significant differences between forested profile descriptions of Pawluk (1980) and Martin et al. (1987) with those of Lejoly et al. (2021).

It is more difficult to make inferences regarding cultivation- or bioturbation-induced changes in Dark Gray Luvisols with data from the NPDB. There was no apparent difference in the relative frequencies of nonplaty and platy structures between cultivated and uncultivated Dark Gray Luvisols (Table 5). Median SOC in uncultivated Dark Gray Luvisols was closer to levels found in cultivated Dark Gray Chernozems, both higher than all other cultivated Gray Luvisolic subgroups. Perhaps these results are explained by the possibility that the classification of a pedon could change from Orthic Gray Luvisol under forest to a Dark Gray Luvisol following cultivation (Pettapiece et al. 2010), and that the cultivated and uncultivated pedons from the NPDB were not grouped as cultivated–uncultivated pairs near to each other. Further, given the similarities between uncultivated Dark Gray Luvisols and cultivated Dark Gray Chernozems (Table 5), it is not surprising that cultivated Dark Gray Luvisols are often classified as Orthic Dark Gray Chernozems (Pettapiece et al. 2010), which is discussed in the following paragraphs.

We further propose the incorporation of a polygenetic model of Luvisolic soil genesis into the CSSC as a natural evolution of the classification system which has a genetic bias (see p. 8 in Soil Classification Working Group 1988), but before the human-driven impacts of tillage and earthworms can be recognized, we first propose amendments that reduce confusion in classifying Dark Gray Luvisols and Orthic Dark Gray Chernozems.

In the current CSSC, the diagnostic horizons for the Luvisolic and Chernozemic orders are the Bt and the Chernozemic A horizon, respectively (p. 61, Soil Classification Working Group 1988). Chernozemic A horizons are defined as Ap, Ah, or Ahe horizons that have the following characteristics: (*i*) at least 10 cm thick; (*ii*) dark in color—color values $\leq$ 5.5 dry or $\leq$ 3.5 moist, chroma $\leq$ 3.5 moist; (*iii*) darker than the C horizon by 1 Munsell color unit; (*iv*) contain 1%–17% organic C with C:N < 17; (*v*) structure that is not massive or single-grained; (*vi*) base saturation > 80% with Ca being the dominant exchangeable cation; and (*vii*) a mean annual soil temperature of 0 °C and a soil moisture regime drier than humid.

In the current CSSC, both Bt and Chernozemic A horizons may occur in profiles belonging to either order. For example, a profile with Ap, Ae, Bt, Ck horizon sequences could be classified as a Dark Gray Luvisol or Orthic Dark Gray Chernozem. If the Ap is Chernozemic, the thickness of the Ae horizon is used to distinguish between Dark Gray Luvisols (Ae $\geq$ 5 cm or thicker than Ap) and Orthic Dark Gray Chernozems (Ae < 5 cm). However, comparing the cultivated soil profiles and their forested counterparts at the Breton Plots and Winfield, AB, even if an Ae horizon $\geq$ 5 cm thick was originally present, it has likely been transformed and (or) incorporated into an Ap overlying an Ahe or AB with cultivation. Because of the transition from Ae to an Ap with granular structure, these soils are often classified as Dark Gray Chernozems (Table 3; Pettapiece et al. 2010) as long as they have a moist color value $\leq$ 3.5 and one Munsell unit darker than the C horizon, although they likely did not develop under a grassland ecosystem. In summary, there is currently no mechanism in the (CSSC) to recognize the boreal heritage of many Orthic Dark Gray Chernozems that were Orthic Gray and Dark Gray Luvisols prior to cultivation.

For cultivated Gray Luvisols, only modest modification to the CSSC is required to deconvolute Dark Gray Luvisols and Orthic Dark Gray Chernozems. First, we propose and have provided evidence that Ae thickness is not an adequate criterion to distinguish between Dark Gray Luvisols and Orthic Dark Gray Chernozems. Although observable profile characteristics are the preferred diagnostic criteria in the CSSC, there is likely no single observable characteristic in a pedon with an Ap, Ahe/Ae, Bt, Ck horizon sequence that would clearly distinguish if the soil were a Dark Gray Chernozem or a Gray or Dark Gray Luvisol prior to cultivation. Nevertheless, we propose that the classification system be amended in one of the following ways: (*i*) create a new Dark Gray great group in the Luvisolic order that combines the Dark Gray Chernozemic great group and the Dark Gray Luvisolic subgroup or (*ii*) restrict Dark Gray soil profiles with Bt horizons to the Luvisolic order even if a Chernozemic A horizon is present.

Both potential amendments have the advantage of a specific profile sequence Ap, Ahe/Ae, Bt, Ck which may currently be either a Dark Gray Luvisol or Orthic Dark Gray Cher-

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nozem, always resulting in the same classification—i.e., Orthic Dark Gray Luvisol. With the Bt horizon as the diagnostic horizon the ambiguity associated with allowing Chernozemic A horizons in the Luvisolic order would be eliminated.

Combining Dark Gray Luvisols and Dark Gray Chernozems into a new Luvisolic great group, is consistent with the discontinuous distribution of Dark Gray Chernozems in the Dark Gray soil zone and the likelihood that Dark Gray Chernozems were forested for a significant period of their development anyways. It should be noted here that, in the proceedings of the sixth meeting of the Soil Classification Working Group in 1965 (National Soil Survey Committee 1965), there was a Dark Gray great group in the Luvisolic order, but it was subsequently changed to a subgroup of the Gray great group as indicated in the proceedings of the seventh meeting in 1968 (National Soil Survey Committee 1968). The disadvantage combining Dark Gray Luvisols and Chernozems is uncertainty about whether it is appropriate to include all subgroups in the current Gray Luvisolic and Dark Gray Chernozemic great groups into the proposed new Dark Gray Luvisolic great group, but these challenges are not insurmountable. With this amendment, all of the cultivated profiles in Table 3 would be likely be classified as Orthic Dark Gray Luvisols.

The second possible proposed amendment would also result in all profiles with Ap, Ahe/Ae, Bt, Ck horizon sequences being classified as Dark Gray Luvisols. Orthic Dark Gray Chernozem would be restricted to profiles with Btj or Bm horizons and Chernozemic A horizons, which is consistent with the other Chernozemic Great Groups. The Bt horizon would still be in the Eluviated subgroup of the Brown, Dark Brown, and Black Chernozemic great groups. This approach is the more modest of the two proposed amendments and would require fewer revisions to the CSSC.

With either of these proposed amendments, however, there is no way to distinguish whether a soil with an Ap, Ahe/Ae, Bt, Ck horizon sequence was an Orthic Gray or a Dark Gray Luvisol in its precultivation state. Nonfield criteria could be used to supplement the classification decision of the pedologist such as laboratory measurements, ecozone/ecoregion in which the pedon is located (Ecological Stratification Working Group 1996; Natural Regions Committee 2006), historical air photos, historical documents, other profile characteristics (e.g., laboratory-measured properties), and climate data. There are many examples of nonfield criteria such as climate that are used to distinguish between soil orders (e.g., mean soil temperature for the Gray Brown Luvisols and for the Chernozemic Order). In this case, the C:N ratio of the Ap horizon may help distinguish between cultivated Luvisols and cultivated Dark Gray Chernozems. The median Ap C:N in the cultivated Gray and Dark Gray Luvisols in Tables 1 and 6 is quite low (<11:1) and the C:N in the Ap of cultivated Dark Gary Chernozems is apparently higher (13:1; Table 6). Other readily measurable soil properties to help distinguish the origins of cultivated soils may also emerge with time. We also observed a trend in the NPDB data that cultivated Orthic Gray Luvisols had lower pH than cultivated Dark Gray Luvisols, but more observations are required to determine if an unambiguous pH threshold exists.

Further, we propose the introduction of an Anthric subgroup to the Luvisolic order (which could also be included in any order in the CSSC) to fully reflect the polygenetic nature of the Luvisolic soils we have discussed here. Even though the abovementioned amendments provide clearer boundaries between Dark Gray Luvisols and Orthic Dark Gray Chernozems, they do not explicitly recognize human agricultural activities as the dominant soil forming factor during the last 100 years (Richter 2007) like the addition of an Anthric subgroup would.

Finally, with respect to bioturbation, because Chernozemic A horizons must be Ap, Ah or Ahe horizons, the profiles with Ahu horizons in Table 3 do classify as Dark Gray Luvisols, but this classification does not reflect the dominance of human-introduced earthworm bioturbation. In Gray Brown Luvisols, the mull Ah diagnostic horizon is a recognition of earthworm activity, but potentially not human-introduced earthworm and boreal soils are still excluded from this great group because they do not have annual average soil temperatures > 8 °C (see Table S2 for a summary of soil temperatures at the Breton Plots between 2005 and 2021). If the Anthric subgroup were adopted, all of the soils in Table 3 would be classified as Anthric Dark Gray Luvisols.

Conclusion

The fifth attribute of the CSSC (Soil Classification Work Group 1988) described on p. 6 states that "Differentiate among the taxa are based upon soil properties that can be observed and measured objectively in the field or, if necessary, in the laboratory". In the following paragraph, this attribute is discussed in the context of the genetic bias inherent to the system: "…properties or combinations of properties that reflect genesis are favored… [but] classification is not based on presumed genesis because soil genesis is incompletely understood….". The polygenetic model for Gray Luvisols and modest amendments proposed here are certainly limited by incomplete understanding but are based on interpretation of observable soil characteristics, preserving the balance between observation and interpretation inherent in the CSSC.

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Notes

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Data availability

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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Supplementary material

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References

Agriculture and Agri-Food Canada. 2016. National Pedon Database. Available from https://open.canada.ca/data/en/dataset/6457fad6-b6f5-47a3-9bd1-ad14aea4b9e0 [accessed 17 February 2021].

Amundson, R., and Jenny, H. 1991. The place of humans in the state factor theory of ecosystems and their soils. Soil Sci. **151**: 99–109. doi:10.1097/00010694-199101000-00012.

Bronick, C.J., and Lal, R. 2005. Soil structure and management: a review. Geoderma, **124**: 3–22. doi:10.1016/j.geoderma.2004.03.005.

C.F. Bentley, A.M.F. Hennig, T.W. Peters and D.R. Walker(eds.). 1971. Gray wooded soils and their management. Bulletin B-71-1. 7th ed., University of Alberta, Edmonton, AB, Canada.

Cameron, E.K., and Bayne, E.M. 2009. Road age and its importance in earthworm invasion of northern boreal forests. J. Appl. Ecol. **46**: 28–36. doi:10.1111/j.1365-2664.2008.01535.x.

Cameron, E.K., Bayne, E.M., and Jill, M. 2007. Human-facilitated invasion of exotic earthworms into northern boreal forests. Ecoscience, **14**: 482–490. doi:10.2980/1195-6860(2007)14[482:HIOEEI]2.0.CO;2.

Dyck, M.F., and Puurveen, D. 2020. Long-term rotation impacts soil total macronutrient levels and wheat response to applied nitrogen, phosphorus, potassium, sulfur in a Luvisolic soil. Can. J. Soil Sci. **100**: 430–439. doi:10.1139/cjss-2019-0155.

Dyck, M.F., Roberston, J.A., and Puurveen, D. 2012. The University of Alberta Breton plots. Prairie Soils Crops J. **5**: 96–115. Available from https://prairiesoilsandcrops.ca/articles/volume-5-10-screen.pdf.

Ecological Stratification Working Group. 1996. A national ecological framework for Canada. Available from https://sis.agr.gc.ca/cansis/publications/manuals/1996/A42-65-1996-national-ecological-framework.pdf.

Ellert, B.H., and Bettany, J.R. 1995. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Can. J. Soil Sci. **75**: 529–538. doi:10.4141/cjss95-075.

Ellis, J.H. 1938. The soils of Manitoba. Manitoba Economic Survey Board. pp. 112.

Grant, R.F., Juma, N.G., Robertson, J.A., Izaurralde, R.C., and McGill, W.B. 2001. Long-term changes in soil carbon under different fertilizer, manure and rotation: testing the mathematical model *ecosys* with data from the Breton plots. Soil Sci. Soc. Am. J. **65**: 205–214. doi:10.2136/sssaj2001.651205x.

Grant, R.F., Dyck, M., and Puurveen, D. 2020. Nitrogen and phosphorous control carbon sequestration in agriculture ecosystems: modelling carbon, nitrogen and phosphorous balanced at the Breton plots with *ecosys* under historical and future climates. Can. J. Soil Sci. **100**: 408–429. doi:10.1139/cjss-2019-0132.

Hamley, W. 1992. The farming frontier in northern Alberta. Geogr. J. **158**: 286–294. doi:10.2307/3060297.

Howitt, R.W., and Pawluk, S. 1985. The genesis of a gray luvisol within the boreal forest region. I. Static pedology. Can. J. Soil Sci. **65**: 1–8.

Izaurralde, R.C., McGill, W.B., Robertson, J.A., Juma, N.G., and Thurston, J.J. 2001. Carbon balance of the breton classical plots over half a century. Soil Sci. Soc. Am. J. **65**: 431–441. doi:10.2136/sssaj2001.652431x.

Jackson, M., Myrholm, C., Shaw, C., and Ramsfiled, T. 2017. Using nested PCR to improve detection of earthworm eDNA in Canada. Soil Biol. Biochem. **113**: 215–218. doi:10.1016/j.soilbio.2017.06.009.

Jenny, H. 1941. Factors of soil formation, a system of quantitative pedology. McGraw-Hill Book Company, Inc., New York. pp. 281.

Landi, A., Anderson, D.W., and Mermut, A.R. 2003. Organic carbon storage and stable isotope composition of soils along a grassland to forest environmental gradient in Saskatchewan. Can. J. Soil Sci. **83**: 405–414. doi:10.4141/S02-021.

Lavkulich, L.M., and Arocena, J.M. 2011. Luvisolic soils of Canada: genesis distribution and classification. Can. J. Soil Sci. **91**: 781–806. doi:10.4141/cjss2011-014.

Lejoly, J., Quideau, S.A., and Langaniere, J. 2021. Invasive earthworms affect soil morphological features and carbon stocks in boreal forests. Geoderma, **404**: 115262. doi:10.1016/j.geoderma.2021.115262.

Martin, T.C., Robertson, J.A., and Pawluk, S. 1987. Change in the micromorphology and analytical properties of a gray luvisol (Cryoboralf) under a 49 year old forage stand. Geoderma, **40**: 209–224. doi:10.1016/0016-7061(87)90023-1.

National Soil Survey Committee. 1965. Proceedings of the sixth meeting of the National Soil Survey Committee of Canada. Available from https://soilsofcanada.ca/documents/national_soil_survey_proceedings/1965_nssc_6thmeeting.pdf.

National Soil Survey Committee. 1968. Proceedings of the sixth meeting of the National Soil Survey Committee of Canada. Available from: https://soilsofcanada.ca/documents/national_soil_survey_proceedings/1968_nssc_7thmeeting.pdf

Natural Regions Committee. 2006. Natural regions and subregions of Alberta. Available from https://open.alberta.ca/dataset/dd01aa27-2c64-46ca-bc93-ca7ab5a145a4/resource/98f6a93e-c629-46fc-a025-114d79a0250d/download/2006-nrsrcomplete-may.pdf.

Pawluk, S. 1980. Micromorphological investigations of cultivated gray luvisols under different management practices. Can. J. Soil Sci. **60**: 731–745. doi:10.4141/cjss80-082.

Pettapiece, W., Robertson, J.A., and Anderson, D.W. 2010. Cultivated gray luvisol soils of the Prairie region. Prairie Soil Crops J. **3**: 73–83. Available from https://prairiesoilsandcrops.ca/articles/volume-3-10-print.pdf.

R Core Team. 2018. R: a language and environment for statistical computing.

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,Richter, D.d., Jr. 2007. Humanity's transformation of earth's soil: pedology's new frontier. Soil Sci. **172**: 957–967. doi:10.1097/ss.0b013e3181586bb7.

,Richter, D.d., Jr. 2020. Game changer in soil science: the Anthropocene in soil science and pedology. J. Plant Nutr. Soil Sci. **183**: 5–11. doi:10.1002/jpln.201900320.

Richter, D., and Yaalon, D.H. 2012. The changing model of soil revisited. Soil Sci. Soc. Am. J. **76**: 766–778. doi:10.2136/sssaj2011.0407.

Rockstrom, J., Steffen, W., Noone, K., Persson, Å., ,Chapin, F.S., III, Lambin, E.F., et al. 2009. A safe operating space for humanity. Nature, **461**: 472–475. doi:10.1038/461472a. PMID: 19779433.

Ross, S.M., Izaurralde, R.C., Janzen, H.H., Robertson, J.A., and McGill, W.B. 2008. The nitrogen balance of three long-term agroecosystems on a boreal soil in western Canada. Agric. Ecosyst. Environ. **127**: 241–250. doi:10.1016/j.agee.2008.04.007.

Saltmarsh, D.M., Bowser, M.L., Morton, J.M., Lang, S., Shain, D., and Dial, R. (2016). Distribution and abundance of exotic earthworms within a boreal forest system in southcentral Alaska. NeoBiota, **28**: 67–86. doi:10.3897/neobiota.28.5503.

Shaw, C.H., Banfield, E., and Kurz, W.A. 2008. Stratifying soils into pedogenically similar categories for modeling forest soil carbon. Can. J. Soil Sci. **88**: 501–516. doi:10.4141/CJSS07099.

Soil Classification Working Group. 1998. The Canadian system of soil classification. 3rd ed., Agriculture and Agri-Food Canada Publication 1646. pp. 187.

Sorenson, P.T., Quideau, S.A., Rivard, B., and Dyck, M. 2020. Distribution mapping of soil profile carbon and nitrogen with laboratory imaging spectroscopy. Geoderma, **359**: 113982. doi:10.1016/j.geoderma.2019.113982.

Tarnocai, C. 1997. Chapter 6. The amount of organic carbon in various soil orders and ecological provinces in Canada. *In* Soil processes and the carbon cycle. *Edited by* R. Lal, J.M. Kimble, R. F Follett and B.A. Stewart. Lewis Publishers, CRC Press, Boca Raton, FL. pp. 8192.

Van Oost, K., Govers, G., de Alba, S., and Quine, T.A. 2006. Tillage erosion: a review of controlling factors and implications for soil quality. Prog. Phys. Geogr. **30**: 443–466. doi:10.1191/0309133306pp487ra.

Wani, S.P., McGill, W.B., Haugen-Kozyra, K.L., and Juma, N.G. 1994. Increased proportion of active soil N in breton loam under cropping systems with forages and green manures. Can. J. Soil Sci. **74**: 67–74. doi:10.4141/cjss94-009.

Watson, K. 2007. Soils illustrated. International Remote Sensing Surveys, Kamloops, BC.

Watson, K., and Pennock, D. 2016. Field handbook for the soils of Western Canada, section 3: profile description. Available from https://soilecology.ca/wp-content/uploads/2018/08/Soil-Profile-Description.pdf.

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