Features and Properties of Soils in the Eurasian Steppe

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Summary

For the purpose of the rangeland rehabilitation and prevention of the desertification, we should get the fundamental and primary knowledge of the features and properties of ‘the soils’ in the first place, which can support vegetation and assure the subsequent reproduction of biomass. The rangelands in the Eurasian steppic regions and semi-arid regions are covered by a great variety of soils.

In the southeastern part of Kazakhstan, the *toposequence* of the soils ranged from the mountains to deserts can be observed. Fertile and rich ‘black soils’, Chernozems and Kastanozems, are dominant in the steppic zone, which must be one of the best rangeland soils in the world, usually not used for grazing but for a wheat production. Infertile and/or sandy soils, Calcisols and Arenosols are commonly found in the semi-arid zone, where extensive ranging is the most common and critical land use.

The greater part of lands is covered by Chernozems and the related soils in Ukraine, where must be the central and representative Chernozemic zones in the Eurasian steppe. In the eastern part of Ukraine, the *climosequence* of the soils from the northern wetter zones to the southern drier zones can be distinctly observed. Under the moist conditions in the north, Typical Chernozems and Ordinary Chernozems, which can be distinguished by a deep black surface horizon, high in organic matter, and the 'mycelium'-type accumulation of calcium carbonate in the deeper horizons, are predominant. Southern Chernozems and Dark Chestnuts are the common subtypes under the relatively dry moisture regime, the profiles of which can be characterized by a relatively thin dark-brown or brown surface horizon and a 'white eye'-type calcium carbonate accumulation at the shallower depth of the profile. The carbon stock as organic carbon and/or inorganic carbon through the profile is extremely high in either case, can support and assure a luxuriant production of plant and biomass.

The lands covered by Chernozemic soils and the climatic conditions in such areas are suitable for wheat, barley and maize production, alongside other food crops and vegetables. The intensive agricultural practice would induce soil carbon degradation, due to low input of plant residues and high microbial decomposition of organic matter accompanied by plowing, resulting in irreversible decrease in the soil fertility. The soil colors of the surface horizons in the arable soils of Hungary are brownish black to dark brown, not real black, and the organic carbon contents in the topsoils of Hungary are relatively lower than those of Kazakhstan and Ukraine, probably reflecting the soil carbon degradation through agricultural practices.

Keywords: Chernozems, Eurasian steppe, Kastanozems, soil carbon degradation, soil profiles

1. Introduction

The rangelands in the Eurasian steppe are covered by a great variety of soils. Some of the soils are very fertile, rich in nutrients and organic matter, and can support a luxuriant production of plants and biomass. On the other hand, some of the soils are all along impoverished, poor in nutrients and organic matter, and a possibility and a potential to keep a sustainable reproduction may be comparatively low.

The climatic conditions are one of the most critical factors to determine the soil formation processes and distribution in the area. Steppe and steppic regions receive between 250 and 500 mm of precipitation annually, i.e. more than twice the quantity that falls in true desert areas where rainfall is insufficient to support vegetation that could protect the land from erosion, degradation, and desertification. These areas are usually covered with ‘loess’ materials carried by strong winds during the Ice Age, or either covered with tills, deglaciation sediments, or lacustrine sediments. These materials are usually calcareous, unstratified, and yellowish-grey. The vast loess and till plains are now colonized by grass and/or forest. They are the home of some of the best soils of the world: the ‘black earths’. Deep, black Chernozems occupy the central parts of the Eurasian steppe zone. Brown Kastanozems are typical of the drier parts of the steppe zone and border on arid and semi-arid lands.

Arid and semi-arid regions are distinguished on the basis of the annual precipitation sum and include: 1) Real deserts with an annual precipitation sum < 50 mm/year and devoid of vegetation, 2) Arid regions with 50 – 250 mm/year precipitation and sparse vegetation, and 3) Semi-arid regions with a precipitation sum of 250 to 500 mm/year and a steppe vegetation. Arid and semi-arid regions harbor a wide variety of soils that occur also in more humid environments. Typical dry-zone soils are soils whose formation was conditioned by aridity, accumulation and/or redistribution of inorganic compounds.

2. Rangeland Soils in the Eurasian Steppe

2-1. Landscape and Steppe Soils in Southeastern Kazakhstan

In southeastern part of Kazakhstan, a wide variety of landscape and related soils can be observed in accordance with the geographical features and climatic zones (Fig. 1). The Tian-Shan Mountains are soaring on the south, while the Betpak-Dala deserts are spreading on the north. Since the annual rainfall is relatively high and the mean temperature is quite low in the Mountains at the higher elevation (more than 2,000 m a.s.l.), the soils are distinguished by large contents of organic matter in the surface horizons, classified into Mountain-forest soils and Mountain-meadow soils. Between the Tian-Shan Mountains and the Betpak-Dala deserts, the steppe and semi-arid areas are widely distributing.

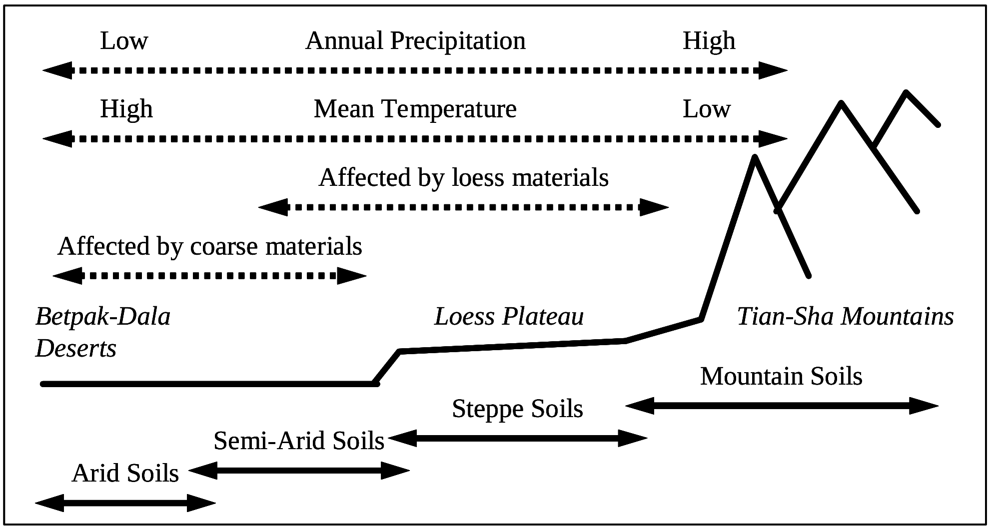

Figure 1. Scheme of the landscape and related soils in accordance with the geological features and the climatic zones in the southeastern part of Kazakhstan.

Chernozems

The steppe and steppic regions in southeastern Kazakhstan are extensively covered by loess materials, from which Chernozems and Kastanozems (in WRB classification; FAO, 1998) are commonly formed and developed. Chernozems are soils of the tall grass or steppe plains and hills in region with a continental climate (warm summers and cold winters). Vast areas of Chernozems are found in Eastern Europe, Central Asia, and North America. During the warm summers, large quantities of organic matter are produced, which is incorporated in the soils mainly by soil fauna. During the cold wintertime, soil animals move downwards, thereby homogenizing the soil. Popularly known as “Black Earths”, Chernozems have typically a deep black surface horizon, high in organic matter, immediately over a brown or yellowish horizon with calcium carbonate accumulation.

Russian soil scientists rank the deep, central Chernozems among the best soils in the world. With less than half of all Chernozems in Eurasia being used for arable cropping, these soils constitute a formidable resource for the future (FAO, 2002).

Preservation of the favorable soil structure thoroughly timely cultivation and careful irrigation at low water rates prevents ablation and erosion. Application of P-fertilizers is required for high yields. Wheat, barley and maize are the principal crops grown, alongside other food crops and vegetables. Part of the Chernozem area is used for livestock rearing. In the northern temperate climatic belt, the possible growing period is short and principal crops grown are wheat and barley, in places in rotation with vegetables. Maize is widely grown in the warm temperate belt. Maize production tends to stagnate in drier years unless the crop is adequately irrigated.

An illustrative profile of Chernozems and its description

Soil type: Leached Chernozemic soils (in Russian classification; Stolbovoi, 2000), Pachic Hapludolls (in US classification; USDA, 1998)

Location and elevation: 10 km southwest from Almaty (N43°09' E76°53'), 1,200 m a.s.l.

Annual precipitation: 750-800 mm

Table 1. Brief description of the soil profile (Chernozem)

horizon	depth (cm)	color	texture	structure	$CaCO_3$ accumulation
A1	0-10	black	loam	strongly-developed granular	
A2	10-30	black	loam	strongly-developed granular	
A3	30-50	black	loam	moderately-developed subangular blocky	
B1	50-71	brown	clay loam	strongly-developed subangular blocky	
B2	71-91	brown	clay loam	strongly-developed subangular blocky	
Bk	91-105	brown	clay loam	strongly-developed subangular blocky	
Ck1	105-124	yellowish brown	silty clay loam	weakly-developed subangular blocky	
Ck2	124-150+	yellowish brown	silty clay loam	weakly-developed subangular blocky	mycelium-type

Kastanozems

Kastanozems occur adjacent to Chernozems on the drier side of the Chernozem belt (FAO, 2002). The climax vegetation consists of short grasses. The name of Kastanozems refers to the chestnut color of many of these soils. Organic matter production on Kastanozems is less than in the Chernozem belt but enough to form a dark mollic surface horizon. Accumulation of calcium carbonate or gypsum in the solum is a characteristic of Kastanozems. The vast, almost level plains of the Central Asian Kastanozem belt are suitable for large-scale mechanized agricultural enterprises.

Kastanozems are potentially rich soils; periodic lack of soil moisture is the main obstacle to high yields. Irrigation is nearly always necessary for high yields; care must be taken to avoid secondary salinization of the surface soil. Small grains and (irrigated) food and vegetable crops are the principal crops grown. Wind erosion is a problem of Kastanozems, especially on fallow lands.

Extensive grazing is another important land use on Kastanozems but the sparsely vegetated grazing lands are inferior to the tall grass steppe on Chernozems and overgrazing is a serious problem (FAO, 2002).

An illustrative profile of Kastanozems and its description

Soil type: Dark Chestnut soils (in Russian classification; Stolbovoi, 2000), Typic Calciustolls (in US classification; USDA, 1998)

Location and elevation: 26 km west from Almaty (N43°10' E76°32'), 950 m a.s.l.

Annual precipitation: 450-500 mm

Table 2. Brief description of the soil profile (Kastanozem)

horizon	depth (cm)	color	structure	$CaCO_3$ accumulation
A1	0-2	dark brown	strongly-developed granular	
A2	2-22	dark brown	moderately-developed subangular blocky	
AB	22-34	brown	moderately to strongly-developed subangular blocky	
Bk	34-50	brown	strongly-developed subangular blocky	white eye-type
Ck1	50-90	yellowish brown	strongly-developed subangular blocky	
Ck2	90-140+	yellowish brown	strongly-developed subangular blocky	

2-2. Soils under Arid and Semi-Arid Climatic Conditions in Southeastern Kazakhstan

Under arid and semi-arid climatic conditions in southeastern Kazakhstan between the steppe zone and the really dry desert, intermediate soil types, Calcisols (FAO, 1998) affected by calcareous materials to some degree and described as Serozems in Russian classification systems (Stolbovoi, 2000), and Arenosols (FAO, 1998) affected by coarse materials and distinguished by a sandy texture are distributing.

Calcisols

During the cool rainy winter and spring carbonates dissolve and move through the soil. Soil water evaporates during the dry hot summers and carbonates precipitate again. Parent materials rich in carbonates (loess materials) are widespread in the semi-arid and arid regions. Crops will only grow with irrigation. Drip irrigation is applied close to the plants to make the best use of the scarce irrigation water. Extensive ranging (sheep, goats) is the most common land use in semi-arid regions. Vast areas of 'natural' Calcisols are under shrubs, grasses and herbs and used for extensive grazing. Drought-tolerant crops such as sunflower might be grown rain-fed, preferably after one or a few fallow years, but Calcisols reach their full productive capacity only when carefully irrigated. In palaces, arable farming is hindered by stoniness of the surface soil and/or a petrocalcic horizon at shallow depth.

An illustrative profile of Calcisols and its description

Soil type: Common Serozems (in Russian classification; Stolbovoi, 2000), Ustic Haplocambids (in US classification; USDA, 1998)

Location: 50 km northwest from Almaty (N43°19' E76°04')

Annual precipitation: 300-400 mm

Table 3. Brief description of the soil profile (Calcisol)

horizon	depth (cm)	color	texture	$CaCO_3$ or $CaSO_4$ accumulation
A	0-3	brown	loam to sandy loam	
CA	3-32	brown	loam to sandy loam	
Ck1	32-53	yellowish brown	loam	
Ck2	53-115	yellowish brown	loam	
Cy	115-130+	yellowish brown	loam	gypsum accumulation

Arenosols

All Arenosols have a coarse texture, accountable for the generally high permeability and low water and nutrient storage capacity. Arenosols in arid lands, where the annual rainfall sum is less than 300 mm, are predominantly used for extensive (nomadic) grazing. Dry farming is possible where the annual rainfall sum exceeds 300 mm. Uncontrolled grazing and clearing for cultivation without appropriate soil conservation measures can easily make these soils unstable and revert the land to desert areas.

3. Climate and Soils in the Eurasian Steppe

3-1. Chernozemic Soils in Ukraine

Popularly known as “Black Soil Belts”, Chernozemic zones are composed of one of the most fertile and rich black-soils in the world, distributing in Eastern Europe, Central Asia including South Russia, North America (known as prairie) and South America (known as pampa). In particular, the greater part of lands is covered by Chernozems and related soils (Kastanozems) in Ukraine (Fig. 2), where must be the central and representative Chernozemic zones in the Eurasian steppe.

Figure 2. Soil Map of Ukraine (in Russian).

3-2. Moisture Regime and Soil Development in Ukraine

The distribution of each subtype of Chernozems and Kastanozems in Ukraine is controlled by only climatic conditions, especially the soil moisture regime, and the soil zonality is quite distinct. In the northern part of Ukraine, the mean temperature, annual precipitation, and evaporation is relatively cool, high, and low, respectively, compared to the southern part. As a result, the soil moisture regime is drier in the southern part than the northern part. The more moist conditions can stimulate the accumulation of plant residues and their humification processes, resulting in a deep black surface horizon, high in organic matter. The leaching of calcium carbonate from surface horizons to lower parts of the profile and the consecutive 'mycelium'-type accumulation of calcium carbonate in the deeper horizons can be also observed. In the meantime, the more droughty conditions can build up a profile with a relatively thin dark-brown or brown surface horizon and a 'white eye'-type calcium carbonate accumulation at the shallower depth of the profile.

As an instance, four subtypes of Chernozems and the related soils, which can be found in the eastern part of Ukraine; 'Typical Chernozems', 'Ordinary Chernozems', 'Southern Chernozems', and 'Dark Chestnuts' (according to Russian classification system; Stolbovoi, 2000) are described here. The illustrative profile of Typical Chernozems under natural steppe vegetation was found in Grakovo, close to Kharkiv where the second largest cities in Ukraine, distinguished by a thick black A horizons (0-70 cm). On the way from Kharkiv to the south, the representative profile of Ordinary Chernozems was found in wheat filed of Krasnograd, which had a thick black to dark-brown A horizons (0-65 cm). Askania-Nova, the southeastern part of Ukraine, is the vast 'UNESCO Natural Reserved' area of natural virgin-steppe vegetation. The most dominant soils in Askania-Nova were Dark Chestnuts and Southern Chernozems, characterized by thin dark-brown A horizons (38 and 55 cm, respectively) and 'white-eye' type calcium carbonate accumulation in Bk horizons at the shallower depths.

Table 4. Brief description of the soil profiles in Ukraine

horizon	depth (cm)	color	accumulation
Typical Chernozem in Grakovo			
A1	0-30	black (2.5Y 2/1)	humic
A2	30-46	black (10YR 2/1)	humic
A3	46-70	brownish black (7.5YR 3/1)	humic
AB	70-105	dull yellowish brown (10YR 5/3)	mycelium-type $CaCO_3$
Bk	105-120+	dull brown (7.5YR 5/4)	mycelium-type $CaCO_3$
Ordinary Chernozem in Krasnograd			
Ap	0-23	brownish black (10YR 3/1)	humic
A1	23-48	black (7.5YR 2/1)	humic
A2	48-65	brownish black (7.5YR 3/1)	humic
BA	65-88	dull yellowish brown (10YR 5/3)	mycelium-type $CaCO_3$
BC	88-100+	dull yellowish brown (10YR 5/4)	white eye-type $CaCO_3$
Southern Chernozem in Askania-Nova			
A1	0-25	brownish black (7.5YR 3/1)	humic
A2	25-55	brownish black (7.5YR 3/1)	humic
BA	55-70	brownish black & dull yellowish brown(10YR 3/2 & 10YR 5/4)	
Bk	70-92	dull brown (7.5YR 5/4)	white eye-type $CaCO_3$
BC	92-103+	dull yellowish brown (10YR 5/4)	
Dark Chestnut in Askania-Nova			
A1	0-25	brownish black (7.5YR 3/2)	humic
A2	25-38	grayish brown (7.5YR 4/2)	humic
BA	38-64	dull yellowish brown(10YR 4/3)	
Bk	64-90	dull brown (7.5YR 5/4)	white eye-type $CaCO_3$
C	90-108+	dull yellowish brown (10YR 5/4)	

4. Agricultural Use and Soils in the Eurasian Steppe

4-1. Chernozemic Soils in Hungary

Chernozemic soils are one of the most fertile soils in the world, rich in both organic matter and plant nutrients. During the warm summer, large quantities of organic matter are produced under natural steppe and mixed vegetation, which can assure the everlasting fertility of Chernozemic soils. However, the lands covered by Chernozemic soils and the climatic conditions in such areas are suitable for wheat, barley and maize production, alongside other food crops and vegetables. The intensive agricultural practice would induce soil carbon degradation, due to low input of plant residues and high microbial decomposition of organic matter accompanied by plowing, resulting in irreversible decrease in the soil fertility.

Chernozemic soils are widely distributing in Hungary, especially in the vast areas of the eastern plain. Since the intensive wheat and maize productions have been conducted in such areas, lands under the natural steppe vegetation are almost scarce. The soil colors of the surface horizons in these areas are brownish black to dark brown, not real black, probably reflecting the soil carbon degradation through agricultural practices.

A brief description of a Leached Chernozemic soil in an experimental farm of the Godollo University was shown in Table 5. The Leached Chernozems should have deep 'black' surface horizons, rich in organic matter, as shown in section 2.1 (Table 1). However, the soil color of the surface plow layer is dark brown, and that of the subsurface horizon is brownish black, not representative 'black'. The external surface of the subangular blocky structure is relatively black, however, the inner colors of the structure is nearly brown, suggesting the leaching of the decomposed organic matter and subsequent re-adhesion on the surface.

Table 5. Brief description of the soil profile of a Leached Chernozem

horizon	depth (cm)	color	$CaCO_3$ accumulation
Ap	0-32	dark brown (10YR 3/3)	
A	32-60	brownish black (7.5YR 3/2)	
B	60-90	brownish black & dull yellowish brown(7.5YR 3/2 & 10YR 5/4)	
2Ck1	90-135	brown (7.5YR 4/6)	mycelium-type
2Ck2	135-170+	brown (7.5YR 4/4)	mycelium-type

4-2. Intensive Agriculture and Soil Carbon Degradation

The weighted-average values of organic carbon contents (%) in the surface layers (0 to 30 cm) of Chernozems were shown in Fig. 3. The organic carbon content is highest in a Leached Chernozem of Kazakhstan, followed by a Typical Chernozems, an Ordinary Chernozem, and a Southern Chernozem of Ukraine. The contents in arable soils of Hungary are generally lower than these soils, mostly less than 2 %.

The soil carbon degradation would cause a global warming through carbon dioxide emission and also a desertification of semi-arid and/or steppic zones. The balance of 'soil moisture', 'soil organic matter', and 'salt and other cations' should be critical to preserve the vast areas of the fertile soils in the Eurasian Steppe, which could assure a luxuriant production of crops and grasses. The basic information on soil features, properties, and distribution in the steppic zones must be indispensable to discuss on a sustainable agricultural practices. We still have a lot of subjects to be done in these areas.

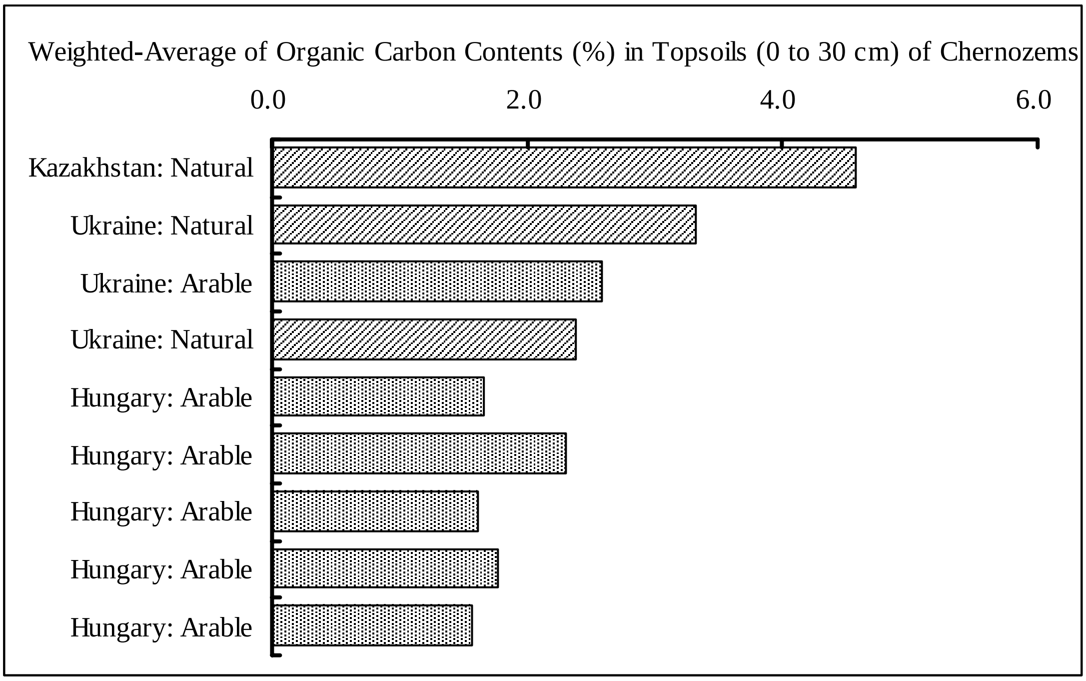

Figure 3. Weighted-average of organic carbon contents in topsoils (0-30 cm) of Chernozems.

References

FAO, 1998; World reference base (WRB) for soil resources. FAO, Rome, Italy.

FAO, 2002; Major Soils of the World, Land and Water Digital Media Series 19. FAO, Rome, Italy (in CD-ROM).

Stolbovoi, V., 2000; Soils of Russia: Correlated with the Revised Legend of the FAO Soil Map of the World and World Reference Base for Soil Resource. IIASA, Laxenburg, Austria.

USDA, 1998; Keys to Soil Taxonomy, Eighth Edition. USDA, Washington, D.C., USA.