Soils of the agricultural lands of the Horatskaya Plain

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The Horatskaya Plain is located in north-eastern Belarus (Fig. 1). This territory is a ravine-riddled landscape formed in the interglacial conditions after the retreat of the last glaciation (Makhnach, 2001).

Fig. 1. Location

Lithology and topography

The Horatskaya Plain is a region of undulating plateau-like plains heavily dissected by river and stream valleys and a dense network of deep ravines with moraine ridges rising in a number of places in the form of small hills. The relief of the plain consists of thick loess and loess-like silt loams and sandy loams. The loess covers the watersheds and slopes of elevated parts of the territory devoid of forest vegetation (Yakushko et al., 2011).

A characteristic feature of the relief is the formation of a large number of suffusion depressions – "saucers". Numerous depressions on the plain are due to the leaching of carbonate soils by thawed snow and rainwater, the washing out of clay particles and subsequent subsidence of the surface. The depth of the valleys is 1–1.5 m, the diameter is 50–80 m. In the spring, the depressions are filled with snow water, and in the summer they overgrow with shrubs and grass vegetation. Many of them have today been transformed into regularly shaped artificial reservoirs. Absolute heights are in the range of 150–200 m above sea level. In the plain there are a number of rivers, the largest being the Pronya (Yakushko et al., 2011).

Land use and vegetation

Loess deposits have favourable natural physical conditions and fertile soils are formed on them, which has resulted in the intensive use of these lands in agriculture (approximately 51% is occupied by arable land). Forests occupy a limited space. The most common spruce forests (*Picea abies*) and secondary deciduous (*Betula pendula*, *Populus tremula*) (Miasnikovich, 2002).

Climate

In the climatic relation, the plain enters the central moderate-moist thermal zone of Belarus - its eastern sub region. According to Kottek et al. (2006) the region is located in the snow, fully humid climate with warm summer. The average annual air temperature is 5-7 degrees. The average temperature in January is -7.5 ° C to -8 ° C, in July - from 17.5 ° C to 18 ° C. The length of the growing season is about 185 days, and the frost-free period is up to 150 days. The amount of precipitation varies within 650 mm per year. The main part of precipitation falls in the summer period of the year. The most humid month is July, but in May, moisture is sometimes not enough. In some years, rains do not fall for more than a month. In winter, a fifth of the annual amount of precipitation falls. This is approximately 30 centimetres of snow cover (Loginov, 1996).

Profile 1 – Endolamellic **Luvisol** (Aric, Cutanic, Pantosiltic, Ochric)
Localization: flat and vast summit (inclination 2˚), arable land, 186 m a.s.l.,
N 54°14′13″ **E** 31°7′5″

Morphology:

Ap – 0–22 cm, ploughed humus horizon, silt loam, brownish-gray with brown spots (10YR 4/3), granular structure, moist, compacted, inclusions of organic (manure); few roots, abrupt and smooth boundary;

Ap2 – 22–34 cm, humus horizon ploughed in the past, silt loam, pale brown (10YR 6/3), granular structure, slightly moist, compacted, worms, few roots; abrupt and smooth boundary;

EBg – 34–39 cm, discontinuous transitional horizon, stagnic properties, silt loam, pale brown (2.5YR 7/4), fine weak subangular structure, slightly moist, crotovinas, clear and broken boundary;

Bt – 39–71 cm, *argic* horizon, silt loam, reddish brown (5YR 4/4), with whitish veins, medium moderate subangular structure, slightly moist, many clay coatings, gradual boundary;

BC – 71–128 cm, transitional horizon, silt loam, reddish brown (5YR 4/4) illuvial lamellaes and pale and light-gray interlamellaes material, medium moderate subangular structure, slightly moist, compacted, gradual boundary;

C – 128–(140) cm, parent material, silt loam, light yellowish brown (10YR 6/4), medium moderate subangular structure, compacted, slightly moist.

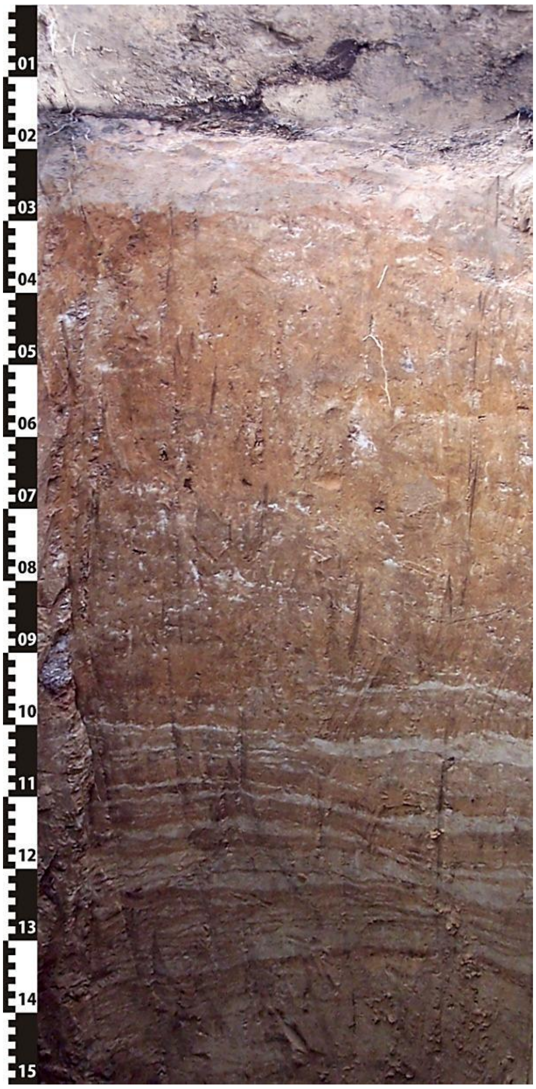
Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–22	–	0	18	60	8	4	10	SiL
Ap2	22–34	–	0	24	54	4	8	10	SiL
EBg	34–39	–	0	27	55	6	6	6	SiL
Bt	39–71	–	0	24	54	6	8	8	SiL
BC	71–128	–	0	22	52	8	3	15	SiL

Table 2. Agrochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[g·kg^{-1}]			
Ap	0–22	26.9	5.9	4.49	3.76	14.91	1.17
Ap2	22–34	15.5	4.6	2.72	3.12	10.60	1.07
EBg	34–39	4.0	5.0	2.33	0.32	8.90	1.22
Bt	39–71	3.1	4.5	1.97	0.63	15.93	2.79
BC	71–128	1.9	4.0	3.11	0.44	8.95	1.96

Profile 2 – Stagnic **Luvisol** (Aric, Cutanic, Pantosiltic, Ochric, Bathylamellic)
Localization: upper slope (inclination 8°), arable land, 182 m a.s.l.,
N 54°14′15″ **E** 31°7′1″



Morphology:

Ap – 0–22 cm, ploughed humus horizon, silt loam, brownish-gray with brown spots (10YR 4/3), granular structure, moist, compacted, inclusions of organic (manure); few roots, abrupt and smooth boundary;

ABp – 22–28 cm, humus horizon ploughed in the past, some inclusions of material from illuvial horizon with cutans, silt loam, pale brown (10YR 6/3), granular structure, slightly moist, compacted, worms, few roots; abrupt and smooth boundary;

Bt(g) – 28–63 cm, *argic* horizon, silt loam, reddish brown (5YR 4/4), with whitish veins, medium moderate subangular structure, slightly moist, weakly developed stagnic properties, many clay coatings, gradual boundary;

Btg – 63–113 cm, *argic* horizon with stagnic properties, silt loam, reddish brown (5YR 4/4), with whitish veins and common fine reductimorphic mottles (5Y 5/4), medium moderate angular blocky/platy structure, compacted, moist, common clay coatings, gradual boundary;

BC – 113–(150) cm, transitional horizon, silt loam, reddish brown (5YR 4/4) illuvial lamellaes and pale and light-gray interlamellaes material, medium moderate subangular structure, moist, compacted.

Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–22	–	1	12	67	6	7	7	SiL
ABp	22–28	–	0	23	53	5	5	14	SiL
Bt(g)	28–63	–	0	15	56	8	7	14	SiL
Btg	63–113	–	0	15	54	9	6	16	SiL
BC	113–(150)	-	1	15	55	8	6	15	SiL

Table 4. Agrochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[g·kg^{-1}]			
Ap	0–22	23.6	4.8	2.33	4.19	15.45	2.14
ABp	22–28	6.5	5.8	5.52	1.94	14.23	2.23
Bt(g)	28–63	3.2	4.3	2.55	0.56	13.18	1.87
Btg	63–113	3.6	3.8	2.94	0.60	12.12	2.28
BC	113–(150)	2.6	4.0	2.94	0.46	8.55	1.67

Profile 3 – Stagnic **Luvisol** (Aric, Cutanic, Pantosiltic, Ochric, Bathylamellic)
Localization: middle slope (inclination 8°), arable land, 178 m a.s.l.,
N 54°14′17″ **E** 31°6′58″

Morphology:

Ap – 0–20 cm, ploughed humus horizon, silt loam, light brownish gray (10YR 6/7), some inclusions of material from illuvial horizon with cutans, granular structure, moist, compacted, inclusions of organic (manure), few roots, abrupt and smooth boundary;

Bt(g) – 20–60 cm, *argic* horizon, silt loam, reddish brown (5YR 4/4), with whitish veins, medium moderate subangular/platy structure, moist, weakly developed stagnic properties, many clay coatings, clear and smooth boundary;

Btg – 60–105 cm, *argic* horizon with stagnic properties, silt loam, reddish brown (5YR 4/4), with whitish veins and common fine reductimorphic mottles (5Y 5/4), medium moderate angular blocky/platy structure, compacted, moist, common clay coatings, clear and smooth boundary;

BC – 105–(150) cm, transitional horizon, silt loam, reddish brown (5YR 4/4) illuvial lamellaes and pale and light-gray interlamellaes material, medium moderate subangular structure, moist, compacted.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–20	–	1	17	57	6	7	12	SiL
Bt(g)	20–60	–	0	17	54	8	7	14	SiL
Btg	60–105	–	0	16	53	9	6	16	SiL
BC	105–(150)		0	15	52	10	6	17	SiL

Table 6. Agrochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[g·kg^{-1}]			
Ap	0–20	12.5	4.69	1.76	3.47	8.21	1.35
Bt(g)	20–60	4.5	3.97	2.11	0.66	9.49	0.88
Btg	60–105	4.0	3.84	3.09	0.63	10.50	1.81
BC	105–(150)	3.8	4.56	1.64	0.64	8.89	2.30

Profile 4 – Eutric **Stagnosol** (Aric, Colluvic, Humic, Pantosiltic)
Localization: toe slope (inclination 3°), arable land, 178 m a.s.l.,
N 54°14′18″ **E** 31°6′55″

Morphology:

Ap – 0–25 cm, ploughed humus horizon, colluvial material, silt loam, dark grayish brown (2.5Y 4/2), very few fragmented cutans (papules), granular structure, moist, compacted, inclusions of organic (manure), few roots, abrupt and smooth boundary;

Ag1 – 25–40 cm, humus horizon with stagnic properties, colluvial material, silt loam, grayish brown (2.5Y 5/2), common whitish reductimorphic material and oximorphic rusty spots, very few fragmented cutans (papules), granular structure, moist, compacted, abrupt and smooth boundary;

Ag2 – 40–90 cm, humus horizon with stagnic properties, colluvial material, silt loam, olive brown (2.5Y 4/3), common oximorphic rusty spots, very few fragmented cutans (papules), granular structure, moist, compacted, clear and smooth boundary;

Ag3 – 90–105 cm, humus horizon with stagnic properties, colluvial material, silt loam, dark bluish gray (GLEY 2 5PB 4/1), common oximorphic rusty spots, very few fragmented cutans (papules), granular structure, moist, compacted, clear and smooth boundary;

2Agb – 105–123 cm, buried humus horizon, silt loam, bluish black (GLEY 2 5PB 2.5/1), granular structure, moist, compacted, clear and wavy boundary;

2Bg – 123–(150) cm, illuvial horizon with reducing conditions, silt loam, olive gray (5YR 5/2) and yellowish red (5YR 4/6) spots, massive structure, wet.

Table 7. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm							Textural class
		1–0.5	0.5–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Ap	0–25	–	0	17	57	8	5	13	SiL
Ag1	25–40	–	0	15	58	8	6	13	SiL
Ag2	40–90	–	0	13	60	7	6	14	SiL
Ag3	90–105	–	0	13	57	8	6	16	SiL
2Agb	105–123	–	0	13	55	10	7	15	SiL
2Bg	123–(150)	–	0	11	53	11	8	17	SiL

Table 8. Agrochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH KCl	P_2O_5	K_2O	Ca	Mg
				[g·kg^{-1}]			
Ap	0–25	30.6	5.7	2.61	4.19	15.03	3.28
Ag1	25–40	14.4	5.4	1.24	2.28	9.80	1.85
Ag2	40–90	11.5	5.0	0.60	1.23	8.03	1.65
Ag3	90–105	14.8	4.7	0.85	2.18	7.89	1.55
2Agb	105–123	29.9	4.3	0.47	2.24	13.00	1.57
2Bg	123–(150)	7.1	4.0	1.09	0.59	9.74	0.84

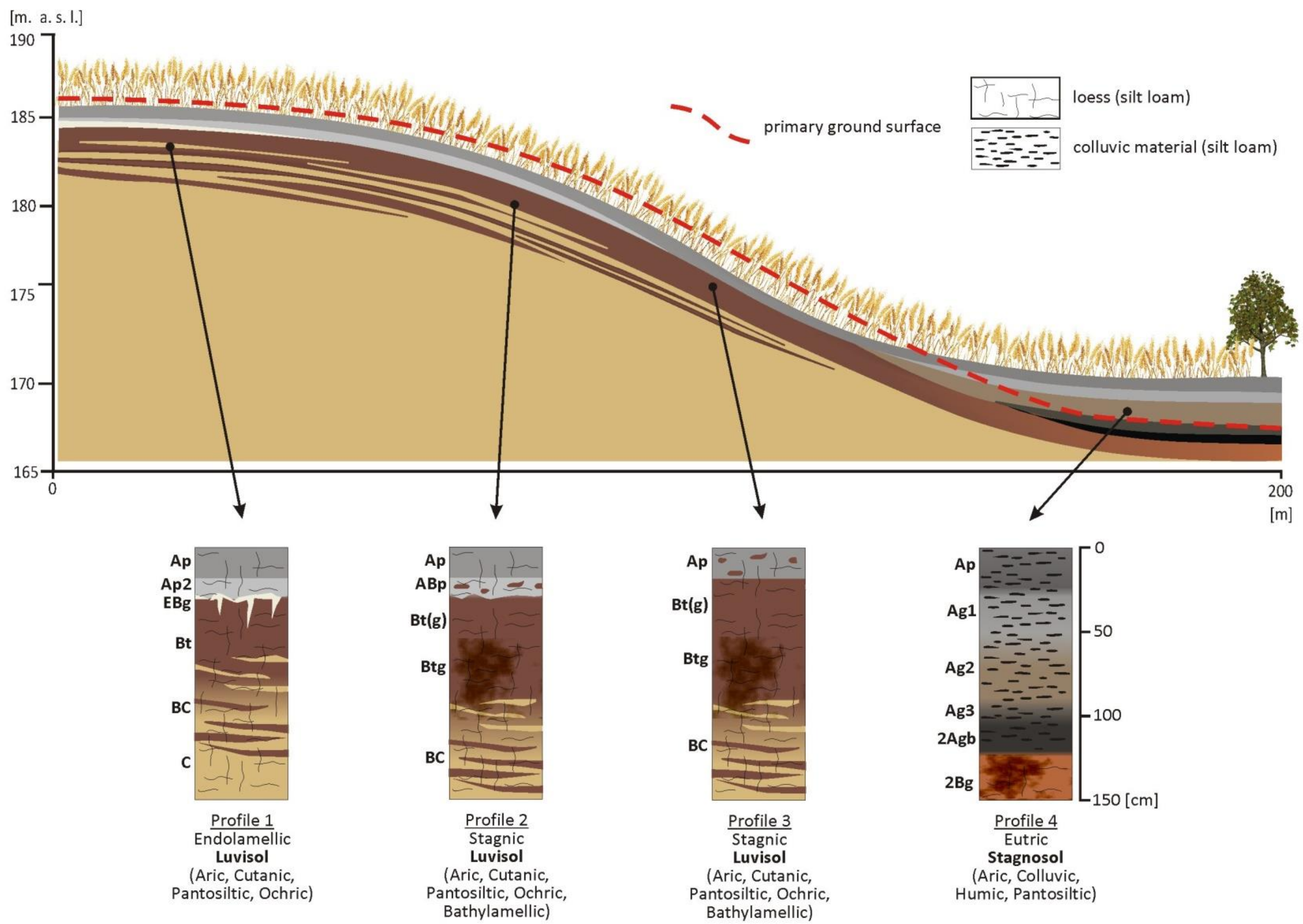


Fig. 2. Toposequence of soils of the agricultural lands of the Horatskaya Plain

Soil genesis and systematic position

All studied soils had two common features: they were ploughed to a depth 20 cm of more and developed from material with a silt loam texture. Accordingly, the ***Aric*** and ***Pantosiltic*** qualifiers were used in all cases.

The region's humid climate, with relatively high mean annual effective rainfall, favours the lessivage process and clay translocation (Arkley, 1967; Quénard et al., 2011). Moreover, the silt loam texture of the loess maintains the perfect conditions for the vertical downwards flux of water (Quénard et al., 2011; Cornu et al., 2014). The above factors led to the development of Bt *argic* horizons with abundant illuvial clay coatings and infillings in most investigated soils (Profiles 1–3). The common presence of illuvial clay forms was expressed by the ***Cutanic*** supplementary qualifier. These pedons had no other diagnostic horizons and no *retic* properties, and were characterised by: (i) more-or-less homogenous vertical texture (lack of *abrupt textural difference*), (ii) high-activity clays, and (iii) high base status. All of these features allowed them to be classified as **Luvisols** (IUSS Working Group, 2015). In all three cases the upper part of the *argic* is homogenous, but the form of the lower section has many clearly visible illuvial lamellae changing gradually into parent material. In Profile 1 the lamellae start at 71 cm from the mineral surface of the soil, which has been marked by the ***Endolamellic*** principal qualifier. In the second and third pedons the depth of lamella occurrence is higher than 100 cm, and they are thus expressed only in the supplementary subqualifier ***Bathylamellic***. *Argic* horizons in Profiles 2 and 3 had higher content of clay fraction than Bt in Profile 1. This resulted in their low permeability and was probably the main cause of distinct stagnic properties (***Stagnic*** principal qualifier). The stagnation of water was also reflected in some features of the EB horizon in the first profile but it was not thick enough (only 5 cm) to use this qualifier. The humus horizons of the described Luvisols were not dark enough to fit the requirements of *Mollic* or *Umbric*. However, having organic carbon content higher that 0.2% (Table 2) with total depth more than 10 cm, they fit with the requirements of the ***Ochric*** qualifier.

The last pedon was developed as a result of accumulation of young slope deposits (***Colluvic***) which have visible vertical zonation associated with a varied content of humus (e.g., Świtoniak, 2015). These colluvial mineral deposits have too light a colour for any of the diagnostic surface horizons (*mollic*, *umbric*, etc.) but have significant stocks of organic carbon – high enough for the ***Humic*** qualifier. The discussed soil was located in a depression, resulting in its substantial moisture. Reductimorphic and oximorphic mottles are common from a depth of 25 cm. The shallow occurrence of stagnic properties led to the profile being classified as a **Stagnosol**. The effective base saturation in the major part between 20 and 100 cm from the mineral soil surface is higher than 50%, as emphasised by the ***Eutric*** principal qualifier.

Soil sequence

All studied soils located within the summit and slopes are formed on the same parental material – loess (with silt loam texture), which is the most prone to erosion (Chernysh, et al., 2009). The same climatic conditions influenced the soil-forming factors in the whole catena, so the key factor determining the features of the described soils is their location in different parts of the slope. Intensive agricultural use led to intensive erosional processes (e.g., Papendick and Miller, 1977; Jankauskas et al., 2003; Van Oost et al., 2003; De Alba et al., 2004; Marcinek and Komisarek, 2004; Leopold and Völkel, 2007; Dreibrodt et al., 2010; Świtoniak, 2014).

All investigated profiles showed strong alterations associated with slope processes (Chernysh et al., 2009).

The first pedon is located on an almost flat summit and was slightly changed by truncation. The primeval eluvial horizon was partially washed away and/or mixed with humus horizon by ploughing. Currently it forms only discontinuous and fragments between the Ap2 and Bt horizon. The second **Luvisol** is characterised by almost total lack of an eluvial zone. The surface humus horizons contain coarser material, primarily from the E horizon, which was completely mixed by ploughing with Ap horizons. Moreover, some of the material from the Bt horizon is incorporated into the lower part of the plough layer (ABp). In this stage of truncation, soil can be classified as moderately eroded (Świtoniak, 2014). In the strongly eroded Profile 3 the whole material from the eluvial horizon was removed by erosion and the pedon become texturally homogeneous. Surface horizons include illuvial material from the *argic* horizon (Bt).

The changes in the degree of erosion are connected with the character of the parental material, the length and steepness of the slope, and many other factors. In the conditions of the investigated territory, the steepness of the slope plays the greatest role. The soils that form are non-eroded on the slopes with a steepness of less than 1°, slightly eroded on the slopes of gradient 1–3°, medium-eroded on the slopes of 3–5°, strongly eroded on slopes of 5–7°, and strongly and moderately eroded on steeper soils (Chernysh, 2005).

Strong erosion processes led to accumulation of thick colluvium in foot-slope and toe-slope positions. This was confirmed by Profile 4, where slope deposits were more than 1 m thick. The low permeability of these deposits led to the development of **Stagnosol**. Colluvial material also contains remains of Bt horizons comprising material from slope erosion in the form of fragmented cutans (papules) that were partially destroyed when the material was transported down the slope (Brewer, 1976; Kemp, 1998; Świtoniak et al., 2016).

To prevent soil degradation and reduce the intensity of erosion processes, it is necessary to introduce soil protection systems in agriculture and, first of all, to increase the areas of perennial grasses.

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