ABSTRACT

South Dakota is an important agricultural state in the United States with annual cash receipts from agricultural products exceeding $9 billion dollars. This production is possible because of large areas of productive soils. This publication describes the general characteristics and qualities of the major soil groups recognized in South Dakota. The soil forming factors are briefly described, soil classification is introduced, and the genesis of typical Udalf and Ustoll soils are discussed. Soil management issues impacting the use of SD soils are considered. Long-term (>70 yrs) cultivation has significantly reduced surface soil organic carbon levels (>30% reduction) when compared to non-cultivated soil. Soil test phosphorus levels significantly increased in cultivated fields due to commercial P fertilization. The major long-term production problems for SD soils are conservation of soil moisture, organic matter and nitrogen losses, fertility management, and wind and water erosion control.

Key words: Soil organic carbon, morphology, geography, fertility, productivity, Udalf, Ustoll, Udolly, Ustalf, Ustert

Ⅰ. Introduction

South Dakota (SD) is an agricultural state with an area of 199,550 km² and a population density of about 4 persons km⁻². Its 2008 cash receipts from agriculture were more than $9.2 billion. About 61% of this total came directly from crops (USDA-ERS, 2010). In 2008 SD ranked nationally 2nd in flaxseed (Linum L.), alfalfa (Medicago sativa L.) hay, and sunflowers (Helianthus L.); 3rd in oats (Avena sativa L.), all wheat [winter and spring] (Triticum aestivum L.); all grass [winter and spring] (Triticum aestivum L.); proso millet (Panicum miliaceum L.); 4th in all hay; 5th in corn (Zea mays L.) and durum wheat (Triticum durum Desf.); 6th in soybeans (Glycine max (L.) Merr.); 9th in grain sorghum (Sorghum bicolor (L.) Moench ssp. bicolor); 10th in grass (wild) hay; 14th in dry edible beans (Phaseolus vulgaris L.); 15th in barley (Hordeum L.); and 17th in total cash receipts from crop production (USDA-NASS, 2010). These crops or their products, along with forage and pasture grown in the state, provide feed for large numbers of livestock. In 2008 South Dakota ranked nationally 1st in bison (Bison bison); 2nd in lambs (Ovis aries) born; 5th in beef (Bos taurus) cows that have calved and all sheep and lambs; 6th in calves born; 7th in cattle on feed; 8th in all cattle and calves; 9th in pigs (Sus vittatus) born; 11th in pigs, 21st in milk production, and 20th in cash receipts from livestock (USDA-NASS, 2010). This production is possible because SD has large areas of productive soils.

This publication describes, in general, the characteristics and qualities of soils recognized in SD. It briefly discusses the genesis, geographic distribution, classification, and management concerns for the state’s soil resources. For specific purposes, such as farm planning, public land acquisition, flood control, and engineering uses, consult large scale county soil association maps, published modern detailed soil surveys, and detailed soils information on the Web Soil Survey (USDA-NRCS, 2010).

Ⅱ. Major Soil Regions

South Dakota is near the center of the great grassland area of mid-North America that once extended between the eastern and western forest regions. Except for the forested Black Hills and scattered cottonwoods (Populus
L.) and shrubs of the alluvial lands, SD was a vast sea of grass for thousands of years before its soils were tilled. This grassland environment and the accompanying subhumid to semiarid climatic environment are the two factors which have exerted the greatest influence on the development of the state's soils. Effects of parent material, relief, and time are also important soil forming factors that will be considered later.

1. Seven Regions

Climate and vegetation have interacted in SD to produce seven major soil regions (see Fig. 1) with more than 550 different soils (Malo, 2003). These regions are named: Cool, Moist Forest (frigid/mesic, Typic Udalfs and Cryalfs); Cool, Very Dry Plain (frigid, Aridic/Typic Ustolls, Ustepts, and Ustorthents); Warm, Very Dry Plain (mesic, Aridic/
Typic Ustolls, Usterts, Ustetps, and Ustorthents); Cool Dry Plain (frigid, Typic Ustolls and Ustorthents); Warm Dry Plain (mesic, Typic Ustolls and Ustorthents); Cool Moist Prairie (frigid, Typic Udolls, Albolls, and Aquolls); and Warm Moist Prairie (mesic, Udic/Typic Ustolls, Usterts, and Aquolls). The Cool Moist Forest Region, the Black Hills, is unique for SD because the soils there have developed under forested conditions in a cool, humid climate. In the other regions soils have developed under grassland in climates ranging from moist subhumid to semiarid. In Fig. 1, arrows indicate the general kind of soil profile which has developed on well-drained positions in each region.

2. Soils Reflect Climate

In SD the lines of equal temperature and the lines of equal precipitation cross roughly at right angles. Relatively speaking, this makes the southeast warm and moist, the northeast cool and moist, the southwest warm and very dry, and the northwest cool and very dry. One way in which the climate of the state is reflected in the soils is in the depth of leaching of carbonates. Fig. 1 shows that the depth of leaching is greater in the more humid east than in the drier west and greater in the warmer south than in the cooler north.

3. Organic Matter Varies

Native grassland vegetation, which was greatly influenced by climate, has determined the amounts of organic matter in the soils. In general, the more humid eastern portion of the state supported tall grass stands that left relatively large amounts of organic matter in the soils. Moving westward, the grass type changed to mid and finally to short grasses in response to the drier climate. This change was reflected in the lower contents of organic matter in the soils developed under drier climates.

Temperature also has played a part in determining the organic matter content of the soils. In the cooler northern part of the state more soil organic matter and total nitrogen (N) were present than in the southern part under comparable precipitation. This is due to slower biological decomposition and chemical activity under cooler temperatures.

Organic matter and total N content of most soils in SD today are substantially lower than when the original prairie sod was plowed. These losses are generally about one-third of the total and apply about equally over the state (Malo, et al., 2005). The approximate amounts of organic matter and total N now present in the hectare-furrow slice of the typical, well-drained soil in each region are given in Table 1.

4. Soil Colors Differ

Differences are apparent in the mineral surface soil color in the various areas of the state. The two variables which give the best measure of surface soil color differences among the soil regions are value and chroma of the moist soil. These data are given in Table 1. Table 1 shows that the darkest soils are in northeast SD. These soils also have the lowest chroma, and highest organic matter levels in the soils. In general, the more humid eastern portion of the state supported tall grass stands that left relatively large amounts of organic matter in the soils. Moving westward, the grass type changed to mid and finally to short grasses in response to the drier climate. This change was reflected in the lower contents of organic matter in the soils developed under drier climates.

Table 1. Selected soil properties for typical well-drained soils in the major soil regions of South Dakota.

<table>
<thead>
<tr>
<th>Soil Region</th>
<th>Organic Matter (Mg ha(^{-1}))</th>
<th>Total N (kg ha(^{-1}))</th>
<th>Munsell Value</th>
<th>Munsell Chroma</th>
<th>Major Soil Taxonomic Groups Present in Soil Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool Very Dry Plain</td>
<td>52</td>
<td>2700</td>
<td>2.5–3.5</td>
<td>2.5–3.5</td>
<td>Frigid Aridic/Typic Ustolls, Usterts, Ustorthents</td>
</tr>
<tr>
<td>Cool Dry Plain West</td>
<td>64</td>
<td>3300</td>
<td>2.0–3.0</td>
<td>1.5–2.5</td>
<td>Frigid, Typic Ustolls and Ustorthents</td>
</tr>
<tr>
<td>Cool Dry Plain East</td>
<td>70</td>
<td>3600</td>
<td>2.0–3.0</td>
<td>1.5–2.0</td>
<td>Frigid, Typic Ustolls and Ustorthents</td>
</tr>
<tr>
<td>Cool Moist Prairie</td>
<td>84</td>
<td>4300</td>
<td>1.5–2.5</td>
<td>1.0–1.5</td>
<td>Frigid, Typic Udolls, Albolls, and Aquolls</td>
</tr>
<tr>
<td>Cool Moist Forest</td>
<td>110</td>
<td>5700</td>
<td>2.0–4.0</td>
<td>1.0–3.0</td>
<td>Frigid/mesic Udalfs and Cryalfs</td>
</tr>
<tr>
<td>Warm Very Dry Plain</td>
<td>46</td>
<td>2400</td>
<td>3.0–4.0</td>
<td>2.5–3.5</td>
<td>Mesic, Aridic/Typic Ustolls, Usterts, Usterts, and Ustorthents</td>
</tr>
<tr>
<td>Warm Dry Plain West</td>
<td>60</td>
<td>3100</td>
<td>2.5–3.5</td>
<td>2.0–3.0</td>
<td>Mesic, Typic Ustolls and Ustorthents</td>
</tr>
<tr>
<td>Warm Dry Plain East</td>
<td>66</td>
<td>3400</td>
<td>2.5–3.5</td>
<td>1.5–2.5</td>
<td>Mesic, Typic Ustolls and Ustorthents</td>
</tr>
<tr>
<td>Warm Moist Prairie</td>
<td>74</td>
<td>3800</td>
<td>2.0–3.0</td>
<td>1.0–2.0</td>
<td>Mesic, Udic/Typic Ustolls, Usterts, and Aquolls</td>
</tr>
</tbody>
</table>

* West = west of the Missouri River, East = east of the Missouri River
* Approximate values from SDSU Soil Testing Lab data summaries, 2002-2008 (Gelderman, 2010, personal communication).
and total N supplies of any grassland region in the state. Fig. 1 indicates that the climate for this region is cool-moist.

The soils of southwest SD have the lightest color (highest value), are browner (highest chroma), and have less organic matter and total N than soils of the other regions. Fig. 1 indicates that the climate here is warm and very dry. Thus, it is that color value correlates well with total amounts of organic matter and N present.

Soil test data (Gelderman, 2010 [personal communication]) show that N release to plants is more a function of temperature than of precipitation. Southern and western soils release N faster than the northern and eastern soils. Data show that in southeastern SD slightly >2% of the total N usually is released annually to plants. In northeastern SD slightly <2% of the total N of the soils is released annually. The amounts of available N, therefore, appear to correlate well with chroma, being greatest for the highest chromas and least for the lowest chromas. This brief outline of the climatic and vegetative environments of the soils of the state shows how these environments gave rise to major soil regions. In each region the typical well-drained soils are characterized by certain colors, depths of leaching of carbonates, and amounts of organic matter and total N.

III. Soil Forming Factors

The kind of soil that develops in any area is the result of interaction of five soil forming factors: climate, vegetation or organisms, parent material, relief (topography), and time.

Climate controls the distribution of vegetation. Together climate and vegetation often are called the active factors of soil formation. This is because on gently undulating topography within a certain climatic and vegetative zone a characteristic or climax soil will develop unless parent material differences are great. Thus the tall and mid grass prairie soils have developed across a variety of parent materials.

The factor of parent material exerts its influence on soils principally by determining their texture and to a great extent their mineralogical composition. In Soil Taxonomy, climate and vegetation tell what order, suborder, and great group a soil is in. Parent material, to a large extent, determines the soil’s family, and series (Soil Survey Staff, 1999, 2010). For example, tall grass prairie soils developed from glacial till are classified in the Vienna series, while tall grass prairie soils developed in thin loess overlying glacial till are classified in the Kranzburg series.

The factor of relief (topography) exerts its greatest influence by determining what drainage a soil will have. Steep slopes have excessively drained, thin soils; flat or depressed topographic areas usually have poorly drained, thick soils. The mature, typical, well-drained grassland soils develop only on undulating relief where climate and vegetation are given full expression.

The factor of time in soil formation can be illustrated by comparing a soil on a flood plain which receives annual increments of alluvium with a soil on a terrace. The former is without developed B horizons although it may have strata of contrasting alluvium, while the latter usually has an ABC horizon sequence.

1. Climate

South Dakota, because of its inland position, has a continental climate with extremes of summer heat, winter cold, and rapid fluctuations of temperature. Temperatures during the winter months often drop to -30°C or lower while in the summer readings of 40°C or more are common in most areas of the state. Cold fronts moving across the state may cause temperatures to drop 20° to 35°C in 24 hours. The warmest recorded temperature in SD was 49°C at Gann Valley on July 5, 1936 while the coldest was -50°C at McIntosh on February 17, 1936 (Todey, 2010). The average annual temperature is 8°C and ranges from 9°C in the south to 5°C in the north and 3°C in the upper elevations of the Black Hills, Cool Moist Forest soil region (Todey, 2010).

Annual precipitation ranges from 66 cm in the southeast to 36 cm in the northwest SD (see Fig. 1). Most precipitation is in spring and early summer. Approximately 75% of the total annual precipitation falls when temperatures are ideal for plant growth (April – September). The fall, winter, and spring moisture falls mostly as frontal precipitation and is the result of condensation as warm moist air from the Gulf of Mexico overrides heavier polar air masses. Much of the summer precipitation comes as short hard showers of the convectional thundershower type. In eastern SD, June normally has the most thunderstorms while in western SD most of them normally come in July.

Seasonal snowfall averages about 75 to 130 cm in the lower elevations of the state to over 255 cm in the Black
Hills. Annual snowfall amounts vary widely. For example, in 1930-31 Canton in Lincoln County, only received 6 cm of snow but in 1961-62 recorded more than 255 cm. The highest annual snowfall recorded outside the Black Hills was 280 cm in 1936-37 at Aberdeen. In the Black Hills annual snowfalls in excess of 410 cm are common and in one 5-day storm in Deadwood in 1998 over 260 cm of snow was received (Todey, 2010; Spuhler, et.al., 1971).

Average depth of frost penetration ranges from about 65 cm in southwestern SD to 130 cm in the northeastern part. Depth of frost depends to a large degree on the amount and timing of snowfalls in relation to winter temperature extremes.

For the area excluding the Black Hills the average last spring frost (0°C) date is about May 5 in the southeast to May 20 in the northwest. Average date for the first fall frost is September 15 in the northwest to October 5 in the southeast. Average length of time without killing frost varies from 120 days along the northern part of the state to 160 days in the southeastern part. The Black Hills area generally has shorter growing seasons than the rest of the state, with average of frost-free days ranging from 90 to 130 days. During cold seasons winds are from the northwest, and are from the southeast during the warm season. Annual average surface wind velocity for the state is 15 to 20 km hr\(^{-1}\). The average number of clear days per year is 120 to 140. Partly cloudy days per year average 100 to 130 and cloudy days average 100 to 120. Normal annual number of hours of sunshine is about 2,850 in the southwest to 2,700 in northeast SD.

The Thornthwaite (1948) climatic classification designations for the climate of SD are as follows: (referring to Fig. 1) Moist subhumid-eastern SD (approximates the Cool Moist Prairie and the Warm Moist Prairie regions); Dry subhumid-central SD (approximates the Cool Dry Plain and the Warm Dry Plain regions); and Semiarid-western SD except for the Black Hills (approximates the Cool, Very Dry Plain and the Warm, Very Dry Plain regions). The Black Hills climate ranges from dry subhumid to humid.

2. Native Vegetation

Except for the Black Hills, which are timbered, and the river valleys where trees and brush grew, the native vegetation of SD was originally grassland (Weaver, 1954; Weaver and Albertson, 1956). Starting with the eastern border of the state and extending to the eastern edge of the James River Valley, the principal association was one of tall grasses (big bluestem (*Andropogon gerardii* Vitman), sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), and switchgrass (*Panicum virgatum* L.) present along with upland and lowland forbs.

Moving westward across the James River Valley, the tall grasses gradually dropped out, being found only on sandy soils and on cool northern exposures, and the medium and short grasses assumed dominance. Important species of the midland area were needleandthread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth), green needlegrass (*Nassella viridula* (Trin.) Barkworth), western wheatgrass (*Pascopyrum smithii* (Ryd.) A. Löve), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shiner), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), prairie junegrass (*Koeleria macrantha* (Ledeb.) Schult.), and buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus).

Moving into western SD, shorter grasses largely replaced mid grass species, because of decreased rain fall. Here we find blue grama, needleandthread, western wheatgrass, prairie junegrass, and little bluestem (*Schizachyrium scoparium* [Michx.] Nash).

Certain variations in this general pattern occur in western SD as a result of extremely sandy or clayey soil texture. For example, on the Pierre plain, an area of clay soils (Kp on Fig. 2), the principal association was one of western wheatgrass, blue grama, and buffalograss. In the sand hills (Psh on Fig. 2) of southwestern SD an important association was little bluestem, prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.), and needleandthread.

3. Parent Material

The kinds of soil parent material in SD are shown in Fig. 2 (Flint, 1955; Rothrock, 1943). As this map illustrates, soils of the state have developed from a large variety of materials. They include ancient crystalline and metamorphic rocks in the central Black Hills, sedimentary rocks including shale, sandstone, and limestone in western SD, and glacial materials of several ages in eastern SD. Additional parent materials include loess, alluvium, and colluvial materials formed from upland deposits.

4. Relief and Physical Divisions

Relief. Relief, as used here, refers to the lay-of-the-land.
West of the Missouri River
Psh – Sand Hills
Oa – Oligocene–Arickaree – sandstone and siltstone
Ow – White River beds – silts and clays
Pflc – Cannonball, Ludlow, Fort Union, undifferentiated
Kh – Hell Creek – sandy shales
Kf – Fox Hills sandstone
Kp – Pierre shale

East of the Missouri River
Qa – Alluvium
Qi – Glacial Lake Basin – silts, clays, sands
Qm – Late Wisconsin glacial drift – loam till
Qc – Late Wisconsin glacial drift – loam till, patchy silts
(Q stagnant ice moraine)
Qt – Early Wisconsin glacial drift – loam till, thin loess
Qi – Early Wisconsin glacial drift – usually thick loess
BH – Black Hills – undifferentiated crystalline, metamorphic,
and sedimentary materials

Fig. 2. Soil parent materials in South Dakota.

It may be level, undulating, rolling, hilly, rough broken,
or mountainous. It may be smooth with a network -of
small streams, or it may be choppy with many closed
basins dotting the landscape. Relief usually varies from
hectare to hectare so it is difficult to show on small-
scale soil association maps. However any particular area
usually is dominated by certain relief characteristics. For
example, most of the Black Hills area is mountainous
while most of the glacial Lake Dakota Plain in Spink
and Brown Counties is level.

Physical Divisions of South Dakota. This section and
the map (Fig. 3) describe natural land forms of South
Dakota as classified by Fenneman (1938) and Rothrock
(1953) and revised by Flint (1955). The most significant
physical boundary is that separating the Central Lowland
from the Missouri Plateau (heavier line on Fig. 3) and is
located in the Cool Dry Plain and the Warm Dry Plain
areas.

The Minnesota River-Red River Lowland (Fig. 3, area
1) is a broad, gently undulating, valley-like area with an
elevation of 275 to 335 m above sea level. Browns Valley,
Minnesota, situated midway between Lake Traverse and
Big Stone Lake, is the “East-West” continental divide
between drainage to the Arctic Ocean and to the Gulf of
Mexico. The northeastern slope of the Coteau des Prairies
rises sharply, nearly 305 m, to form the western limit of
this lowland.

The Coteau des Prairies (area 2) is a highland area be-
tween the Minnesota-Red River Lowland and the James
River Lowland to the west. It slopes gently to the south
and west. Its eastern and western slopes are steep at the
northern end and taper off on the south. Elevations range
from 610 m above sea level on the north to about 485 m
on the south. It is drained to the south by the Big Sioux
River, whose tributary streams enter mainly from the east.
West of the Big Sioux River, the surface of the Coteau
is dotted with lakes, while very few lakes occur east of
the river.

The James River Lowland is a gently undulating plain
lying considerably lower than the Coteau des Prairies on
the east and the Coteau du Missouri on the west. The James River drains through the area from north to south (with a gradient of <10 cm km\(^{-1}\)) and occupies a rather narrow steep sided valley. Elevations range from 395 to 425 m above sea level.

The Lake Dakota Plain (area 4) is the nearly level surface formed by deposition of sediment when glacial Lake Dakota was ponded with water. The area is sandy at the northern end and silty clay loam and silty clay texture elsewhere.

The James River Highlands (area 5) consist of a group of three ridges located at the southern end of the James River Lowland. They are remnants of former stream divides. Below the mantle of glacial drift is bedrock consisting of the Niobrara chalk, overlain in places by the Sharon Springs member of the Pierre shale (Flint, 1955).

The Coteau du Missouri (area 6) is part of the Missouri Plateau of the Great Plains province, separated from the main body of the Missouri Plateau by the Missouri River. This highland area is covered with glacial deposits and underlain by Pierre shale and older formations. Several broad shallow sags traverse the coteau, which mark positions of former stream valleys of eastern continuations of the Grand, Moreau, Cheyenne, Bad, and White Rivers (Flint, 1955, Plate 7).

The Missouri River Trench (area 7) averages a little over 2 km in width with the valley floor 90 to 180 m below the tops of the steep dissected bluffs. The Missouri River flows south-southeast with a gradient of about 20 cm km\(^{-1}\). Erosion and deposition are believed to be in equilibrium. As early travelers to the region reported the water to be turbid, rapid erosion apparently was in progress before the advent of agriculture, although cultivation in the tributary region certainly has added to the sediment load (Westin and Malo, 1975).

The Northern Plateaus (area 8) is a series of plateaus and isolated buttes underlain by the Fox Hills sandstone and younger Cretaceous strata. They range in elevation from 610 to 910 m above sea level.

The Pierre Hills (area 9) consist of a series of smooth hills and ridges with rounded tops. The region is underlain by the Pierre shale formation and has lower elevations (550 to 850 m) than the plateau country which rims it to the north and south.
The Black Hills (area 10) is a region of mountainous terrain consisting of a series of upturned sedimentary strata, called hogbacks, arranged concentrically around a core of ancient crystalline and metamorphic rocks. Elevations range from 975 to >2130 m).

The Southern Plateaus (area 11) are divided into two regions. The large area to the southwest consists of a series of benches and buttes, underlain by Tertiary sandstones, siltstones, and shale. Elevations range from 850 to 1095 m. The Badlands comprise the northwestern part. The second area occurs in southeastern SD. This is a stream dissected highland underlain by a thick mantle of loess. Elevations range from 365 to 455 m (1,200 to 1,500 feet).

The Sand Hills (area 12) is an extension of the Sand Hills region of Nebraska. It consists of a series of rounded hills interspersed with low, swampy areas, the whole region being underlain by eolian sand. Elevations range from 910 to 1095 m.

5. Time

Time is important in the formation of a soil. If the materials are easily eroded by wind and water, as in the case of the Pierre shale, the soil of steep slopes is destroyed almost as fast as it is formed. On undulating topography, soil formation on these materials and erosion go on at about the same pace. On flat slopes, due to the grass root mat which retards destructive processes, deeper soils develop which are relatively older from the standpoint of soil formation, than are the undulating and rolling soils. Thus, the time factor is relative and varies across materials of the same geologic age.

IV. Regional Distribution of South Dakota Soils

The typical, well-drained soils of South Dakota reflect the subhumid and semiarid climates and the original tall, mid, and short grass or forest vegetation of the state (see Table 2). Most soils in the state are well-drained, they have the same general sequence of horizons, and they generally are uniform over relatively large geographic areas.

Also, within each major soil subgroup region are other soils which lack B horizons and are not well-drained.

<table>
<thead>
<tr>
<th>Soil Region</th>
<th>Climate</th>
<th>Native Vegetation</th>
<th>Typical Profile</th>
<th>Parent Materials</th>
<th>Topography</th>
<th>Soil depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool Very Dry Plain</td>
<td>Cool, semi-arid</td>
<td>Short and mid grasses</td>
<td>A, Bt (w), Bk, BC (k), C</td>
<td>Sandstones, shale, siltstones</td>
<td>Undulating to strongly sloping with buttes and mesas</td>
<td>Very shallow to very deep</td>
</tr>
<tr>
<td>Cool Dry Plain West</td>
<td>Cool, dry</td>
<td>Mid and short grasses</td>
<td>A (p), Bt (w), Bk, BC (k or z), C</td>
<td>Shales, sandstones, and siltstones</td>
<td>Gently undulating to rolling with buttes and mesas</td>
<td>Shallow to very deep</td>
</tr>
<tr>
<td>Cool Dry Plain East</td>
<td>Cool, dry</td>
<td>Mid and short grasses</td>
<td>A (p), Bw (t), Bk, BC (k or z), C</td>
<td>Loess and glacial drift</td>
<td>Gently undulating to undulating</td>
<td>Shallow to very deep</td>
</tr>
<tr>
<td>Cool Moist Prairie</td>
<td>Cool, humid/subhumid</td>
<td>Tall grasses</td>
<td>Ap, Bw (t), Bk, BC (k), C</td>
<td>Glaciolacustrine, glacial drift</td>
<td>Nearly level to rolling</td>
<td>Deep to very deep</td>
</tr>
<tr>
<td>Cool Moist Prairie</td>
<td>Cool, humid/subhumid</td>
<td>Pine and spruce</td>
<td>Oi, A, E, B/E (BE), Bt, BC, C</td>
<td>Granite, schist, slate, limestone, shale, sandstone</td>
<td>Gently sloping to very steep, mountain peaks, steep side slopes, and broad ridges/valleys</td>
<td>Very shallow to very deep</td>
</tr>
<tr>
<td>Warm Very Warm Dry</td>
<td>Warm, semi-arid</td>
<td>Short and mid grasses</td>
<td>A (p), Bt (w), Bk (z), BC (k), C</td>
<td>Shales, siltstones, sandstones</td>
<td>Gently undulating to rolling in Very shallow shales; undulating to strongly to very deep sloping in buttes and plateaus in siltstone and sandstones</td>
<td></td>
</tr>
<tr>
<td>Warm Dry Plain West</td>
<td>Warm, dry</td>
<td>Mid and short grasses</td>
<td>A (p), Bt (w), Bk (z), BC, C</td>
<td>Sandsin, siltstones, shales</td>
<td>Gently undulating to rolling</td>
<td>Very shallow to very deep</td>
</tr>
<tr>
<td>Warm Dry Plain East</td>
<td>Warm, dry</td>
<td>Mid and short grasses</td>
<td>Ap (A), Bw (t), Bk (z), BC, C</td>
<td>Loess, glacial drift, alluvium</td>
<td>Nearly level to strongly undulating; steep and hilly near Missouri River</td>
<td>Shallow to very deep</td>
</tr>
<tr>
<td>Warm Moist Prairie</td>
<td>Warm, moist</td>
<td>Tall grasses</td>
<td>Ap, Bw (t), BC (Bk), C</td>
<td>Loess, glacial drift, alluvium</td>
<td>Nearly level to rolling</td>
<td>Deep to very deep</td>
</tr>
</tbody>
</table>

* Letters in parentheses are alternative horizon options.
These include the thin soils formed on steep slopes, sandy parent material, or unstable alluvium; the high lime soils; soils influenced by high sodium contents; soils formed in highly calcareous parent material, and poorly drained soils. The distribution of the major soil subgroups is shown in Fig. 1.

1. Cool, Moist Forest (frigid/mesic, Typic Udalfs and Cryalfs)

Typical well drained soil profile horizons usually present include Oi, A, E, BE(B/E), Bt, BC, and C. The Oi horizon is organic in nature and thin (≤ 5-10 cm thick). The Oi horizon is composed of fresh-forest litter, partially decayed but still distinguishable as to origin, and well decayed litter which is undistinguishable as to origin. The A horizon is a mineral horizon and is thin (<7 cm) or absent. The E horizon is gray (10YR 6/2 dry, 10YR 4/2 moist), weak medium platy in structure, and ranges in thickness from 5-50 cm.

Between the E and Bt horizons is a transitional horizon, BE or B/E, about 10 cm thick, which has weak medium prismatic structure. Each prism is coated with gray material from the E horizon but is brown, like the Bt horizon, beneath the gray coating. The Bt horizon is brown (7.5 YR 5/6 dry, 7.5 YR 4/6 moist) and has coarse prismatic structure parting to medium subangular blocky structure. Most of the blocks are of moderate grade and all are coated with thick shiny clay films on all surfaces. This horizon is 25-75 cm thick.

Sometimes a BC horizon is present in which the structure grade is weak. This horizon is a transitional horizon between the Bt and the C horizons. It gradually grades into the parent material. Although the reaction of the profile is acidic, base saturation is over 50%. Where the parent material is calcareous, free carbonates may occur in the BC horizon.

2. Cool Very Dry Plain (frigid, Aridic/Typic Ustolls, Ustepts, and Ustorthents)

Typical well drained soil profile horizons usually present include A, Bt (w), Bk, BCk, and C. The Ap(A) horizons usually are 10-20 cm thick. The plow layer, Ap, usually does involve the upper part of the B horizons. The A horizons are brown (10YR 5/2 dry, 10YR 4/2 moist) and have weak medium prismatic structure. Although annual precipitation for this region and the Cool, Very Dry Plain are the same, it is less effective in this region due to higher annual temperatures. Consequently, soils have supported shorter stands of grasses that have left smaller residues of organic matter. This, coupled with the higher annual temperatures which increase organic matter oxidation, results in the low soil organic matter contents in the soils of the Warm, Very Dry Plain Region (Table 1).

The Bt (w) horizon is pale brown (10YR 6/3 dry, 10YR 5/3 moist) with medium prismatic structure. The thickness of this horizon ranges from 20-60 cm. Some of the structural units may be covered with thin to moderate clay skins and organic coatings.

Beneath the Bt (w) is a Bk horizon that is about 10-40 cm thick and has weak medium subangular blocky or weak medium prismatic structure. The BK horizon is pale...
brown (10YR 6/3 dry; 10YR 5/3 moist) and contains free carbonates in disseminated and soft concretionary form. The CaCO₃ equivalent usually exceeds 15%, and these horizons have at least 5% more CaCO₃ equivalent than the underlying C horizons. Where the parent materials are saline, salts occur in these horizons in concentrations of 0.25% or higher and are designated by the “z” symbol. The BCₖ horizon has massive structure, resembles the Bk in carbonate content and the C horizon in terms of structure and color, gray (7.5YR 7/2 dry; 7.5YR 6/2 moist).

4. Cool Dry Plain (frigid, Typic Ustolls and Ustorthents)

Soils in this subregion have developed in a more humid environment when compared to the Cool, Very Dry Plain subgroup. This increase in annual precipitation from the west edge of the Cool Dry Plain to the east edge of the region causes increases in surface organic matter contents, darker color values, and lower chromas of surface horizons; the tendency of soils to develop color B horizons (increase in color chroma in going from A to Bw horizons); thicker A or Ap (surface) horizons; larger and less strongly developed prismatic structure; and deeper leaching of carbonates. Precipitation increase also results in development of a salic (z) horizon below the calcic (k) horizon where parent materials are saline.

Typical, well drained soil profile horizons usually present include A (p), Bw (t), Bk, BCₖ (z), and C. The A or Ap horizons are dark brown (10YR 4/2 dry, 10YR 3/2 moist), and have weak medium granular structure. The A horizons are usually 15-25 cm thick and the plow layer does not normally involve the B horizon. The granular structure of the A horizons reflects the high base saturation of these soils and the flocculated condition of the clays.

The Bw horizon is brown (10YR 5/3 dry, 10YR 4/3 moist) with weak to moderately developed coarse prismatic structure. The thickness of this horizon ranges from 15-50 cm. Some of the prisms may have a thin clay film coating. The B horizons often do contain more clay than A horizons however not enough to warrant the use of the “t” symbol in most profiles. Soil profiles west of the Missouri River are more likely to have the “t” associated with the B horizon.

Beneath the Bw horizon is a zone of lime accumulation (Bk) about 15-40 cm thick, which has weak coarse prismatic structure. These horizons contain free carbonates in disseminated and soft concretionary form. The CaCO₃ equivalent usually exceeds 15% and have at least 5% more CaCO₃ equivalent than the underlying massive C horizons. The Bk horizon is grayish brown (2.5Y 5/2 dry, 2.5Y 4/2 moist).

BCₖ (z) horizons have massive or very weak coarse prismatic structure and often are saline; in all other respects they resemble the Bk horizons. The saline layer is found deeper in soils of this subgroup when compared to soils of the Cool, Very Dry Plain.

5. Warm Dry Plain (mesic, Typic Ustolls and Ustorthents)

Soils of this region differ from those of adjoining subgroups as follows: (1) from those to the west by being darker and less brown, have higher organic matter contents, thicker A horizons, deeper leaching of carbonates, larger and less strongly developed prismatic structure in the B horizons and thicker soil profiles; (2) from those to the north by being browner and lighter, having lower organic matter contents, thinner A horizons, less leaching of carbonates, having medium sized moderately developed prismatic structure in the B horizons, and shallower horizons of salt accumulation; (3) from those to the northeast and southeast by being browner and lighter, having lower contents of organic matter and total N in the surface horizons, shallower horizons of calcium carbonate and salt accumulation, having lesser tendency for chroma to increase with depth, and greater tendency for clay to accumulate in the Bt horizons. In the southern part of this subgroup, near the mouth of the James River the substrata are usually saline while in other areas it is usually nonsaline unless affected by a high water table.

Typical, well-drained soils of this subgroup normally have the following soil profile horizons: Ap (A), Bw (t), Bk (z), BC, and C. The Ap (eastern part of the region) or the A (western part of the region) horizons are dark gray (10YR 4/1 dry, 10YR 2/1 moist), and have weak medium granular to weak medium subangular blocky structure. The A horizons are usually 15-30 cm thick and the plow layer does not normally involve the B horizon unless moderate to severe erosion has occurred. The granular structure of the A horizons reflects the high base saturation of these soils and the flocculated condition of the clays. There are no free carbonates and the soil reaction ranges from 6 to 7.
The Bw (t) horizon averages 15-40 cm in thickness. Moist color values average 3 to 4, while moist chromas average 2. Structure is compound with moderate medium prisms breaking to moderate medium subangular blocks. Clay films, when present, are usually thin and continuous on all sides of the structural peds. Some of the B horizons in the typical well-drained soils of this subgroup have a considerable clay increase in the B horizon so the “t” symbol is used. Moist consistence is friable and the horizon is free of carbonates.

The Bk (z) horizon ranges from 15-40 cm in thickness and has a CaCO$_3$ equivalent of 15% to 20%. It usually has at least 5% more CaCO$_3$ than the underlying C horizon. The carbonates are in disseminated or soft concretionary form. The primary structure consists of weak coarse prisms and weak medium subangular blocks. In places where the parent material is saline this horizon usually contains soluble salts in excess of 0.25%. The Bk (z) horizon is light brownish gray (2.5Y 6/3 dry, 2.5Y 5/3 moist).

BCk (z) horizons have massive or very weak coarse prismatic structure and can be saline; in all other respects they resemble the Bk horizons. The saline layer is found deeper in soils of this subgroup when compared to soils of the Warm, Very Dry Plain.

6. Cool Moist Prairie (frigid, Typic Udolls, Albolls, and Aquolls)

Soils of this subgroup (see Fig. 1) have black surface horizons (moist Munsell value and chroma are 2/1 or darker). This surface soil color is one of the characteristics setting apart the typical, well-drained soils of this region from the typical, well-drained soils of the surrounding regions. To the west, southwest, and southeast the typical, well-drained soils are lighter in value and browner in chroma.

The relatively cool moist climate of this region has provided an environment which favors the accumulation of organic matter and retards its destruction. The Udic/Typic Ustolls soils of the Warm, Moist Prairie to the southeast have an environment favorable for organic matter accumulation. However, the warmer temperatures of this region favor a faster rate of organic matter destruction than prevails in the northern Cool, Moist Prairie. Soil regions to the west have drier environments and do not favor as fast an accumulation of organic matter although they have about the same temperatures and rate of destruction is about the same as for the Cool, Moist Prairie.

In addition to the color differences, the typical, well-drained soils of the Cool Moist Prairie area are differentiated from adjacent regions which adjoin on the west and the Typic Ustolls of the Warm, Dry Plain which adjoin them on the south by having (1) deeper-lying horizons of carbonate accumulation, (2) deeper-lying horizons of salt accumulation, and (3) higher contents of organic matter and total N in the surface horizons.

From the typical, well-drained soils of the Warm, Moist Prairie which adjoins it on the southeast these soils differ by having (1) shallower-lying horizons of carbonate accumulation, (2) higher contents of organic matter and total N in the surface horizons, (3) thinner B horizons, (4) less tendency for clay to accumulate in the B horizons, and (5) greater tendency for chroma to increase with depth.

Typical, well-drained soils of the Cool, Moist Prairie usually have the following horizons: Ap, Bw, Bk, BCk, and C. Plowing is usually entirely within the Ap horizon. This surface horizon is about 15-20 cm thick and is black (moist value and chroma 2/1). Consistence is friable and the structure is granular, reflecting the high base saturation and the flocculated clays. There are no free carbonates and reaction ranges from 6 to 7.

The Bw horizon averages 20-40 cm in thickness. Moist color values average 3.5 while moist chromas average 2. Structure is compound with moderate coarse and medium prisms breaking to moderate medium blocks. On medium and fine textured soils, clay films (where present) are thin and moderately patchy on all sides of the prisms and blocks. Moist consistence is friable. Free carbonates are not present. The Bw horizon grades smoothly into the Bk horizon.

The Bk horizon is usually 20 cm or more in thickness. Structure is compound with weak medium prisms breaking to weak or moderate blocks. Moist consistence is friable. Carbonates are in disseminated form and in soft concretions. The CaCO$_3$ equivalent usually approaches a maximum of about 20%. The BCk horizon is similar to the Bk except for structure.

7. Warm Moist Prairie (mesic, Udic/Typic Ustolls, Ustepts, and Aquolls)

The environment under which the soils of this region
have developed is relatively warm and moist. The relatively high humidity and rainfall have resulted in the vigorous growth of tall grasses which in turn has resulted in the accumulation of large amounts of organic matter. Relatively high temperatures have encouraged considerable biologic and chemical activity so organic matter destruction is fairly high. This results in a high rate of N release. The colors of the surface soils reflect this environment. They are less dark and browner than the surface colors of the soils of the cooler northeast area but darker and less brown than the surface colors of the soils of the area to the west. Moreover, the depth of leaching of carbonates for the typical, well-drained soils in this region is greater than for the typical, well drained soils of any of the adjacent subgroups.

Other soil characteristics attest to the conclusion that the soils of this subgroup are transitional to the Udolls or tall grass prairie soils. In some of the permeable loess-derived soils the horizon of carbonate enrichment lies below a leached C horizon at depths of 100 to 125 cm from the surface. This indicates a substantial increase in depth of leaching over that in the typical, well-drained soils of adjoining regions.

Carbonates in the soils of this region may occur as large, hard, knotty concretions. Carbonates rarely are found in this form in the soils of the adjoining regions. There is an increase in chroma in going from A to B horizons of about one Munsell unit in the typical, well-drained soils of this region. In the typical, well drained soils of the adjoining northeast area, chroma usually increases one-half a unit or more in going from the A to the B horizon.

Typical, well-drained soils of the Warm, Moist Prairie usually have the following horizons: Ap, Bw(t), BC(Bk), C. The Ap horizon is about 15-20 cm thick and very dark grayish brown (moist value/chroma = 2.5/1.5 to 3/2). The soil is friable and granular in structure. Base saturation is about 80-90%. Occasionally a part of the upper B horizon has been incorporated into the plow layer.

The Bw (Bt) horizon is thick, averaging about 40-60 cm and is usually dark grayish brown (moist value/chroma = 3/2). The structure is moderately developed medium prismatic which breaks to moderately developed blocky. Thin continuous and moderate patchy clay films coat all structural surfaces in Bt horizons. No carbonates are present in the Bw (Bt).

The Bk horizon is about 30 cm thick and dark grayish brown to olive brown (moist value/chroma = 4/3). The structural aggregates are weak medium prisms having thin patchy clay films on the vertical surfaces. Carbonates occur in disseminated form and as hard and soft concretions. The CaCO₃ equivalent usually exceeds 15% and is more than 5% higher than the CaCO₃ of the underlying C horizon. The C horizon usually extends to 150+ cm and resembles the BC (Bk) horizon except for massive structure and lower lime contents.

8. Other Soils Found in Major Soil Regions

Within each major soil region are other soils which are not mature and well-drained. These include the thin soils formed on steep slopes, sandy or unconsolidated parent material, bedrock, or alluvium; the high lime soils; soils influenced by high salt and/or sodium contents; soils formed in calcareous bedrock; and poorly drained soils.

Thin soils formed on bedrock (Lithic subgroups). Thin soils in this group have bedrock near the surface (within 45 cm), occur on steep slopes, and lack B horizons. In this environment, runoff is excessive so that little water has entered the profile to leach it and cause profile development, or to support the vegetative growth necessary to have produced much humus. Erosion keeps A horizons thin and total soil profiles shallow. Although less sensitive to their environments than the typical, well drained soils, these thin soils also reflect the climatic and vegetative environments of the soil subgroup areas and change with them as do the typical, well-drained soils.

Thin soils formed in unconsolidated parent material (Entic subgroups, Orthents, and Psamments). These thin soils occur on steep slopes of unconsolidated parent material such as glacial till, glacial outwash, or sand, and lack B horizons. In this environment runoff is excessive so that little water has the opportunity to cause profile development, to leach the soil profile, or to support the vegetative growth necessary to produce a large amount of organic matter. Erosional activity causes the A horizons of these soils to be thin and the total soil profile to be thin and consist only of A and C horizons. Although less sensitive to their environments than the typical, well-drained soils, these thin soils nevertheless reflect the climatic and vegetative environments of the soil subgroup areas and change with them as do the typical, well-drained soils.

Thin alluvial soils (Fluvents and Fluventic subgroups). Alluvial soils are young soils of flood plains which lack
B horizons. Most of the soils developed from alluvium in South Dakota have B horizons and therefore are classified in the appropriate subgroups discussed earlier. Ordinarily, only the soils which receive increments of fresh alluvium every year or so are classed as alluvial soils.

High lime soils, (Calciaquolls). This group of soils is set apart because of the presence of a strong carbonate horizon (Bk or Bkg) immediately below the A horizon. The CaCO₃ equivalent usually exceeds 15-20% for the horizon (Bk or Bkg) immediately below the A horizon. The cause of the strong concentration of carbonates appears to be related to a parent material high in carbonates (e.g., the area around the rims of prairie potholes in the glaciated areas of eastern South Dakota). These soils are most extensive in the Cool Moist Prairie region, especially around the northern end of the Coteau des Prairies and in the northeast corner of the state.

Saline or salt affected soils. Salts present in these soils are chlorides and sulfates of sodium, potassium, magnesium, and calcium. Soils having high concentrations of CaCO₃ have been considered earlier under the high lime soils discussion. These salty soils develop in environments where drainage is poor and where excess salts are present. The salts are usually brought in by seepage, runoff, streams, or artesian water. High rates of evaporation and slow runoff or permeability result in the development of salt concentrations in excess of 0.25%. Although the salts keep the surface soil in good physical condition, their concentration usually is too great for the growth of economic plants.

Sodium-influenced claypan soils (Natric great groups and subgroups). These soils appear to develop under drainage conditions that consist of alternate wetting and drying. Possibly freezing and thawing is a part of this environment. At any rate, the salts are removed and sodium ions are adsorbed on the soil colloids. When the sodium ions reach a concentration of about 12% or higher of the CEC the clay particles become deflocculated, resulting in a jellylike, strongly alkaline, impermeable Bt horizon which is also called a natric horizon. When the Bt horizon dries, the soil shrinks, hardens, and cracks, forming a columnar structure. Usually, the tops of the columns are rounded. This is indicative of the first step that soils go through when sodium becomes a problem.

It appears that while the deflocculation of the clay is taking place an E horizon develops simultaneously over the dispersed Btn horizon. Evidence indicates that at least the initial stages of the development of this gray horizon may simply be the result of removal of iron and manganese coatings from the soil grains, thus bleaching them by alternate oxidizing and reducing conditions brought about by the alternate wet-dry environment over an impermeable B horizon.

Soils in this category range all the way from those having only a sprinkle of gray dust on the column tops to those having a gray horizon several cm thick. Sodium usually makes up at least 12% of the exchangeable cations of the natric Btn horizons of the immaturely developed or thin surface of these sodium-affected claypan soils. There is usually twice as much exchangeable magnesium as exchangeable calcium in the natric B horizons. As the gray horizon thickens and the soil becomes more mature, nearly all of the exchangeable sodium is lost, although the exchangeable magnesium concentrations remain about twice the exchangeable calcium concentration. As the gray horizon thickens, apparently by hydrolysis of the clay minerals, at the expense of the B horizon until only a vestige of the latter remains. This final step represents the Argialbolls.

Salts of course, are absent in the A, E, and Bt horizons of these soils. Moreover, in the Bt horizon, exchangeable sodium percentages are very low and calcium has replaced magnesium as the dominant exchangeable cation.

Sodium-influenced claypan soils may occur throughout the state on flats and in closed basins or depressions. They are more extensive in the James Valley and west than they are on the Coteau des Prairies.

Poorly drained soils (Argiaquolls, Haplaquolls, Fluvaquents and Calciaquolls). These soils occur in poorly drained depressions that dot the landscape east of the Missouri River. Rarely are they found west of these areas. Depressional soils west of the Missouri River usually are salt or sodium affected.

These poorly drained soils usually are free of soluble salts but not of carbonates. Rank vegetation induced by their wet environment has contributed much organic matter to their surface horizons. Poor aeration limits the activity of microorganisms which normally decompose vegetative residues. Hence, these soils have thick surface horizons high in humus. The lower horizons of these soils have reddish-gray redox features caused by the alternate oxidizing and reducing conditions (Bg horizons).

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Soils formed in calcareous bedrock (Calcic great groups). These soils occur on nearly level to steep upland. They are formed in residuum derived from soft chalky siltstone mainly of the Niobrara formation. They have large amounts of CaCO$_3$ within 25-40 cm of the soil surface. Bedrock is usually encountered within a depth of 90 cm. Components of the bedrock determine to a large degree the chemical and physical properties of these soils. Because of abundance of CaCO$_3$ in the parent material and rather steep slopes, these soils usually do not have a B horizon. The common horizonation for these soils would be A, AC, C, and R.

V. Genesis and Properties of South Dakota Soils

Soils that form under grass vegetation have unique soil properties and characteristics when compared to soils developed under forest vegetation even with similar parent materials.

1. Forest Soil Properties

Forest derived soils (e.g. Citadel soil, fine, smectitic, frigid Typic Hapludalfs) tend to have a thin, high organic matter A horizons (ochric surface) with good structure. Eluviation is the dominant soil process in the platy E horizon (albic) which underlies the A horizon in most forest derived soils (Figs 1 and 4). Evidence of illuviation is seen in the clay enriched Bt horizon and the strong structure developed in the Bt horizons when compared to the A and E horizons (Table 3). The properties of the parent material (e.g. residuum) can be seen in the C horizon that is found at the base of the profile.

2. Prairie Soil Properties

Prairie derived soils (e.g. Houdek soil, fine-loamy, mixed, superactive, mesic Typic Argiustoll) have thick, dark colored, moderately high organic carbon (C) containing A horizons (mollic surface). The dark colored A horizon slowly changes into a B horizon in most prairie derived soils (Figs. 1 and 5). The Houdek B horizon has developed structure and evidence of clay illuviation (Bt horizon). Clay illuviation is much less than that found in the forested soil. Base saturation and soil pH are higher in all layers of the grassland soil. Darker soil colors and organic C levels remain high to a much greater depth than in the forest-derived soil. Organic C levels in the surface horizon of grassland soils are usually not as high as those found in forested conditions. At the soil profile base, the parent material (e.g. glacial till in Houdek), the C horizon is found. The evidence of less intense weathering (higher base saturations, eluviation [less clay migration] and less leaching [higher soil pH values]) is evident in the lab data of the grassland soil when compared to the forest soil (Table 3).

SD grassland soils have:

1. Thick, dark colored, mineral, surface horizon or layer that is humus rich (e.g. 1 to 4% organic C). This is the key property that all grassland soils possess. The thickness of the surface horizon/layer is influenced by the parent material and the extent of profile development.
Table 3. Comparison of selected soil properties of forest (Citadel) and prairie (Houdek) soils in SD (USDA-NRCS National Cooperative Soil Survey, 2010; Westin, 1954).

<table>
<thead>
<tr>
<th>Soil Horizon</th>
<th>Depth (cm)</th>
<th>Clay (g kg⁻¹)</th>
<th>CEC (cmolc kg⁻¹)</th>
<th>pH (1:1)</th>
<th>Organic C (g kg⁻¹)</th>
<th>% Base Saturation</th>
<th>CaCO₃ (g kg⁻¹)</th>
<th>Moist Color</th>
<th>Structure Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citadel (forest derived – fine, smectitic, frigid Typic Hapludalf)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Oi 0-4</td>
<td>Slightly decomposed pine forest litter</td>
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<td></td>
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<tr>
<td>A 4-7</td>
<td>108</td>
<td>30.8</td>
<td>5.8</td>
<td>5.1</td>
<td>81</td>
<td>0</td>
<td>10YR 2/1</td>
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<td>E 7-28</td>
<td>90</td>
<td>6.6</td>
<td>5.2</td>
<td>0.3</td>
<td>70</td>
<td>0</td>
<td>10YR 5/3</td>
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<tr>
<td>Bt1 28-57</td>
<td>382</td>
<td>24.0</td>
<td>6.0</td>
<td>0.3</td>
<td>93</td>
<td>0</td>
<td>7.5YR 4/3</td>
<td>Angular blocky</td>
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<tr>
<td>Bt2 57-76</td>
<td>432</td>
<td>28.6</td>
<td>6.9</td>
<td>0.3</td>
<td>98</td>
<td>0</td>
<td>10YR 4/3</td>
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<tr>
<td>Btk 76-128</td>
<td>271</td>
<td>18.3</td>
<td>7.9</td>
<td>0.2</td>
<td>100</td>
<td>6</td>
<td>2.5Y 5/3</td>
<td>Subangular blocky</td>
<td></td>
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<tr>
<td>C 128-203</td>
<td>191</td>
<td>13.1</td>
<td>8.2</td>
<td>0.1</td>
<td>100</td>
<td>1</td>
<td>2.5Y 5/4</td>
<td>Massive</td>
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<td>Houdek (prairie derived – fine-loamy, mixed, superactive, mesic Typic Argiustoll)</td>
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<td>Ap 0-15</td>
<td>223</td>
<td>22.8</td>
<td>6.5</td>
<td>2.6</td>
<td>92</td>
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<tr>
<td>Bt1 15-25</td>
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<td>Bt2 25-46</td>
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<td>7.1</td>
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<td>0</td>
<td>10YR 4/2</td>
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<td>7.7</td>
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<td>100</td>
<td>17</td>
<td>2.5Y 4/3</td>
<td>Prismatic</td>
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<td>Bk2 71-102</td>
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<td>13.6</td>
<td>7.9</td>
<td>0.5</td>
<td>100</td>
<td>12</td>
<td>2.5Y 5/3</td>
<td>Prismatic</td>
<td></td>
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<tr>
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<td>0.1</td>
<td>100</td>
<td>9</td>
<td>2.5Y5/3</td>
<td>Massive</td>
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</table>

2. The development of B horizons of clay (argillic, Bt), sodium (natric, Btn), or calcium carbonate (calcic, Bk) accumulation. Some grassland soils have strongly developed eluvial horizons (e.g. albic, E). While other grassland soils have only weakly developed B horizons (cambic [Bw], gleyed [Bg]) or no B horizon at all. Most SD grassland soils have Bk horizons while the grassland soils in more humid areas east and south of SD tend to lack horizons of lime accumulation.

3. Adequate storage of plant available water (no irrigation) during the growing season to sustain (at least three months) perennial grasses (tall, mid, or short). The amount of precipitation is sufficient to provide good production of organic residues but not enough to cause severe weathering and leaching (Fenton, 1983).

4. Divalent cations, especially Ca²⁺, dominating the soil cation exchange sites. SD grassland soils have smectite (2:1 lattice silicate clay mineral) present in the clay fraction and have textures finer than loamy fine sand (Kononova, 1975).

5. A relatively high cation exchange capacity (15 to 40 cmolc kg⁻¹).

6. Developed soil structure in surface horizon or layer and are soft when dry. Granular or crumb structure is the most common structure shape found in native SD grassland surface horizons with blocky (humid areas) and prismatic (semiarid areas) structure in the
B horizons. With cultivation, the surface soil structure shape can change to subangular blocky (Soil Survey Staff Division, 1993). Structure development in grassland soils enhances air and water movement.

7. Sufficient strength to provide physical support for livestock grazing or tillage on the soil.

8. High natural fertility due to parent materials containing primary, weatherable minerals containing high base contents and high humus levels.

9. A variety of parent materials, from Quaternary materials (e.g. glacial till, glacial outwash, loess, alluvium) to residuum from bedrock. The slopes where grasses can be found can range from flat alluvial areas and basins to strongly sloping mountain areas. Where slopes and climate allow these soils are intensively cultivated.

3. Genesis of SD Grassland Soils (This section is a modification of Genesis of Grassland Soils [Malo, 2002])

The genesis of SD grassland soils is the result of vegetation interaction with the other soil forming factors. Grasses, a source of organic matter and nutrient cycling, provide these two keys components to the soil body. The principal process in grassland genesis is the accumulation of high base content humus in the soil from the dense grass root systems near the soil surface (Jenny, 1941; Clements and Weaver, 1924; Smith, 1965). Through the microbial decay of plant roots and plant tissue, organic matter is added to the soil surface and the soil profile in grasslands. Soil fauna (e.g. earthworms) incorporate the above ground biomass tissue into the soil surface and help increase surface organic C levels. Most grass roots are found in the top 30 cm of grassland soils (Douglas et. al., 1967). Each year more than 50 percent of the biomass produced by unharvested grasses (nearly all of the above ground biomass and about 30 percent of the below surface biomass) is added to the soil (Kononova, 1966). The amount of above ground grassland biomass production can range from 1500 to 3500 kg ha⁻¹ yr⁻¹, dry weight (Jenny, 1941). The amount of air-dry organic matter added per year can vary depending on climate conditions and vegetation type [e.g. 1250 kg ha⁻¹ for humid prairie areas to 600 kg ha⁻¹ for short to mid grass prairies] (Thorp, 1948).

In most grasslands, there are periods of rapid, prolific vegetative growth and periods of dormancy and senescence (winter). Generally, there is a dry period that slows or stops grass growth before the winter season. There is limited or very little decomposition of grass root during the winter season because of cool temperatures while during the summer, there is rapid breakdown of simple sugars, proteins, and cellulose. Resistant materials (e.g. lignins, fats, and waxes) accumulate and are key components of soil humus. Over time, the amount of resistant organic materials accumulates in the soil and increase soil humus levels until an equilibrium is reached. Melanization, darkening of the parent material caused by direct incorporation of humus into the soil, is the dominant soil forming processes in grassland soils (Fenton, 1983).

The distribution of organic C in grassland soils shows a gradual decline with increasing soil depth due to the gradual decline of fibrous grass roots and microbial activities with increasing soil depth (Table 3, Houdek soil). This pattern of organic C distribution is strikingly different from that found in forest derived soils where the organic C is very high in a thin surface horizon and there is very little organic C in the rest of the soil (Table 3, Citadel soil). As a result, the structural stability of grassland soil peds tends to be stronger than that in non-grassland soils. Humus is not very water-soluble so it tends to stay in one location unless there is suspension or some mechanism for mechanical movement. The organic C decline continues until the native rooting depth of the grasses is reached and there is little or no organic C.

Grasses are large users of bases, especially calcium (Ca²⁺). As a result, when grass residue is added to the soil surface, large amounts of cations (Ca²⁺, Mg²⁺, and K¹⁺) are brought to the surface and replace cations lost by leaching and weathering activities. This results in high soil pH values and higher base saturation throughout the top part of the profile (Table 3, Houdek soil). The high concentration of bases help, along with the high content of shrinking/swelling silicate clay minerals and high humus levels, to form the granular or crumb structure that is so common in grassland soils. In general, the amount of leaching under grass vegetation is minimal when compared to other types of vegetation (e.g., forest). Deep percolation of precipitation to the water table is not common and deep leaching is not usually evident in most grassland soils. Grasses tend to utilize the water in the soil and prevent the deep leaching of nutrients. The grass plants keep recycling bases to the soil surface and this limits soil acidity, clay illuviation, and base saturation.
reductions.
Generally, as the average annual precipitation increases in grassland areas, keeping average annual temperature the same, the depth, darkness, and organic C content of A horizons tends to increase. The more humid areas tend to have darker, thicker A horizons (Buol, et. al., 1997). Generally, increasing the average annual temperature in grasslands while maintaining average annual precipitation levels, the depth, darkness, and organic C content of A horizons tends to decrease (Buol, et. al., 1997). Leaching is active in humid areas where the amount of effective precipitation exceeds plant use. This results in loss of soluble soil weathering and biological products from the soil solum.

Grassland soils have a wide range of leaching and weathering stages and a wide diversity of horizons. In most SD grassland areas, the original parent material contained free calcium carbonate at the beginning of soil formation. As soils developed, lime was translocated or leached from the soil. The depth to lime and the amount of lime are used as key factors in understanding the genesis and development of grassland soils (Redmond and McClelland, 1959; McClelland, et.al., 1959). Many grassland soils in semiarid regions have horizons of lime accumulation, Bk, present (Fig. 5 at the two feet, 24 in [61 cm] depth). The Bk horizons tend to become closer to the soil surface as the annual average precipitation decreases (Jenny, 1980, also see Fig. 1). The Bk horizons represent the depth of effective water movement and profile development (balance of leaching and upward movement of soil solution lime) in these soils. The key property is the presence of the thick, dark colored mineral layer that is high in organic carbon.

The development of textural horizons and silicate clay illuviation in grassland soils tends to happen in three steps (Ruhe, 1969):
1. Removal of free carbonates – As long as free lime is present, the soil remains flocculated and little or no silicate clay will translocate.
2. Silicate clay formation and alteration – Silicate clays are formed and altered as a result of weathering and soil genesis.
3. Silicate clay eluviation and illuviation – The fine silicate clays (<0.2 µm) move and precipitate out lower in the soil profile. The place where silicate clay illuviation occurs depends on pH, lime content, microbial activity, and moisture levels. Often there is joint illuviation of both silicate clays and humus in grassland soils forming organo-argillans.

Another key indicator of soil genesis in grassland soils is phosphorus (P). Significant differences in P species have been noted in different grassland soils. Ustolls have a larger percentage of calcium phosphates when compared to Udolls while Udolls had a higher percentage of iron phosphate (Westin and Buntley, 1967). Phosphorus distributions (total, organic, and inorganic) within the soil
profile depend on horizon, lime illuviation, vegetation and drainage (Ruhe, 1969; Runge and Riecken, 1966; Allaway and Rhoades, 1951). Cultivation has caused significant increases in soil P levels when compared to native soils due to fertilizer additions (see Fig. 6, from Malo, et.al., 2005).

With cultivation in grassland soils, there are significant changes in the soil organic C levels. Significant organic C losses (>30 % reduction in organic C levels after 70+ years of cultivation) and soil quality occur [see Fig. 7] (Douglas, et.al., 1967; Paul and McGill, 1977; Malo, et.al., 2005). The losses are most dramatic in the soil surface and diminish with increasing soil depth (Ruhe, 1969).

VI. SOIL MANAGEMENT PROBLEMS

1. Conserving moisture

One of the most serious soil management problems in South Dakota is moisture conservation. This problem is present in every region of the state, although it is most serious in the Cool Very Dry Plain, the Cool Dry Plain, the Warm Very Dry Plain, and the Warm Dry Plain soil regions. Precipitation is light in these areas while evaporation and runoff losses are considerable, even with a close growing crop such as alfalfa on the land. Moisture losses (not utilized by the crop) under alfalfa amount to about 40% of the total annual rainfall in the Warm Moist Prairie soil region and about 50% in the Cool Dry Plain, the Warm Very Dry Plain, and the Warm Dry Plain soil regions. Moisture losses under corn or wheat are higher, ranging from 50% in the Warm Moist Prairie soil region to about 60% in the Cool Dry Plain, the Warm Very Dry Plain, and the Warm Dry Plain soil regions.

The problem is to reduce moisture losses. It is probably impossible to raise moisture utilization above that achieved by alfalfa which covers the land most of the year. However, if moisture utilization for other crops can even approach that achieved under alfalfa, yields in every region of the state could be substantially increased. Estimates of increased yield based on research in these areas indicate yield increases of 30% for wheat and 40% for corn can be raised with soil moisture conserving practices like no-till (Westin and Malo, 1976).

With the acceptance of no-till and genetically modified (GMO) crops by SD farmers the yields for corn, wheat, and other grains have increased significantly. The advent of no-till and GMO varieties have also allowed soybeans to be planted in areas that were previously not suited for them. In 1975 only a few counties in south east SD had significant areas of soybeans. In 2008 more than half of the counties in SD had significant areas of soybean production (USDA-NASS, 2010).

2. Organic matter and nitrogen loss

A second important soil management problem is the continuing loss of organic matter and N from SD soils. This problem was touched on briefly in discussing the importance of organic matter for increasing moisture absorption by soils.

Available data show that South Dakota soils have lost (in 70-90 years of cropping) from 25% to 35% of the organic C and N originally present in the soils (Fig. 7). Although it is not practical or necessary to maintain the amounts of these materials originally present in the soil, current losses are great enough to affect the tilth and fertility of the soil and hence crop yields.

Management measures and crop residues returned to the soil are the only means of adding organic matter, although N can be added in commercial preparations. Alfalfa can return to the soil as much as 90 kg ha⁻¹ N when the second cutting of a 3-year stand is plowed under. A 8700 kg ha⁻¹ corn crop will remove 310 kg ha⁻¹ N from the soil. This makes it obvious that it is difficult to maintain soil N at present levels by this method alone, even though only one good crop of corn is raised for every 3 years of alfalfa.

Under conventional farming systems the organic matter content of our soils will decline. However, the rate of decline is slowing down as more resistant organic materials are encountered. Although N losses can be made up by commercial products, the effect of lower organic matter levels will further aggravate an already serious moisture conservation problem. No-till farming practices are slowing the rate of decline and in some cases reversing are increasing surface soil organic matter levels.

Soil N and organic matter losses are more serious in the more humid soil regions. This occurs because larger yields of crops in these areas have depleted the more humid soils, although in total amounts of N and organic matter, these soils still rank above the soils of the drier areas.
Other soil nutrients. Except for P, amounts of nutrient elements including potassium, calcium, and magnesium apparently are present in adequate amounts in South Dakota soils at present. Soil reaction is usually neutral to moderately acid in the surface horizons of South Dakota soils, but because of the high base status of the surface soils and free CaCO₃ in the substrata, lime is not needed at present (Ward, et al. 1976).

Plant available P, however, is generally in short supply in certain areas of the state, especially for alfalfa. In the soils of the Warm Moist Prairie and the Cool Moist Prairie areas, available P is very low to medium. In other major soil areas available P, based on a summary of soil tests at South Dakota State University ranges from low to high west of the Missouri River to low to medium in the area west of the James River (Ward and Carson, 1975; unpublished data from Gelderman, 2010).

Generally within any region, calcareous soils have low levels of P availability. This is because the P combines with calcium to form a nearly insoluble compound. Soil tests are the best way to determine the P needs of a soil. Soil P can be maintained by the use of commercial fertilizer.

Wind and water erosion. Soil erosion by wind or water is a soil management problem in all regions of South Dakota. Susceptibility to erosion by wind depends largely upon soil texture. Research has shown that soils with a large percentage of sand-sized particles (2.0 to 0.05 mm) are most susceptible to blowing. These particles may be sand grains or clay or silt particles balled up into sand-sized grains.

Wind erosion is caused by a process called saltation. In this process the sand grains or sand-sized granules are blown several feet into the air and then driven with a high velocity into the soil. The impact of the grains upon the soil sprays soils up into the air. The fine individual silt and clay particles are taken up by the wind and blown out of the area. The sand-sized particles rise several feet into the air and again are driven back into the soil and the cycle is repeated.

Control measures for wind erosion center about keeping a close growing crop or crop residues on the land at all times. Because it is difficult to establish cover on sandy soils during dry periods when it is needed the most, the safest procedure for sandy soils is to keep them in perennial vegetation. If these soils are used for grains or row crops, the residues should be returned and left on the soil surface or partly incorporated into the surface soil. If the soils are bare when wind erosion starts, the soil surface may be roughened and thrown up into ridges by tillage implements. These are “last ditch” control measures, however, and it should not be assumed that they will be too effective. A more complete description of conservation tillage methods can be found elsewhere (Williamson, et al. 1976).

Water erosion occurs when rain water falling on the soil surface runs off and takes with it soil particles in suspension. This erosion is affected by soil slope, texture, amount of organic matter, structure, and fertility status. These factors are more or less interrelated. A good soil management program for sloping soils might involve terrace or contour cultivation and a rotation that includes legumes and commercial fertilizer.

Terraces or contours tend to neutralize the slope factor and improve water intake and reduce the amount of water available for runoff and erosion. Legumes in the rotation and the addition of fertilizer increase the amount of organic matter and nutrient status. This improves the structure and hence the ability of the soil to absorb moisture.

Water erosion is serious on sloping lands, especially in eastern South Dakota. Certain soil associations lend themselves to contour erosion control measures, for example the Kranzburg-Brookings association. These soils have long, smooth slopes. Certain of the till soil associations, such as the Williams-Tonka association, have short, choppy slopes and are difficult to contour.

Erosion control can best be accomplished on these soils by increasing the percentage of legumes and grasses in the cropping sequence and using residue saving tillage (e.g., no-till). The added organic matter will increase the rate of water in take and decrease the amount of water available to runoff and erode.

VII. Summary

Throughout the world where large areas of grasslands are located one finds developed cultures. These soils are extremely productive and have allowed societies to flourish. In SD the grasslands comprise more than 85% of the state. About 35% of the grasslands are tall-grass prairies and 65% are short and mid-grass prairies. Grasslands have higher organism activity than most other soils (Telfair, et.al., 1957). Carbon sequestration in grasslands is critical to the global warming process. Grasslands are not only
important for food and fiber production, but they have the potential to help solve one of the major problems facing human survival, global warming (Brady and Weil, 2009). Grasslands are one of the most important ecosystems in the world.

References


