Effects of agriculture on the classification of Black soils in the Midwestern United States

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Veenstra, J. J. and Burras, C. L. 2012. **Effects of agriculture on the classification of Black soils in the Midwestern United States**. Can. J. Soil Sci. **92**: 403–411. Soil surveys are generally treated as static documents. Many soil survey users assume that pedon data generated 30 to 50 yr ago still represents today's soil, as short-term changes in soil properties are perceived to be limited to the soil surface and thus pedologically insignificant. In this study, we re-sampled and re-analyzed 82 pedons with historical descriptions and laboratory data in Iowa, United States, to evaluate changes in soil profile properties and taxonomic classification after approximately 50 yr of agricultural land use. Using historical and current data, we classified sampled pedons using Canadian Soil Taxonomy, US Soil Taxonomy and the Food and Agriculture Association World Reference Base (FAO-WRB). Our results show that soil characteristics have changed significantly enough to change the classification. In each taxonomic system, the classification of 60% or more of the sampled pedons differed from the original. Classification of 15 to 32% of the sampled pedons changed at the Order (or equivalent) level with 11 to 33% of the pedons originally classified as Black soils – Mollisols, Chernozems or Phaeozems – no longer classified as Black soils. The change in soil classification over such a short-time period challenges the validity and usefulness of treating existing soil maps as static documents as well as traditional soil classification hierarchies.

Key words: Soil taxonomy, classification, Black soils, Midwestern United States, agriculture

Veenstra, J. J. et Burras, C. L. 2012. **Incidences de l'agriculture sur la classification des sols noirs dans le centre-ouest des États-Unis**. Can. J. Soil Sci. **92**: 403–411. En général, on considère les relevés pédologiques comme des documents statiques. Bon nombre de ceux qui les utilisent présument que les données sur les pédons recueillies il y a 30 à 50 ans décrivent encore les sols d'aujourd'hui, estimant que les propriétés du sol de surface connaissent peu de changements à court terme, donc ne présentent guère d'importance sur le plan de la pédologie. Dans le cadre de cette étude, les auteurs ont prélevé puis analysé un nouvel échantillon de 82 pédons situés dans l'Iowa, aux États-Unis et pour lesquels on disposait d'une description et de données de laboratoire historiques, cela afin d'évaluer les changements subis par les propriétés du sol et classer celui-ci après une cinquantaine d'années d'exploitation agricole. En recourant aux données historiques et actuelles, les auteurs ont classé les pédons selon la Taxonomie des sols canadiens, la taxonomie américaine et la Base mondiale de données sur les sols de l'Organisation mondiale de la santé (FAO-WRB). Les résultats indiquent que les caractéristiques des sols ont changé assez pour justifier une reclassification. Peu importe la taxonomie, 60 % ou plus des pédons échantillonnés se sont retrouvés dans une classe différente de l'originale. La classification de 15 à 32 % des pédons échantillonnés a dû être modifiée au niveau de l'ordre (ou de son équivalent) et 11 à 33 % des pédons considérés comme des sols noirs au départ – mollisols, tchernozioms ou phaeozems – n'en faisaient désormais plus partie. Que la classification des sols change aussi vite remet en question la validité et l'utilité de la nature statique des levés pédologiques, ainsi que de la hiérarchie traditionnelle des classes de sols.

Mots clés: Taxonomie des sols, classification, sols noirs, centre-ouest des États-Unis, agriculture

Soil surveys are generally treated as static documents, with users such as farmers, government officials and environmental modelers assuming that data generated decades ago are representative of current soil conditions. Nevertheless several studies have shown that many chemical and physical soil properties change on much shorter time scales (Anderson and Browning 1949; van Bavel and Schaller 1950; Kashirad et al. 1967; Barnes et al. 1971; Bouma and Hole 1971; Davies et al. 1972; Skidmore et al. 1975; Greenland 1977; Meints and Peterson 1977; Van Cleve and Moore 1978; Pidgeon and Soane 1978; Martel and Mackenzie 1980; Coote and Ramsey 1983; Mann 1985, 1986; Johnston 1986; Jenkinson 1991; Sandor and Eash 1991; Bouman et al. 1995; Barak et al. 1997; Khan et al. 2007; David et al. 2009; Mulvaney et al. 2009). These changes are assumed to be inconsequential to the fundamental character of the soil given none of the authors recommended reclassifying their study soils. Additionally, we know of no national soil survey program that is systematically re-examining its published soil maps from the perspective of human impacts on soil classification and distribution. However, changes in soil color, pH, cation exchange capacity (CEC), base saturation, and depth to

Abbreviations: **CEC**, cation exchange capacity; **FAO-WRB**, Food and Agriculture Association World Reference Base; **NCSS**, US National Cooperative Soil Survey; **RSG**, Reference Soil Group carbonates are just a few of the soil changes that could cause changes in soil classification as well as soil productivity –and all of these have been documented in one or another of the cited studies.

Black soils – Chernozems, Kastanozems, Mollisols, or Phaeozems, depending on the classification system – are widespread across the Central Plains of North America. Black soils are characterized by thick, dark, organic matter-rich surface horizons and relatively high base saturation throughout the profile (Fenton 1983; US Soil Survey Staff 1999; WRB 2007; Table 1). They are the most prevalent soil order in the United States, comprising 21.5% of the ice-free land area (US Soil Survey Staff 1999). They are also the soil order most commonly used for agriculture in the United States, with 25% of the Mollisol land area used for cropland agriculture (Amundson et al. 2003). Many of these soils are located in the ''Midwestern'' US, including states such as Iowa, Illinois, Minnesota, Missouri and North and South Dakota.

With increased erosion rates associated with agricultural land use (Montgomery 2007), Black soils are exceptionally at risk for classification changes, because their primary taxonomic feature (thick, dark epipedon) is at the land surface (Smith 1986). Amundson et al. (2003) define endangered soils as soil series that have lost 50% of their land area through soil changes associated with urbanization or agriculture and are rare (represent less than 10 000 ha) or unique (occur only in one state). Soil series is the most specific category in soil classification; it is essentially the soil taxonomic equivalent to ''species'' in biological taxonomy. Even though Midwestern states have average levels of soil series diversity, they comprise six of the top ten states in terms of number of endangered series and nine out of the top ten in terms of percentage of rare soils that are endangered. This is largely a result of the high proportion of agricultural land use in the Midwestern US (Amundson et al. 2003).

Our objective was to evaluate the effect of 50 yr of agricultural soil change on the classification of 82 pedons in Iowa using the Canadian, US and Food and Agriculture Organization World Reference Base (FAO-WRB) systems of soil taxonomy. Iowa provided the ideal location for this study because it has an incredible pedological history, including work by G.D. Smith, the originator of US Soil Taxonomy, R.W. Simonson, a leading theorist of pedology in the second half of the 20th century, and R.W. Arnold, leader of the US Soil Survey during the second half of the 20th century, and it embodies both Mollisols and Midwestern agricultural practices.

MATERIALS AND METHODS

Historical Database of Soil Properties

The US National Cooperative Soil Survey (NCSS) has been surveying and cataloging soils across the nation since 1899. Throughout its history, the NCSS has mapped and classified soils to the soil series level, which is ''the most homogenous category in the taxonomy used in the USA'' (US Soil Survey Staff 1993) and uses a ''local name'', which was established to designate ''each well-defined area'' of a soil within a limited geographic region (Baldwin et al. 1938). In short, the soil series is the fundamental mapped unit in the USA when agricultural land is being surveyed. There are more than 23 699 soil series in the USA (MCSS 2010) with generally 20 to 50 series mapped across a typical county in Iowa. The minimum map unit area for a series is 1 ha, but most individual polygons are 3 to 20 ha in area. The identification of a series is based upon presumed genetic factors, such as parent material and native vegetation, as well as measured properties, such as horizon sequence and thickness, texture, pH, color and consistence (US Soil Survey Staff 1951, 1993; Smith 1986). Since its inception in the 1930s, the US taxonomic classification system has changed dramatically, but soil series and their associated descriptions have remained relatively consistent (US Soil Survey

Table 1. Specific characteristics of Black soils as defined by three soil taxonomic systems

	Canadian	US	FAO-WRB		
Classification	Chernozem	Mollisol	Chernozem	Kastanozem	Phaeozem
Munsell colors, moist	Value and chroma < 3.5	Value and chroma ≤ 3	Value ≤ 3 and chroma ≤ 2	Value and chroma ≤ 3	Value and chroma ≤ 3
Carbon content	1–17% C:N ratio < 17	> 0.6%	> 0.6%	> 0.6%	> 0.6%
Base saturation	> 80%	> 50%	> 50%	> 50%	> 50%
Minimum thickness of mollic colors	10 cm	18 cm[z]	20 cm	20 cm	20 cm
Depth to secondary carbonates	N/A	N/A	Within 50 cm below the base of the mollich horizon	Within 50 cm below the base of the mollic horizon	N/A

[z]Minimum thickness of mollic colors is simplified here for the conditions appropriate to the soils sampled. In other cases, minimum thickness can be 10 cm, between 18 and 25 cm or 25 cm (US Soil Survey Staff 2010).

Staff 1975). For each soil series that is present in each US county, the NCSS has established a ''type location'', which is a specific location that is considered the representative example of that series in that county. For ''type locations'' the NCSS chooses sites with land use that represents the norm of the area and on landscape positions that they assume are unlikely to change (US Soil Survey Staff 1951). As a result of this selection procedure, type locations trend toward lower slopes (0–15%; median 2%) than are representative of Iowa overall.

For type locations, the NCSS maintains a database of soil information, for which Iowa data began in 1943. For this study, we resampled sites that were described between 1943 and 1963 (Soil Conservation Service 1966, 1978) and for which a specific public land survey system location was available. We chose to sample all pedons with available data, not just Black soils, because some pedons could evolve into Black soils over time.

Using ArcGIS, GPS and 1930s through 1960s aerial photos, we were able to relocate the original representative sites, and we sampled them again in 2007 or 2008. Thus, we are assessing approximately 50 yr of change on average. Eighty-two representative pedons, or type locations, from the NCSS database were sampled in 21 counties across Iowa. A map of the counties sampled is presented as Fig. 1. Two 7-cm-diameter, 150-cm-long soil cores were collected at each sampling location with a truck-mounted hydraulic soil sampler (Giddings Machine Company, Windsor, CO). Each sample pedon was analyzed and described separately using standard soil survey methods (US Soil Survey Staff 1996; Schoeneberger et al. 2002). Horizon type, horizon depth, rock fragment content, structure, texture by feel, consistence, color, effervescence, presence of clay films, roots, pores, bulk density, pH and total soil C and N were determined for each of the horizons. CEC, the concentration of extractable base cations and soil particle size distribution (<2 mm) by the pipette method were determined for the horizons from a subset of 33 soil cores (Methods 6N2, 6O2, 6P2, 6Q2, 6H5a, 3A1; US Soil Survey Staff 1996).

Land Use

The bulk of European-style, large-scale, row-crop agriculture in Iowa began between 1850 and 1870 (Thompson 1989). Thus, most of the area has been farmed for more than 140 yr. Currently, land use in this region continues to be primarily agricultural, with corn (*Zea mays*) and soybean (*Glycine max*) as the major crops and alfalfa (*Medicago sativa*) oats (*Avena sativa*) and wheat (*Triticum aestivum*) as minor crops. Seventy-four percent of the total land area of Iowa is used for row-crop agriculture, 14% is in pastureland, federal land or conservation reserve, 4% is in woodland, and the remaining 8% consists of urban areas and water bodies (Miller 2010). The original soil survey data recorded land use at the time of sampling, and we recorded land use at

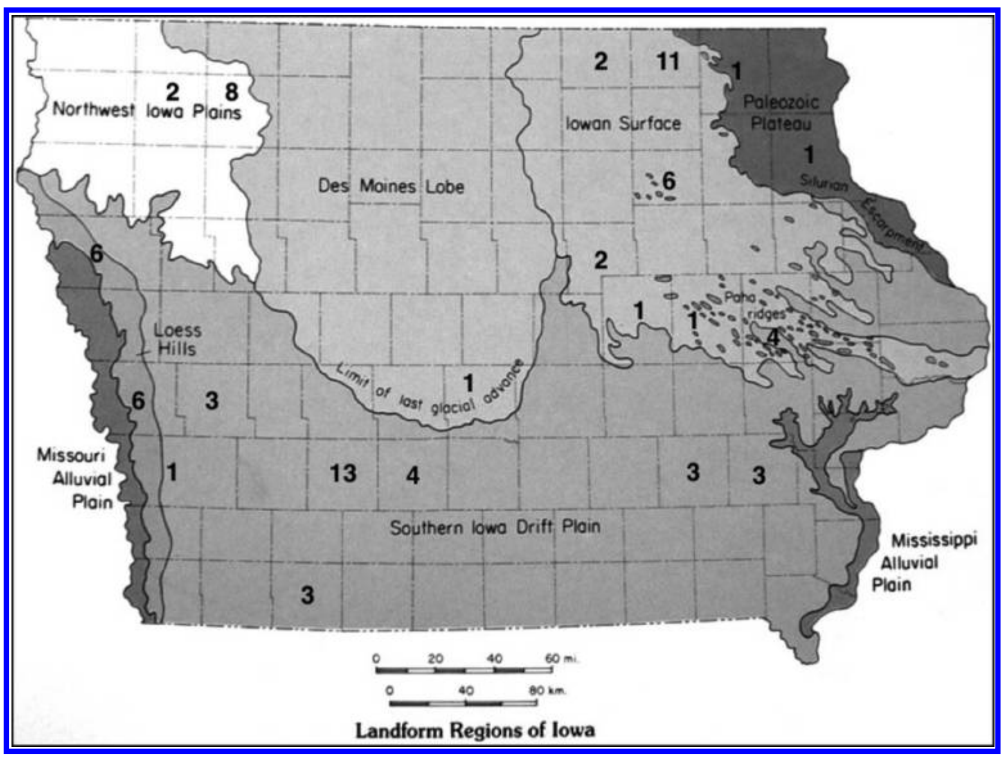

Fig. 1. Location and number of sites sampled per county across landform regions [original map from Landforms of Iowa (Prior 1991)].

the time of our sampling. In order to determine land use change for the interim, we reviewed historical aerial photos, from 1930s, 1950s, 1960s, 1970s, 1980s, 1990s and 2000s available on the Iowa Geographic Map Server (IGMS 2009). Of the 82 sampling sites, 79 of the pedons were in some sort of row crop production for part or all of the time between the original sampling and current sampling date. The remaining three pedons were forested during this time period.

Classification

Using the original and current descriptions and laboratory data, each of the 82 pedons was classified using the current Canadian, US and FAO-WRB soil taxonomic systems to determine changes in soil classification after 50 yr of agricultural land use.

Canadian Soil Taxonomy

Canadian Soil Taxonomy is divided into four hierarchical levels: Order, Great Group, Subgroup and Family (CanSIS 1998). An example family name is: *Gleyed Calcareous Black Chernozem, fine-silty, mixed, cool, humid*, where *Chernozem* is the Order, *Black Chernozem* is the Great Group and *Gleyed Calcareous Black Chernozem* is the subgroup.

In order to classify our sampled soils using the Canadian system, we made the following assumptions. (1) For pedons without chemical data, we assumed that the base saturation in the soil surface horizons was greater than 80% (which is the defined lower limit for the Chernozem order). (2) Moist colors were converted to dry colors by adding one unit to the Munsell moist value (US Soil Survey Staff 1993). (3) Data for pH measured in deionized water were converted to pH measured in 0.05M $CaCl_2$ by adding 0.3 units to the deionized water pH (Foth and Ellis 1996). (4) Particle size class was the only portion of the family classification that could potentially change.

US Soil Taxonomy

US Soil Taxonomy is divided into five hierarchical levels: Order, Suborder Great Group, Subgroup and Family (US Soil Survey Staff 1999). An example family name is: *Fine-silty, mixed, mesic, superactive Aquic Hapludoll*, where *Mollisol* is the Order (signified by the *–oll* suffix), *Udoll* is the suborder, *Hapludoll* is the Great Group and *Aquic Hapludoll* is the subgroup. For the US classification system, we assumed that base saturation was greater than 50% in the pedons without base saturation data, and that particle size class would be the only portion of the family classification that could potentially change over the 50-yr study period.

Food and Agriculture Association World Reference Base (FAO-WRB)

The FAO-WRB is divided into 32 Reference Soil Groups (RSG), to which prefix and suffix qualifiers are added (WRB 2007). An example taxonomic name is: *Pisocalcic Endogleyic Chernozem* (*Anthric, Siltic*), where *Chernozem* is the RSG, *Pisocalcic* and *Endogleyic* are the prefixes, and *Anthric* and *Siltic* are the suffixes. For the FAO-WRB system, in the pedons without the appropriate laboratory data, we assumed that base saturation was greater than 50% and that CEC was greater than 24 cmol(+) kg^{-1}.

Key Features in Classifying Sampled Pedons

The main diagnostic feature of Black soils is a thick, dark surface horizon with Munsell color value and chroma <3.5 in the Canadian system or ≤ 3, moist in the US and FAO-WRB systems. We will refer to these dark colors as "mollic colors" throughout the remainder of this paper.

We identified four major features as key in classifiying our pedons: mollic colors, redoximorphic features, depth to carbonates and the presence or absence of a clay-enriched B horizon. Mollic horizon thickness is the major diagnostic feature defining Black soils at the Order or RSG level. However, the presence or absence of very thick mollic horizons can also distinguish different classes at the subgroup level in US Soil Taxonomy (Cumulic, ≥ 40 cm; Pachic, ≥ 50 cm) and the suffix in FAO-WRB (Pachic, ≥ 50 cm).

Depths to redoximorphic features affect whether or not a pedon is classified as Gleysol Order in the Canadian and FAO-WRB taxonomic systems. It also affects whether or not a pedon is classified in the Gleyed subgroup (Canada), Aquic subgroup (US) or Endogleyic prefix (FAO-WRB). In the US system, depth to redox features is also used to make distinctions at the suborder level (i.e., Aquoll to Udoll).

Depths to effervescence and secondary carbonates also are also used as distinguishing features for pedon classification in the Canadian and FAO-WRB system. In the FAO-WRB, the presence of secondary carbonates within 50 cm of the base of the mollic horizon is the key diagnostic feature that differentiates between Chernozems and Phaeozems. The presence or absence of secondary carbonates within 100 cm of the soil surface also determines whether or not the Pisocalcic prefix is used. In Canadian soil taxonomy, depth to effervescence determines whether or not the Calcareous subgroup is used. US Soil Taxonomy does not use depth to effervescence or carbonates to differentiate between the categories in which the sampled soils are classified.

The presence or absence of a clay-enriched B horizon, (Bt, argillic or argic horizon) was also an important factor in classifying the sampled soils. Additional Black soil classification criteria include carbon content and base saturation (Table 1).

RESULTS

The majority of the 82 sites sampled were originally classified as Black soils in each of the taxonomic systems (Table 2). The remaining pedons were classified as soils with subsurface clay accumulation (Luvisols or Alfisols),

Table 2. Diversity of pedons sampled in terms of the original fundamental classification level (Order or RSG) ($n=82$)

Canadian		US		FAO-WRB		
Order		Order		RSG		Defining characteristics
Chernozem	84%	Mollisol	78%	Phaeozem	60%	See Table 1
				Chernozem	18%	See Table 1
Luvisol	4%	Alfisol	17%	Luvisol	16%	Subsurface clay accumulation
Gleysol	9%					Specific redox features and gleyed colors within 50 cm of the soil surface
Brunisol	2%	Inceptisol	4%	Cambisol	3%	Minimal B horizon development
Vertisol	1%	Vertisol	1%	Vertisol	1%	Cracking, shrink-swell clays, slickensides
				Fluvisol	2%	Evidence of fluvial deposits within 25 cm of the soil surface

Table 3. Percentage of sampled pedons that showed a change in different levels of soil classification after approximately 50 yr of predominantly agricultural land use ($n=82$)

	Canadian taxonomy	US taxonomy	FAO-WRB	
Order	15%	19%	RSG	32%
Suborder	N/A	26%	Prefix	47%
Great Group	49%	32%	Suffix	37%
Subgroup	62%	56%		
Family	66%	60%	At least one change	67%

minimal B horizon development (Brunisols, Inceptisols or Cambisols) or evidence of reducing conditions within 50 cm of the soil surface (Gleysols, Canadian System). In addition, two pedons were classified as Fluvisols (FAO-WRB) and one as a Vertisol.

More than 60% of the pedons sampled changed classification at one or more of the hierarchical levels after 50 yr of agricultural use (Table 3). Fifteen to thirty-two percent of the pedons sampled changed classification at the most fundamental taxonomic level (Order in Canadian and US Soil Taxonomy and RSG in the FAO-WRB). All of the changes at the Order level in Canadian and US soil taxonomy were associated with Black soils, and in the FAO-WRB system, 87% of the changes at the RSG level were associated with Black soils. Thirty-eight percent of the Black soils in the FAO-WRB system changed at the RSG level whereas only 16% of the soils not categorized as Black soils changed at the RSG level. The abundance of Black soils decreased by as little as 5% using the Canadian system and as much as 15% using the FAO-WRB in the time between sampling dates (Table 4). This variation is a simple product of definition, as the Canadian system requires half the depth (10 cm versus 20 cm) and lighter colors (value and chroma <3.5, moist, versus ≤ 3, moist) for a pedon to be classified as a Black soil as compared to the FAO-WRB (Table 1).

Kimble et al. (1999) found even higher levels of Black soil loss. By comparing erosion classes of 208 Mollisols in Iowa, they found that 32% of sites sampled were no longer classified as Mollisols according to the thickness of mollic epipedon. Twenty-seven to seventy-one percent of the thickness of the original mollic epipedon had been lost (Kimble et al. 1999). This result would be expected because they intentionally sampled moderate and severe erosion classes, where the likelihood of substantial erosional effects on mollic thickness is great. In contrast, by using pedons and locations that the National Cooperative Soil Survey defines as representative pedons, we sampled the sites that are assumed to be relatively stable, found on lower slopes than average and not subject to significant erosion and classification change (US Soil Survey Staff 1951).

Two of the three forested pedons did not change classification over the sampling period. They were originally classified as (1) Gleyed Eluviated Dark Brown Chernozem, Fine mixed, mesic Mollic Hapludalf,

Table 4. Percentage of sampled pedons that were classified as Black soils originally and currently in three soil taxonomic systems ($n=82$)

	Canadian	US	FAO-WRB		
Classification	Chernozem	Mollisol	Chernozem	Kastanozem	Phaeozem
Originally (~1959)	84%	78%	18%	0%	60%
Currently (~2007)	80%	70%	13%	0%	54%
No longer[z]	−9%	−13%	−11%	0%	−15%
Newly[y]	+5%	+5%	+6%	0%	+9%

[z]Percentage of sampled pedons that are changed from Black soils to another class.
[y]Percent of sampled pedons that were changed to Black soils from another class.

Cutanic Endogleyic Luvisol, Siltic and (2) Dark Grey Luvisol, Fine-silty mixed mesic Typic Hapludalf, Haplic Luvisol, Siltic in the Canadian, US and FAO classification systems respectively. The third forested site changed classification in the US and FAO classification systems, but did not change in the Canadian classification system (it remained a Dark Grey Luvisol). In the US system, it was originally classified as a Fine-silty mixed, mesic Typic Hapludoll, and now it is classified as a Fine-silty mixed, mesic Typic Eutrudept. In the FAO–WRB, it was classified as a Haplic Chernozem, Siltic, and now it is classified as an Endogleyic Cambisol, Siltic. These changes in classification were the result of the loss of 10 cm of mollic-colored soil. As opposed to the other two forested sites, this site was regularly grazed with cattle and located in a less stable, shoulder landscape position.

Comparison of Three Taxonomic Systems

Changes in the thickness of mollic horizons, depth to redoximorphic features and depth to carbonates were responsible for the majority of changes in all three classification systems. Table 5 shows the most common examples of classification changes based on those three features. Four example pedons with their relevant data as well as the complete classification for each of the three taxonomic systems are shown in Table 6.

Thickness of mollic colors is responsible for about half of the pedon classification changes in the FAO-WRB and US Soil Taxonomy, but only 7% in Canadian Soil Taxonomy. Using Canadian Soil Taxonomy, classification changes at the Order level were because of (a) deepening of redoximorphic features (four pedons), (b) changes in thickness of mollic colored soil (three pedons) and (c) decreases in base saturation (five pedons). These sites represent a third of the sites for which we have base saturation data. Therefore, we hypothesize that more sites likely have changed classification based on base saturation. Ninety percent of the changes at the Great Group level were a result of subtle changes in surface soil color. A change of one unit of Munsell color value can change the Great Group from Dark Brown to Brown to Black Chernozems in the Canadian system (Table 7). Changes in Subgroup were a result of changes in depths to redox features or presence or absence of carbonates (Table 5). Decreases in pH and decreases in total carbon also changed the taxonomy in two pedons (Table 7).

More than half of the changes in classification using US Soil Taxonomy were associated with changes in the thickness of mollic colors (33 pedons). Changes in soil order were exclusively related to gains or losses of mollic colored soil. Changes in the depth to redoximorphic features were responsible for the taxonomic changes at the Suborder level. While the changes at the Great Group level were related to the presence or absence of an argillic horizon, the majority of Subgroup changes

Table 5. Example changes in soil classification in Canadian, US and FAO-WRB Soil Taxonomy after 50 years of agricultural land use[z]

Change in thickness of mollic colored soil			Change in depth to redox features			Change in depth to carbonates		
Canadian	US	FAO-WRB	Canadian	US	FAO-WRB	Canadian	US	FAO-WRB
Order	*Order*	*RSG*	*Order*	*Suborder*	*Prefix*	*Subgroup*	N/A	*Order*
Chernozem	Typic Argiudoll	Chernozem	Gleysol	Typic Endoaquoll	+Endogleyic (7)	+Calcareous (4)		Chernozem
→Luvisol (1)	→Mollic Hapludalf (5)	→Luvisol (2)	→Chernozem (3)	→Aquic Hapludoll (3)	−Endogleyic (13)	−Calcareous (9)		→Phaeozem (6)
→Brunisol (6)	Typic Hapludoll	Phaeozem						Phaeozem
→Regosol (1)	→Typic Eutrudept (3)	→Luvisol (5)	*Subgroup*	*Subgroup*				→Chernozem (5)
	Aquollic Hapludalf	→Regosol (2)	+ Gleyed (7)	Aquic Hapludoll				
	→Aquic Argiudoll (3)	Luvisol	−Gleyed (15)	→Cumulic Hapludoll (2)				*Prefix*
		→Phaeozem (2)						+Pisocalcic (4)
	Subgroup	*Prefix*						−Pisocalcic (3)
	Pachic Hapludoll	+Colluvic (2)						
	→Typic Hapludoll (3)							
		Suffix						
		+Pachic (10)						
		−Pachic (4)						

[z]This table of changes is not comprehensive, but shows examples of how classification has changed in each taxonomic system.
→Classification changes, i.e., a Chernozem became a Luvisol.
+/− A subgroup, prefix or suffix was either added or subtracted, i.e., a Gleyed Chernozem became an Orthic Chernozem or vice versa.
(#) Number of pedons that changed classification as specified.

Table 6. Example pedon data and resulting classification

	Example site 1 (9 − 11)		Example site 2 (14 − 5)		Example site 3 (38 − 1)		Example site 4 (31 − 11)	
Soil series	Cresco		Marcus		Dinsdale		Salix	
Landscape position	Summit		Till plain (0–1% slope)		Backslope		Floodplain (0–1% slope)	
Public Land Survey System Location	835 feet W and 15 feet N of the SE corner of the NW ¼ of Section 35 T99N R13W Howard County, Iowa		260 feet N of the NW corner of the SW ¼ of the SW ¼ of Section 12 T95N R38W Clay County, Iowa		437 feet E and 639 feet S of the NW corner of the NE ¼ of Section 20 T88N R15W Grundy County, Iowa		800 feet E and 200 feet N of SW corner T86N R47W Woodbury County, Iowa	
Date described	1956	2007[z]	1959	2008[z]	1960	2007[z]	1961	2007[z]
Thickness of mollic colors	30	21	61	56	41	25	56	80
Depth to carbonates	109	106	43	63	122	106	114	105
Depth to grey redox features[y]	64	76	61	87	122	135	N/A	N/A
Depth to red redox features[x]	44	41	89	68	76	112	86	151
Depth to redox features[w]	41	39	61	56	76	112	86	128
Base saturation of surface horizon[v]	94%	>80%	114%	>80%	95%	57%	>80%	>80%
pH of surface horizon[u]	6.4	5.5	7.2	6.0	5.9	4.5	N/A	5.1
Bt or argillic horizon?	Yes	Yes	No	No	No	No	No	No
Color of surface horizon	10 YR 2/1	10 YR 2/1	10 YR 2/0.5	10 YR 2/1	10 YR 2/1	10 YR 2/2	10 YR 2/2	N 2/0
Matrix color below chernozemic A/mollic horizon	10 YR 4/2.5	10 YR 4/3	2.5Y 4/2	2.5Y 4/2	10 YR 4/3	10 YR 4/3	2.5 Y 5/3	2.5 Y 4/3
Land use	Row crops	Row crops	Row crops	Row crops	Row crops	Row crops	Row crops	Row crops
Canadian taxonomy	*Gleyed Eluviated Black Chernozem, fine-loamy, mixed, cool, humid*	*Gleyed Eluviated Black Chernozem, fine-loamy, mixed, cool, humid*	*Calcareous Black Chernozem fine-silty, mixed, cool, humid*	*Calcareous Black Chernozem fine-silty, mixed, cool, humid*	*Calcareous Black Chernozem, fine-silty, mixed, cool, humid*	*Orthic Sombric Brunisol, fine-silty, mixed, cool, humid:*	*Calcareous Dark Brown Chernozem fine-silty, mixed, cool, humid*	*Calcareous Black Chernozem, fine-silty, mixed, cool, humid*
US taxonomy	*Fine-loamy, mixed, mesic, superactive Typic Argiudoll*	*Fine-silty, mixed, mesic, superactive Mollic Hapludalf*	*Fine-silty, mixed, mesic, supeactive Aquic Cumulic Hapludoll*	*Fine-silty, mixed, mesic, superactive Aquic, pachic Hapludoll*	*Fine-silty, mixed, mesic superactive Typic Hapludoll*	*Fine-loamy, mixed, mesic, superactive Typic Hapludoll*	*Fine-silty, mixed, mesic superactive Aquic Pachic, Hapludoll*	*Fine-silty, mixed, mesic, superactive Cumulic Hapludoll*
FAO-WRB	*Endogleyic Luvic Phaeozem Anthric*	*Cutanic Endogleyic Luvisol Anthric*	*Endogleyic Chernozem Anthric, Pachic, Siltic*	*Endogleyic Chernozem Anthric, Pachic, Siltic*	*Haplic Phaeozem Anthric, Siltic*	*Haplic Phaeozem Anthric, Siltic*	*Endogleyic Phaeozem Anthric, Pachic, Siltic*	*Haplic Chernozem Anthric, Pachic, Siltic*

[z]2007 pedon data are averaged from two cores.
[y]Grey redox features defined as Munsell color with a value ≥5 and a chroma ≤2.
[x]Red redox features defined as Munsell color with a hue of 10YR or redder, a value ≥4 and a chroma ≥6.
[w]Depth to any redox feature regardless of color.
[v]Percent base saturation by ammonium acetate. If no data were available, we assumed that the percent base saturation was greater than 80%.
[u]Soil pH in 1:1 deionized water suspension.

Table 7. Additional changes in classification specific to Canadian soil taxonomy

Property	Resulting change in classification
Change in surface soil color	Black Chernozem →Dark Brown Chernozem (8) Dark Brown Chernozem →Black Chernozem (6) Dark Gray Chernozem →Black Chernozem (3)
Decrease in base saturation	Black Chernozem →Sombric Brunisol (4)
Decrease in pH	Melanic Brunisol →Sombric Brunisol (1)
Decrease in total C	Gray Brown Luvisol →Gray Luvisol (1)

(#) Number of pedons that changed classification as specified.

were related to thickness of mollic epipedon and depth to redox features (Table 5).

In the FAO-WRB taxonomic system, about half the classification changes at the RSG level were related to a change in the thickness of the mollic horizon (16 pedons), and the other half were related to changes in the depth to secondary carbonates (14 pedons). These changes are likely related to agriculturally accelerated erosion and deposition as well as enhanced microbial respiration associated with tillage and cultivation (Veenstra 2010).

DISCUSSION

On the surface, the three taxonomic systems appear to be very different, but with the soils we sampled, classification was predominately based on thickness of mollic colors, depth to redoximorphic features, depth to carbonates and presence or absence of a clay-enriched B horizon. Each system focuses more heavily on one or two features, specifically, mollic epipedon thickness in the US system, depth to secondary carbonates and mollic horizon thickness in the FAO-WRB, and surface soil color and depth to redoximorphic features in the Canadian system. Despite the fact that each system emphasizes slightly different properties, all of the taxonomies seem to be equally unstable as the soil changes with agricultural land use.

In summary, despite the fact that taxonomic systems are designed to be resilient and unaffected by short-term soil change, over the past 50 yr (a time period historically seen as "short-term" within pedology) agricultural soils in Iowa have changed sufficiently as to result in different classifications at a variety of levels. These changes are likely to be the result of many factors including erosion, tillage, fertilization, tile drainage, and other agricultural practices.

With the extent of these changes and the extent of agricultural land use, this study indicates that existing soil maps increasingly may not represent characteristics of the soil today, nor what conditions will be like in the future. This causes us to conclude that the veracity of soil maps diminishes over time. We advocate the development and implementation of a dynamic soil properties database that includes all properties central to soil classification and land use. Otherwise, scientists, policy makers and the public will likely continue to assume that soil change is a minor issue that only affects one or two properties of any given soil. And ultimately, these changes in soil classification may indicate changes in productivity of the soils as well.

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