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Chernozemic Soils of the Prairie Region of Western Canada

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Summary
Soil distribution in the prairie region is closely linked to climatic and vegetative variations across Western Canada. The dominant soils of the prairie ecosystem are the Chernozemic soils as described in the Canadian System of Soil Classification. Regional variations in climate and vegetation distribution have resulted in the formation of soil zones across the prairies. These zones are named according to the type of Chernozemic soils dominating the particular zone. These include the Brown soil zone, Dark Brown soil zone, Black soil zone and Dark Gray soil zone. In addition to this the Gray soil zone occurs north of the prairie region within the boreal forest where Luvisolic and Brunisolic soils dominate.

The nature and behavior of Chernozemic soils are to a large part determined by the accumulation, decomposition and transformation of soil organic matter within the topsoil (or A horizon). The role of native grassland vegetation and climate play a key role in determining the amount and nature of organic matter retained within the soil. Deposition of plant material belowground in the grassland system has been the primary factor whereby soil organic matter accumulates within Chernozemic soils. Agricultural land management practices that manage soil organic matter properly will provide a means to ensure the long-term sustainability and productivity of Western Canadian Chernozemic soils.

Introduction
In 1938 Professor Joe Ellis of the Department of Soil Science, University of Manitoba penned these words[5],

> *"The living forms, whether of man or beast, or of fish or fowl, that can be supported by any region, all depend for their subsistence primarily upon the plants produced in field and forest, lake and stream, and these in the final analysis are determined by the productivity of the soil and climate."*

These words particularly hold true for the prairie region of Western Canada. The immigration of European settlers to the West and the resulting civilization that we observe has in large part been determined by the distribution of natural resources in this region. Of these resources, it is the soil resource that has played a very significant role in shaping the Western Canada we are familiar with today.

Soils are curious things. The observant eye notices that soils of the southern portion of the prairie region have quite a different appearance than those observed in more northerly regions. When driving along a backcountry road, one can see roughly parallel layers of different colors that seem to appear and disappear in varying patterns as the layers follow along the knolls, side slopes and depressions of the exposed adjacent ditch. The producers who farm the heavy clay gumbo (Vertisolic Order soils) of the Regina Plains or the Red River Valley experience quite different challenges compared to those farming more sandy soils. The diversity of soils and the distribution of the various soil types are a source of wonderment for those connected to the land.

A few questions begin to arise when pondering these things, "What is responsible for this diversity of soils and varying patterns that can be observed throughout the prairie region of Western Canada?" Why is it that some soils are darker than others and why do soils vary in their inherent productivity? Farmers and soil scientists have pondered these questions for generations.

To answer these questions we need to visit with some of the earliest philosopher scientists whose careers and hobbies led them to discover some of the reasons why soils can be so varied in their distribution, properties and behavior.

Factors Controlling Soil Development in the Prairies

Some of the earliest writings explaining why soils are the way they are occurred in 19th century Russia[3]. The author was a geographer named Vasily Vasil'evich Dokuchaev (1846-1903). Dokuchaev is considered to be the first to study the geographic distribution of soils and to formulate reasons why soils were found where they were. He came to the conclusion that soils were determined by more than just the materials from which they formed (i.e. parent materials). Other factors such as climate and topography also influenced soil distribution and behavior as well. Dokuchaev also introduced a rudimentary system of soil classification.

Canadians on the whole generally tend to be rather humble people and are not known for great pronouncements of patriotism or promoting of our own. It is for this reason that very few know of the "groundbreaking" work of a Canadian soil scientist. The understanding of soils of Western Canada, and particularly of Manitoba, was greatly advanced as a result of the work and musings of a professor of Soil Science from the University of Manitoba named Joseph Henry Ellis (1890-1973).

Professor Ellis published a book entitled "The Soils of Manitoba" in 1938 within which he described his understanding of why the soils in Manitoba were so diverse and distributed as they are. Professor Ellis stated[5],

"Soils are natural objects which have developed at the surface of the earth as the result of the action of climate on the geological deposits that are under the influence of organic life. Soils differ from the geological material over which they lie. These differences are shown by the physical and chemical characteristics of the soil which may be enumerated under the headings of color, texture, structure, consistency, intrusions and concretions or products of soil weathering, reaction, etc. The sum of these characteristics determines the soil type (soil group)."

Professor Ellis went on to describe the factors that control the nature and distribution of soils in Manitoba[5](p 14). He listed these factors as:

1. "*The climate, or the temperature and moisture within the soil*";
2. "*The vegetation, which determines the type of organic matter added to the soil*";
3. "*The parent material, or the geological deposits which determine the minerals on which the soil is formed, and in turn affect the texture, the water retention capacity, and the mineral reserve*";
4. "*The position in which the soil is found in relationship to the topography*";
5. "*The presence or absence of ground water within the soil profile*";
6. "*The age or length of time the soil has been under the influence of its environment*"; and
7. "*In the case of cultivated soils – the modifying effects of culture or the work of man.*"

A contemporary of Professor Ellis in the United States, Hans Jenny (1899-1992) of the University of California at Berkeley, published a work in 1941 called "*Factors of Soil Formation: A quantitative system of pedology*"[8]. Professor Jenny identified what he originally called Factors of Soil Formation in 1941 and later referred to as State Factors in 1980[9]. He identified climate, organisms, relief (topography), parent material, and time as the five factors of soil formation that explained the distribution and nature of soils. Both Hans Jenny in the USA and Joe Ellis in Canada had identified similar factors to explain the distribution and nature of soils.

If we consider the distribution and nature of soils within the prairie region of Western Canada in the light of these factors that control soil formation and distribution it is possible to glean some insight on why and where prairie soils are where they are.

Factors Influencing Soil Formation in the Prairie Region

The primary factors that influence the development of soils in the prairie region are climate and vegetation. The other factors (relief or topography, parent material and time) are no less important; however, they tend to influence soil development at a more local scale; whereas, climate and vegetation tend to influence soil development and distribution over a broader regional scale.

Climatic variation across the prairies results in general trends in precipitation and temperature as one proceeds from south to north in the region (Table 1). Generally speaking, there are increasing amounts of precipitation and lower average annual temperatures as one proceeds from Medicine Hat to Slave Lake in Alberta, from Swift Current to Nipawin in Saskatchewan and from Deloraine to Arborg in Manitoba.

Table 1. Climatic data for various locations across the prairie region of Western Canada. [Source: Environment Canada (http:// climate.weatheroffice.ec.gc.ca/climate_normals/)]

	Average Annual Temp (°C)	Total Precipitation (mm)	Degree Days > 5 °C	Degree Days > 15 °C
Alberta				
High Level	-1.3	394	1226	127
Slave Lake	1.6	503	1243	102
Grande Prairie	1.9	447	1338	124
Edmonton	2.4	483	1360	136
Stettler	3	481	1430	168
Oyen	3.8	322	1683	299
Medicine Hat	5.7	334	1963	422
Saskatchewan				
La Ronge	-0.1	484	1323	191
Meadow Lake	0.8	415	1372	169
Nipawin	0.7	439	1474	233
Melfort	1	412	1517	254
Muenster	1.5	414	1520	248
Watrous	2.3	434	1628	290
Swift Current	3.9	349	1697	318
Manitoba				
Thompson	-3.2	517	1059	133
Arborg	1.1	506	1560	292
Bisset	1.3	557	1575	309
Swan River	1.6	530	1575	283
Dauphin	2	508	1628	312
Brandon	1.9	472	1634	308
Deloraine	3.3	478	1826	419

These trends in climatic conditions throughout the prairies have resulted in varying types of natural vegetation. The warmer and drier areas of the prairies, such as those found at Medicine Hat and Swift Current correspond to an area referred to as the Mixed Grassland Ecoregion[4]. Proceeding north from the Mixed Grassland Ecoregion we encounter the Moist Mixed Grassland, Fescue Grassland and Aspen Parkland ecoregions. These ecoregions represent a transition from the semiarid shortgrass prairie in the south to the more subhumid Aspen Parkland ecoregion where grassland begins to meet forest vegetation.

The soil-forming processes largely responsible for the development of soils in the prairie region are strongly correlated with the factors of climate and vegetation. The variation in climate and vegetation type across the prairies has resulted in development of “soil zones” which reflect the effect of precipitation, temperature and dominant vegetation type (i.e. grassland vs. forest) on soil-forming processes and hence on soil properties and types (Figure 1). These soil zones are referred to as the Brown, Dark Brown, Black, Dark Gray and Gray soil zones roughly corresponding to the Mixed Grassland, Moist Mixed Grassland, Fescue Grassland, Aspen Parkland and Boreal Forest ecoregions, respectively.

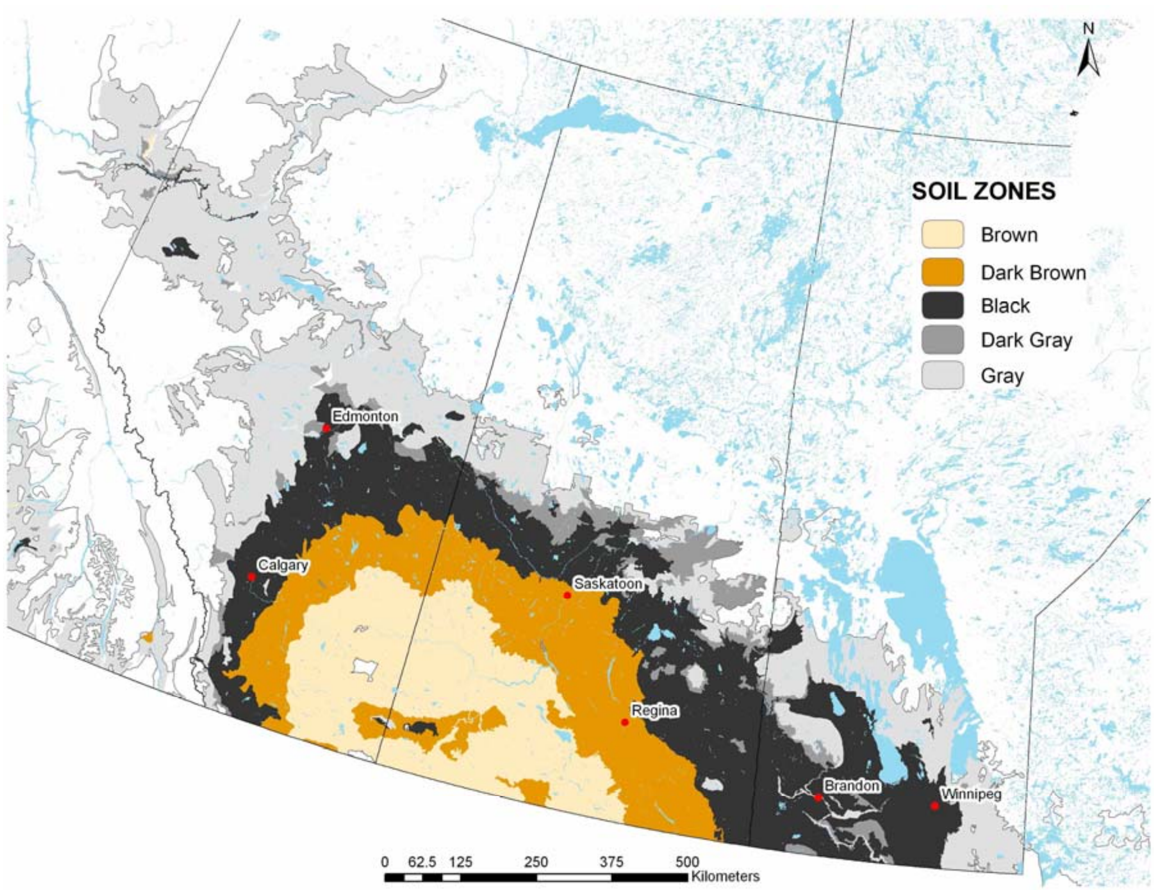

Figure 1. The soil zones of the Prairie Provinces

The soils that dominate the prairie landscape in response to these changes in climatic conditions and vegetation type are referred to as “Chernozemic” soils within the Canadian System of Soil Classification[12]. These soils are defined as “*well to imperfectly drained soils having surface horizons darkened by the accumulation of organic matter from decomposition of xerophytic or mesophytic grasses and forbs representative of grassland communities or of grassland-forest communities with associated shrubs and forbs.*” Chernozemic soils are not water-logged for extended periods of time (i.e. not wetland soils) and have a dark colored surface horizon (i.e. topsoil) resulting from accumulation of organic matter with the root zone of grasslands or grassland-forest transition areas. The importance of organic matter to soil productivity and behavior is well-known[1].

The Chernozemic soils found within the prairie region of Western Canada are examples of “zonal soils”. The Brown, Dark Brown, Black, and Dark Gray soil zones are dominated by Chernozemic soils that have developed under grassland and varying climatic conditions. The Canadian System of Soil Classification recognizes Chernozemic soils at the broadest level of taxonomy, namely, the Order level. The Chernozemic Order is further divided into "Great Groups" that include the Brown Chernozem soils, Dark Brown Chernozem soils, Black Chernozem soils and Dark Gray Chernozem soils (Figure 2).

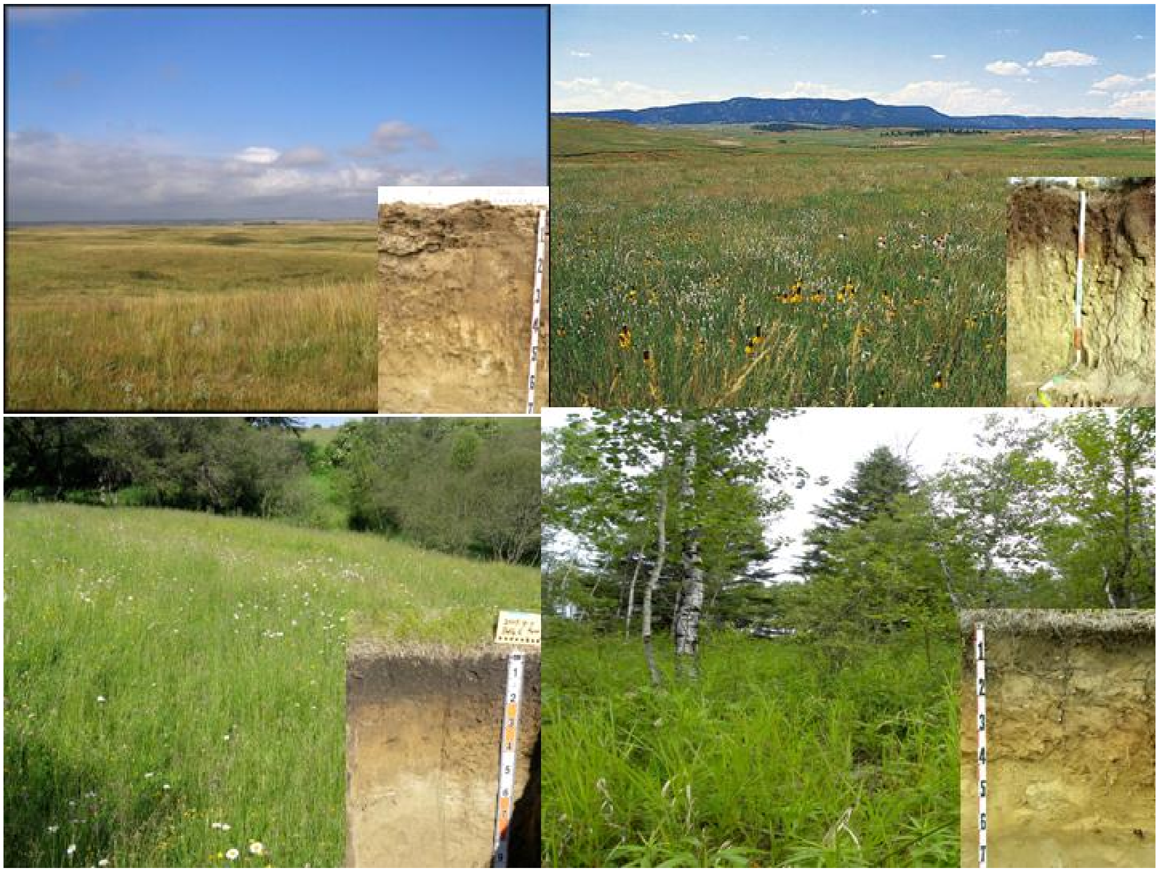

Figure 2 Landscapes with natural vegetation and related soils of (from upper left), the Brown, Dark Brown, Black and Dark Gray soil zones of the Prairies.

The Gray soil zone is not part of the prairie landscape but rather is associated with boreal forest landscapes. The boreal forest lies to the north of the Aspen Parkland ecoregion and is generally more cool and moist. Here forest vegetation dominates and grasslands cannot be found. Chernozemic soils are replaced by Luvisolic and Brunisolic soils.

Chernozemic Order soils are included in the Mollisol Order of the American classification, Soil Taxonomy. The root word used in the name is 'mollis', meaning soft, referring to the friable structure of the organic matter-rich Ah and Ap horizons. Chernozemic soils are mainly in the Cryoll Suborder based on the cold climate in which the soils occur[14].

Soil Forming Processes and Resulting Soil Properties

The factors of soil formation describe the environment within which Chernozemic soils occur; however, they do not speak to the processes responsible for soil development. The factors described above determine the environment within which soil-forming processes act over time to produce the soil we see and work with. Factors are relatively static whereas soil-forming processes can be quite dynamic.

Many different physical, chemical and biological processes continually act to determine the nature and behavior of soils. Some of the processes most responsible for determining the characteristics of Chernozemic soils include organic matter accumulation, decomposition and transformation (or humus formation). The Brown, Dark Brown, Black, and Dark Gray soil zones are dominated by the respective Great Groups of the Chernozemic Order. The color notation is an indication of the effect of climate and vegetation type on the quantity and quality of organic matter that accumulated within the topsoil (i.e. A horizon) prior to removal of the native vegetation and conversion of the soils to agricultural use.

To understand how organic matter accumulated requires an understanding of grassland vegetation. Soil organic matter consists mainly of dead plant matter and its various decomposition and transformation products. Soil organisms are responsible for breaking down fresh plant matter into soil organic matter and ultimately transforming it into humus (a relatively stable form of organic matter residing in soil). The fresh plant material may come from plant parts above ground that are incorporated into the soil by various small organisms such as mites and worms or it may come from deposition of belowground plant matter such as roots and root.

If we evaluate the relative partitioning of plant matter aboveground and belowground in grassland ecosystems we see that about 75 to 80% of the total plant matter in a grassland ecosystem occurs below ground and approximately 80% of the new plant growth occurs belowground each year (Table 2)[2]. The new growth is added to the soil and is subject to further decomposition and transformation processes. The end result is organic matter accumulation below ground within the soil profile. The soils that develop under a grassland system are essentially carbon storage systems that facilitate the retention of organic matter within the soil profile.

An examination of the distribution of this plant matter by depth reveals that approximately 60% of the total belowground plant matter occurs within the first 30 cm depth and as much as 80% occurs within the top 60 cm[2].

If we compare a forested ecosystem to a grassland ecosystem we will see that the partitioning of plant matter in a forest system is quite different. In fact, the proportion of belowground plant matter in a forested system averages around 20-25% of the total plant matter. The vast majority (approximately 80%) of the plant matter occurs aboveground and has a long turnover time. Also, a significant amount of carbon in a forest system sits on top of the soil as leaf litter. Therefore, mineral surface horizons of soils developed under forest conditions tend to be deficient in organic matter. Luvisolic soils and Brunisolic soils of the forested Gray soil zone have a low organic matter content in the mineral surface horizon and hence the gray surface color of these soils when cultivated

Table 2. Distribution of plant matter (biomass) above and below ground at Matador Saskatchewan during 1968 to 1972.

Biomass Compartment	Total Biomass Distribution (g/m^2)	Proportion of Total Biomass (%)	Annual Biomass Increment (g/m^2)	Proportion of Annual Increment (%)
Aboveground Canopy	486	17	143	20
Aboveground Litter	238	8	--	--
Underground	2167	75	555	80
Total	2891	100	698	100

The organic matter content of the surface horizon of native (uncultivated) Chernozemic soils is a function of the productivity of the grassland and the amount of plant matter produced in relation to climate. As one proceeds from the semiarid Brown soil zone to the more subhumid Black soil zone there is a general trend of increasing organic matter content of surface horizons and total organic matter stores[11]. However, organic matter content of the Dark Gray Chernozem soil tends to be lower than that of the Black Chernozem soil due to the influence of forest vegetation on the development of the Dark Gray soil. In the Boreal Forest the Gray Luvisol soils have very little organic matter in their surface mineral horizon.

The Aspen Parkland ecoregion represents a transition zone between the grassland ecosystems to the south and the boreal forest ecosystem to the north. Within this ecoregion we can find Black and Dark Gray Chernozem soils as well as Gray Luvisol soils depending on local conditions and the duration of grassland vs. forest vegetation at a particular site. The question arises as to what happens to Chernozemic soils that undergo a transition from grassland-dominated vegetation to forest-dominated vegetation. This transition from grassland to forest is accompanied by a shift in the relative proportion of plant matter found belowground. In essence, as forest cover increases and shades out grass species there is a shift to less belowground plant matter production. Less input of organic material in the form of grass roots and root exudates results in a decrease in the amount of organic matter found within the surface horizon. This in fact does occur, and is one reason why Dark Gray Chernozem soils occur within the Aspen Parkland and generally show decreased amounts of soil organic matter relative to Black Chernozems, particularly in the lower part of the A horizon[6] and Figure 3.

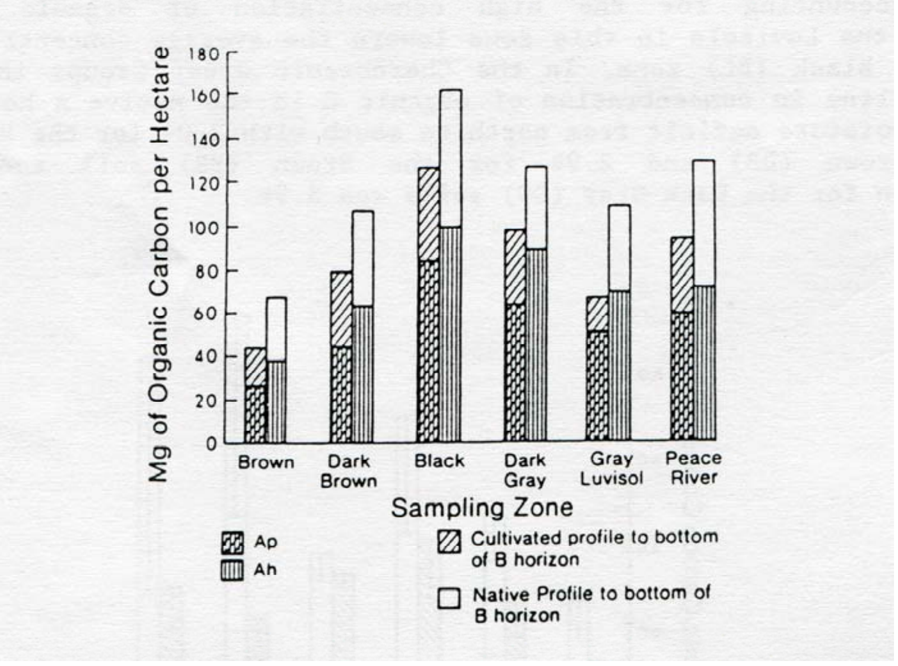

Figure 3 The amount of organic carbon stored in native and cultivated equivalents of Chernozemic and Luvisolic soils in Alberta[11]. The organic matter carbon content of Ah horizons increases from 3.5% for Brown , to 4.5% for Dark Brown and 6.5% for Black Chernozems, then decreasing to 4% for Dark Gray Chernozems[11].

Considerations for Soil Management

So how does all this relate to management and conservation of Chernozemic soils in the prairie region? It is clear that Chernozemic soils developed under a continuous cover of grassy vegetation where annual input of plant material belowground contributed to the buildup of organic matter in the humus-rich surface horizon. These conditions are quite different than the wheat-fallow cropping system that was initially used on the prairies. Decreases in or cessation of continuous inputs of large amounts of belowground plant matter could be expected to have significant effects on the organic matter content of Chernozemic soils brought under cultivation. The macro-organic matter content of soils shows a substantial decline following the conversion of grassland soil to arable agricultural use[7,11]. After approximately five years of cultivation the macro-organic matter concentration decreased to 4 g/kg from an initial value of 11 g/kg under grassland. After 60 and 90 years of cultivation the value continued to decline to approximately 3.2 and 2.7 g/kg, respectively. The conversion of grassland to an annual cropping system results in a rapid decline in soil organic matter followed by a much slower rate of decline. The overall decline can be attributed, at least in part, to a decrease in organic material deposition and transformation processes under a different vegetative regime (i.e. arable cropping) compared to the grassland system. The different rates of soil organic matter decline are believed to be related to the nature of the organic matter and the degree of stabilization within the soil.

A study comparing an annual cereal cropping system and an adjacent grassland system in Saskatchewan showed very large differences in the amount of belowground plant matter between the two systems[11]. The amount of belowground plant matter in the grassland soils ranged from 18,500 to 36,600 kg/ha whereas the soils under spring wheat had 2000 to 2900 kg/ha. The cereal cropping system generally had less than 10% of the belowground plant matter when compared to the native fescue grassland. The decline in soil organic matter under the annual cropping system could be related to the lower amounts of belowground plant matter in that system. It is interesting to note that the amount of belowground plant matter under grassland reported in this study is similar to the values reported at Matador Saskatchewan[2].

Another consideration is the relative partitioning of plant material above and belowground in an annual cropping system. Plant breeders have selected for varieties to produce grain. This has resulted in greater partitioning of plant matter above ground as yields have continued to increase due to plant breeding efforts. The relative partitioning of plant matter in domestic crops is very similar to that found in forested systems, that is, the vast majority (>80%) occurs aboveground. Removal of aboveground plant matter as grain and/or straw removes a substantial amount of carbon from the system.

In addition to these considerations, it is well understood that tillage speeds up the decomposition of soil organic matter and decreases the stability of organic matter in soil. The influence of tillage has been well documented as a factor in decreasing historic soil organic matter levels. The answer to this seems to be a no-till system system; however, the belowground plant matter dilemma still exists under these tillage systems.

So we are left with a situation where the cultivation of Chernozemic soils and conversion of the grassland system to a cereal or oilseed system has significantly altered the amounts of plant matter added belowground and the relative partitioning of plant matter in annual cropping systems has been reversed relative to the conditions under which these soils originally developed. No-till removes the negative effect of tillage-induced organic matter losses and maintains good soil cover to prevent erosion; however, the problem of lower plant matter additions belowground remains.

Concluding Thoughts

The question then becomes, “Is it possible to maintain healthy productive soils having lower organic matter levels compared to the organic matter levels of native Chernozemic soils?” Loveland and Webb ask whether there is there is a critical level or organic matter in temperate agricultural soils, below which substantial decreases in soil physical quality and nutrient cycling processes would occur thereby causing impairment of the soil[10]? The answer to this question is not simple. Management practices that manage for both crop yield and soil organic matter will most likely lead to the long-term sustainability of prairie soils. Such management strives to reduce soil disturbance, maximizes plant matter production through proper nutrient management and incorporates grass-legume forages into the crop rotation to facilitate increased *in situ* deposition of plant matter belowground. While we may never see the same levels of soil organic matter that developed under the influence of thousands of years of continuous grassland, we can manage better the remaining soil organic matter and strive to increase it within the constraints of our agricultural land management practices and production systems.

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