Diversity of soils in the Dnipro River valley (based on the example of the Dnipro-Orilsky Nature Reserve)

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Abstract

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The study established the classification position of the soils of the Dnipro River valley (within the Dnipro-Orilsky Nature Reserve) according to the international WRB classification. The pits were laid along three transects that passed through the most significant relief gradients within the study area. The study of the morphological structure of 20 soil profiles showed that the soil cover is closely related to the geomorphological structure of the river valley. The morphological characteristics of typical profiles of these soils reflect their structure, properties and genesis and determine the classification position of the soils according to the WRB. Multidimensional scaling allowed us to perform soil ordination in the space of two dimensions. Dimension 1 differentiates soils by the gradient of relief height and/or moisture level. Dimension 2 differentiated hydromorphic soils. The properties of Quaternary sediments were found to determine the position of soils at both levels of classification (reference groups, main and additional classifiers). The distribution of each of the reference groups is clearly related to the geomorphology of the valley. Arenosols and Cambisols form the soil cover of the floodplain terrace, while Fluvisols and Gleysols are found mainly in the floodplain.

Keywords

floodplain, landscape management, multidimensional scaling, nature conservation, soil cover, transition matrix

Introduction

Information on the diversity and leading factors of land cover formation is important for understanding the current state and developing strategies for the conservation of rivers and landscapes shaped by their activities (Diviaková et al., 2022; Ward et al., 2002). Soils in floodplains and riparian zones provide important ecosystem functions and services (Gregory et al., 1991). Understanding the natural variability of soil properties is the basis for developing effective monitoring programs to assess the potential changes in riparian soil properties. Floodplain management has therefore shifted from river control to river and floodplain restoration (Serra-Llobet et al., 2022). The management of riparian systems to restore soil ecosystem services depends on the identification of effective environmental indicators that can be applied as a measure of progress toward restoration (Bujnovský and Koco, 2022; El Hourani and Broll, 2021; Hale et al., 2014).

Meandering and anabranching rivers were the most common types of channel forms in Europe in the Late Pleniglacial (~30,000–14,700 cal BP – "calibrated years before the present"), Late Ice Age (14,700–11,700 cal BP), and Holocene (Słowik, 2023). In many parts of the European continent, well-developed terrace systems have been preserved. In contrast, the rivers within the Eastern Euro

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pean Platform have a large sedimentary archive that has not been preserved as terrace steps (Ponomarenko et al., 2022). Instead, they form sets of laterally piled sedimentary rock packages that are never more than a few tens of meters above or below the modern river level. The different preservation styles of fluvial archives are of great importance for Quaternary stratigraphy (Demir et al., 2018). Dnipro River valleys are among the youngest and most dynamic landforms. They were formed in the Holocene and continue to develop actively (Parkhomenko, 2015). Within the Holocene, three paleohydrological epochs of millennial scale were revealed: (1) high activity 12,000–8,000 cal BP, characterized by large river paleo-systems; (2) low activity 8,000–3,000 cal BP, characterized by the formation of zonal soils on floodplains; short episodes of high floods occurred between 6,500–4,400 cal BP; (3) contrasting hydrological fluctuations starting from 3,000 cal BP, with periods of high floods between 3,000–2,300 (2,000) and 900–100 cal BP, separated by a long interval of low floods of 2,300 (2,000)–900 cal BP, when floodplains were not flooded and zonal soils were formed. In the last millennium, four centennial intervals were identified: high floods occurred in the mid-11th to mid-15th century and the mid-17th to mid-20th century. Intervals of flood activity similar to the present occurred in the mid-15th to mid-17th century and from the mid-19th century to the present (Panin et al., 2014). Valley ecosystems are complex natural complexes with considerable spatial variability (Rinklebe and Langer, 2006; Scoggins and Van Iersel, 2006; Stolt et al., 2001). The soils of valley landscapes are affected by erosion processes (Mounirou et al., 2022) and sedimentation phenomena (Krasa et al., 2019), as well as transformation and translocation of matter (Ma et al., 2023), which in general results in a constant impact that forms strata and layers of sand or clay deposits and varying degrees of humus accumulation (Gritsan et al., 2019; Kunakh et al., 2022). The soil formation of floodplain soils is significantly influenced by the formation of parent and subsoil rocks, variability of the water table, past and current river flow rates, relief positions, proximity to the riverbed or dam, and anthropogenic factors (Wälder et al., 2008; Kunakh et al., 2023). The valley soils are understood as complex polygenetic and polychronous formations (Šamonil et al., 2018) that reflect ancient stages of litho- and pedogenesis and the geomorphological and geological structure of river valleys (Didukh et al., 2015; Woronko et al., 2022; Zuffetti et al., 2018).

The territory of the Dnipro-Orilsky Nature Reserve provides a unique opportunity to study the diversity of soils in the Dnipro River valley landscapes. The soil cover of the protected area is subject to limited anthropogenic impact, which allows to study the natural factors of soil formation in the river valley, in particular the role of Quaternary sediments as parent material. According to the national classification, the soil cover of the Dnipro valley is formed by a complex of alluvial meadow, alluvial sod, soddy bog, meadow, meadow-bog, bog and meadow-chernozem soils (Zhukov et al., 2017; Gritsan et al., 2019). The information on the diversity of soil cover in the Dnipro River valley based on the international WRB classification is fragmentary and needs to be expanded and generalized.

The aim of the study was to determine the classification position of the soils of the Dnipro River valley (within the Dnipro-Orilsky Nature Reserve) according to the international WRB classification and the role of Quaternary sediments in forming the diversity of the valley soils.

Materials and methods

The research was conducted in the Dnipro-Orilsky Nature Reserve (Fig. 1). The modern relief of the reserve is very mosaic. The Dnipro floodplain is formed by furcation, and the meandering of the riverbed is almost undeveloped (O. Kunakh et al., 2023). The genetic zones of the modern floodplain, formed as a result of channel furcation, are superimposed on genetic zones associated with the degree of remoteness from the main channel, i.e. with the attenuation of alluvial intensity (Manyuk, 2005). The geomorphological structure of the Dnipro valley is complicated by the geological activity of the Dnipro's left tributaries, the Oril River and the Protoch River. The latter is currently a sequence of ancient lakes (Manyuk, 2019). The Quaternary rocks of the valley are represented by lake, lake-bog, alluvial, alluvial-diluvial and aeolian sediments (Gritsan et al., 2019). The relief of the Reserve's territory is represented by the alluvial forms of the Prydniprovska lowland. There are three terraces in the area of the Reserve. The lowest position in relation to sea level is occupied by a well-developed floodplain terrace, crossed in different directions by numerous channels, dotted with lakes and swamps. The floodplain terrace extends along the Dnipro River for 16 km within the reserve. In its widest part, in the Taromskyi ledge, it reaches 2 km, and in its narrowest part, in the Mykolaivskyi ledge, it reaches 1 km (Zymaroieva et al., 2022). The floodplain in the modern relief of the reserve corresponds to the first and second geostructural terraces of the Dnipro. The first geostructural terrace, due to its low hypsometric position (+48–+50 meters above sea level), was almost completely flooded by the waters of the Dnipro and is present in the form of separate fragments in the modern mouth of the Protoch River. Most of the modern floodplain is located on the second geostructural terrace, the surface of which is at +50–+55 meters above sea level. The floodplain is represented by layered modern alluvium. The lower layers of alluvium are represented by the channel facies formed as a result of sedimentation during the water level drop. There are numerous lakes in the floodplain, some of which have turned into swamps and are cut by a network of winding or sickle-shaped ditches and channels. The second geomorphological terrace corresponds to the third geostructural terrace, with elevations ranging from +55 to +65 meters above sea level. It is a so-called arena. The arena is a large elevated massif of alluvial sands, processed and significantly complicated by aeolian processes to form a mound-hilly relief typical for the Prydniprovia region. Aeolian processes are manifested in the dispersal and re-suspension of alluvial sands in places where there is no soil and vegetation cover, mainly in the northwestern part of the Reserve. This results in the formation of mounds 4–6 meters high. The highest mounds are developed on the border of the arena and the

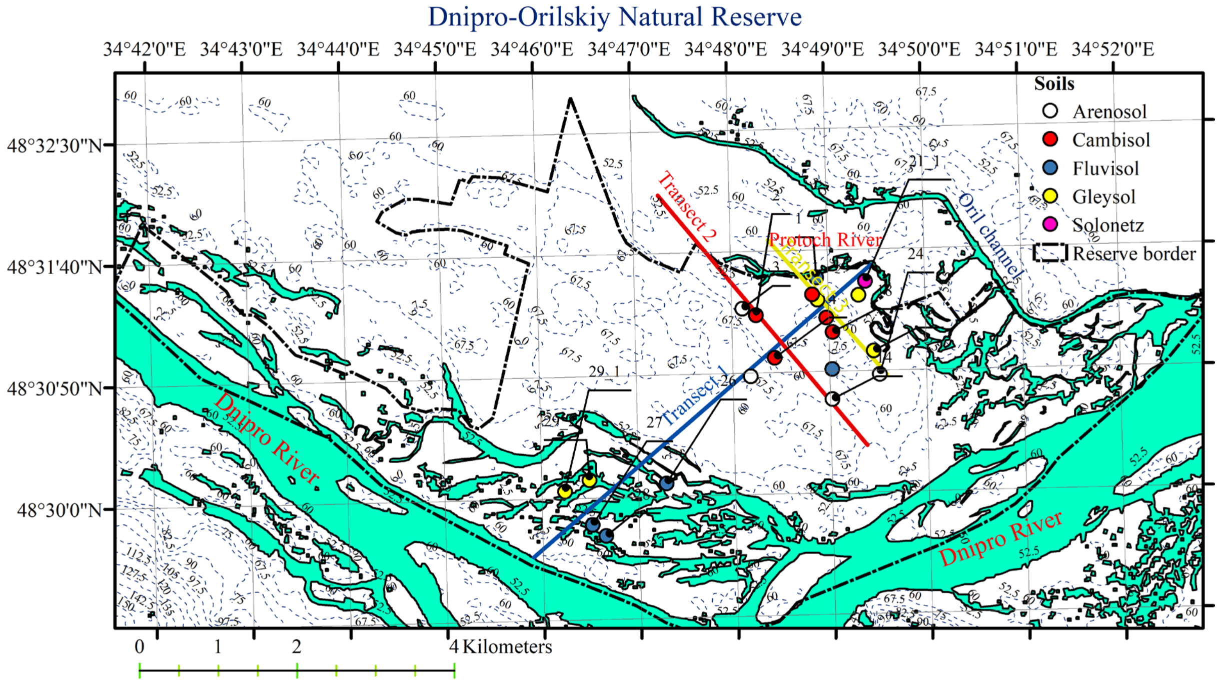


Fig. 1. Transects along which pits were dug within the Dnipro-Orilsky Nature Reserve and WRB Reference Soil Groups.

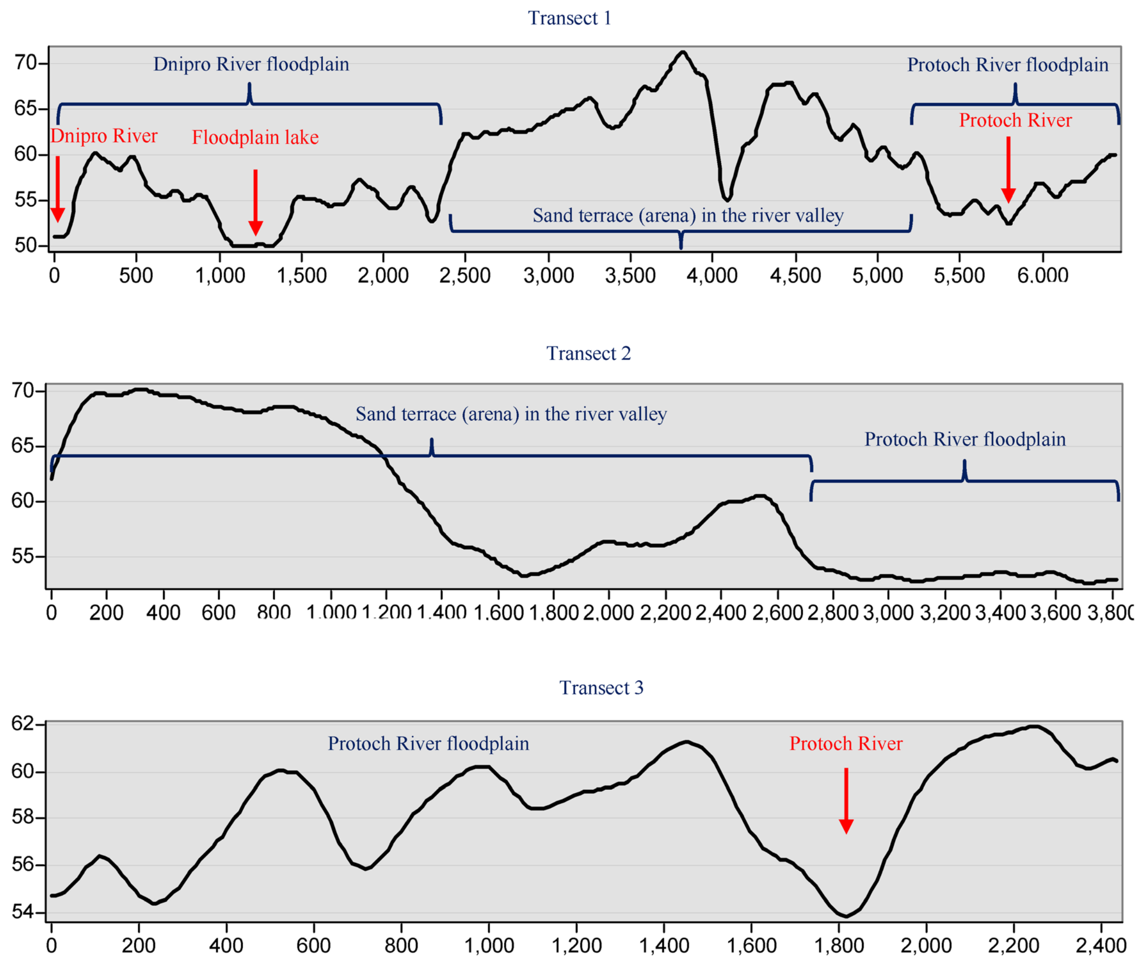


Fig. 2. Terrain elevation changes along the transect. The abscissa is the distance (m); the ordinate is the elevation in meters above sea.

floodplain, near Lakes Mala Khatka and Horbove, where the alluvial sand hills rise to 70 meters above sea level and rise to a height of 18–19 meters above the floodplain. Aeolian deposits are represented by quartz light gray and yellow sands. The thickness of these deposits is 12–14 m.

The pits were excavated between May and September along three transects that ran across the most significant relief gradients in the study area (Fig. 2). Transect 1 embraced the floodplain of the Dnipro River and the first above-floodplain terrace (arena). Transect 2 covered the zone of transition of the above-floodplain terrace into the floodplain of the Protoch River. Transect 3 covered the floodplain of the Protoch River.

Soil morphology was described according to the FAO Guidelines (WRB, 2015). The genetic type of soil profile was determined by Rozanov (Rozanov, 2004). The type, shape, and intensity of redoximorphic features (mottling and concentration) as well as soil structure and colour in the upper and subsoil horizons were focused on. The soils were classified according to the WRB classification (WRB, 2015). Soil colour (when wet) was determined using Munsell colour charts.

The groundwater level was determined visually in the soil pits. If the groundwater was below the depth of the soil pit, then the level was estimated using the altitude above channel network. Altitude above channel network, or Vertical Distance to Channel Network (VDTCN), is the difference between elevation and channel network height (Olaya and Conrad, 2009). It is a reliable marker of the water table and can be used for soil mapping (Bock and Köthe, 2008).

Soil profiles were numerically compared by properties using a function profile_compare from the package *aqp* (Beaudette et al., 2022). The profiles were classified by the colour of the horizons (‘hue’, ‘value’, ‘chroma’), horizon thickness, and the presence of the qualifier (Eutric, Pantofluvic, Loamic, Protocalcic, Humic, Aeolic, Ochric, Arenic, Mollic, Calcic, Gleyic, Fluvic, Lamellic, Nechic, Thaptoochric), texture class according to USDA classification (FAO, 2006): S – sand; gS – gravelly sand; LS – loamy sand; SL – sandy loam; L – loam; SiCL– silty clay loam; SiL – silt loam; SC – sandy clay; structure class: gr – granular, sb – subangular blocky, ab – angular blocky, pr – prismatic, pl – platy, m – massive, sg – single grain; and also subordinate characteristics within horizons: accumulation of pedogenetic carbonates (k), accumulation of organic matter (h), pedogenetic accumulation of salts more soluble than gypsum (z), buried genetic horizon (b), concretions or nodules (c), gleying (l), strong reduction (r), illuvial accumulation of silicate clay (t). Soil horizons A are mineral horizons that formed at the surface. B horizon is formed below an A horizon and in which the dominant features are the obliteration of all or much of the original rock structure. C horizon or layer is little affected by pedogenetic processes. W layer are water layers in soils or water submerging soils, either permanently or cyclic within the time frame of 24 hours. For transitional horizons dominated by properties of one master horizon but having subordinate properties of another, two capital letter symbols are used, such as AB, EB, BE and BC. Transitional horizons in which distinct parts have recognizable properties of two kinds of master horizons are indicated as above, but the two capital letters are separated by a virgule (/), such as A/C, B/C and A/B.

The distance matrix derived from the comparison was analyzed by Nonmetric Multidimensional Scaling (NMDS) scaling using the package *vegan* (Oksanen et al., 2022). The soil profiles were sorted along the MDS1 or MDS2 dimensions. Then, for each sorting option, a transit matrix was calculated for both soil horizons and soil horizon colours using a function *hzTransitionProbabilities* from the package *aqp*. 1,000 transit matrices were calculated for the profiles that were sorted randomly. The transition matrices for the variants with sorting along the dimensions were compared with the random alternatives using the *as.randtest* function from the *ade4* package (Thioulouse et al., 2018). The statistically significant transition probabilities for $p < 0.05$ only were presented graphically.

The spatial database (Valerko et al., 2022) was created in the software ArcGIS (ESRI, 2011). Digital elevation model (DEM) is a presentation of the Earth’s surface in numerical format. The Advanced Land Observation Satellite – ALOS (http://www.eorc.jaxa.jp/ALOS/en/index.htm) data were used to generate a digital elevation model. Spatial resolution for the study area is 30 meters, nominal vertical accuracy and nominal horizontal accuracy is 5 meters. By means of kriging procedure DEM was resampled to a resolution of 10 m (Susetyo, 2016; Kunakh et al., 2020; Zhukov et al., 2021). The kriging procedure also made it possible to obtain a DEM suitable for calculating the derived layer – Vertical Distance to Channel Network (VDTCN) (Hojati and Mokarram, 2016).

Results

Soil diversity in the Dnipro River valley

The Quaternary sediments of the Dnipro Valley are characterized by geological youth and dynamism of the land forming processes, which determines their decisive role as parent rocks in the formation of the diversity of soils in the valley. The study of the morphological structure of 20 soil profiles (Table S1) in the different parts of the valley revealed that the soil cover is clearly related to the geomorphological structure of the river valley. According to the WRB, the soil cover of the floodplain terraces is formed mainly by Fluvisols and Gleysols, the soil cover of the over floodplain terraces is mainly Arenosols and locally, where the granulometric composition is sandy loamy, Cambisols are represented. The Protoch River floodplain is also covered by Solonetz. The morphological characteristics of the typical profiles of these soils reflect their structure, properties, and genesis and determine the classification position of soils according to WRB (Fig. 3).

Arenosols

The Arenosols pits were located at relief heights of 62.0–70.2 m (65.6 ± 3.8 m). The groundwater level was 3.3–12.6 m (7.7 ± 3.9). The Arenosols’ profile was represented by the Ah, CA (sometimes A/C), CAb, and C horizons.

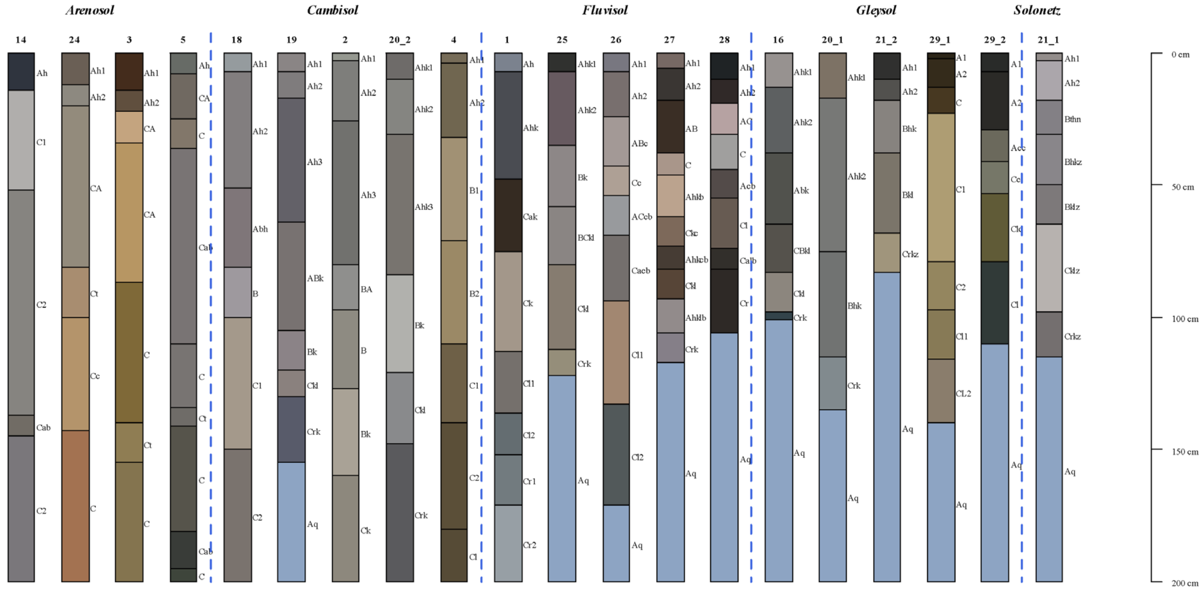


Fig. 3. Soil profiles. Shown are the colours of soils close to natural. Arenosol: 3 is Eutric Arenosol (Aeolic, Ochric); 5 is Eutric Arenosol (Aeolic, Ochric, Thaptoochric); 14 is Eutric Arenosol (Aeolic, Ochric, Thaptoochric); 24 is Eutric Lamellic Arenosol (Aeolic, Ochric); Cambisol: 2 is Eutric Cambisol (Humic, Loamic); 4 is Eutric Cambisol (Loamic, Ochric); 18 is Eutric Cambisol (Humic, Loamic); 19 is Eutric Cambisol (Arenic, Protocalcic, Humic); 20_2 is EutricCambisol (Arenic, Protocalcic, Humic); Fluvisol: 1 is Eutric Pantofluvic Fluvisol (Protocalcic, Humic, Loamic); 25 is Eutric Gleyic Pantofluvic Fluvisol (Protocalcic, Humic, Loamic, Nechic); 26 is Eutric Gleyic Panthofluvic Fluvisol (Arenic, Ochric, Thaptoochric); 27 is Eutric Gleyic Pantofluvic Fluvisol (Protocalcic, Humic, Loamic, Thaptoochric); 28 is Eutric Gleyic Pantofluvic Fluvisol (Humic, Loamic, Thaptoochric). Gleysol: 16 is Eutric Fluvic Calcic Mollic Gleysol (Humic, Loamic); 20_1 is Eutric Calcic Mollic Gleysol (Humic, Loamic); 21_2 is Eutric Fluvic Calcic Mollic Gleysol (Arenic, Humic, Salic), 29_1 is Fluvic Gleysol (Arenic, Ochric); 29_2 is Eutric Fluvic Mollic Gleysol (Humic, Loamic). Solonetz: 21_1 is Calcic Mollic Gleyic Solonetz (Fluvic, Humic, Loamic).

The Ah horizon was located in the range of soil depths of 0–52 cm (average 0–23.5 cm). It was typically dark gray, dry, non-aggregated sand. The horizon had a loose consistency, heavily intertwined with the root systems of herbaceous plants. This horizon was either homogeneous or differentiated into sub-horizons Ah1 and Ah2. The transition to the next horizon was sharp in colour. The transitional horizon CA was located in the range of soil depths 15–84 cm (average 21.0–56.8 cm). The buried CAb horizon was located in the range of soil depths of 36–200 cm (average 108.5–155.0 cm). The C horizon started at a depth of 52 cm (average 124.2 cm). Sometimes it contained concretions or nodules or iron-cemented lamellae (pseudofibers). The iron-cemented lamellae pseudofibers were found at a depth of 118–132 cm. The C horizon was sometimes represented by two sub-horizons that differed in composition: the upper sub-horizon was usually loose, and the lower sub-horizon was soft or slightly hard.

Cambisols

The Cambisols pits were located at elevations of 51.1–66.5 m (59.4 ± 4.6 m). The groundwater level was 1.6–8.1 m (3.4 ± 2.6 m). The Cambisols' profile was represented by horizons A, transitional horizons (AB, AC, A/C, CA), B, transitional horizons (BC, CB), and bedrock C. Horizon A could reach a depth of 106 cm, with an average of 45.2 cm. Gray, dry sandy loam. Weakly aggregated, crumbly, some aggregate units are held together by clusters of cereal roots, the structure is granular-dusty. Loose consistency, heavily intertwined with root systems of herbaceous plants. The horizon was either homogeneous or could be divided into 2 or three sub-horizons. The transition between the sub-horizons was sharp and wavy in colour, structure, and root saturation. Horizon B ranged from 18.0 to 114.8 cm (mean 49.0 to 77.8 cm). Horizon B was homogeneous or differentiated into two sub-horizons. Horizon C began at a depth of 31 cm (average depth 106.3). Horizon C was homogeneous or differentiated into two sub-horizons. The transition between the sub-horizons is sharp in terms of texture and colour. A gluey, grayish-gray sand of loose composition was found at a depth of more than 180 cm.

Fluvisols

The Fluvisols pits were located at elevations of 53.6–59.0 m (53.4 ± 2.1 m). The water level was 1.1–2.2 m (1.5 ± 0.5 m). The Fluvisols' profile was represented by horizons A, transitional horizons (AB, AC, CA), B, and transitional horizon BC, and bedrock C. The A horizon could extend from the surface to a soil depth of 106 cm, but on average, this horizon was 43.0 cm thick. The horizon was dark gray, well-structured, lumpy-grained, and contained coprolites. It was of loose consistency, abundantly intertwined with the root systems of herbaceous plants. The horizon could be homogeneous or consisted of two sub-horizons. The transition between the sub-horizons was smooth in composition. Horizon B is usually weakly expressed, most often the connection between horizon A and horizon C occurs through transitional horizons. Buried horizons were found at depths of 44–55 and 74–82 cm. In the latter case, traces of glazing were found in the horizon. In the immediate vicinity of groundwater, an alluvial gley horizon with strong reducing conditions was formed.

Gleysols

The Gleysols pits were located at elevations of 52.7–60.6 m (55.6 ± 3.1 m). The groundwater level was 0.2–1.4 m (0.96 ± 0.21 m). The Gleysols' profile was represented by horizons A, transitional horizons (AB, A/C), B, transitional horizon CB, and bedrock C. The A horizon could extend from the surface to a soil depth of 56.6 cm, but the average thickness of this horizon was 20.8 cm. Horizon A is a surface humus-accumulative, soddy horizon. The colour of the horizon was brown to dark gray. Sandy loam. Poorly compacted, abundantly interlayered with herbaceous root systems and decaying leaves. Fine- and coarse-grained, aggregates easily break up when pressed. Horizon material is easily separated from the next horizon. The transition to the next horizon is sharp in colour, structure and root system. Horizon A is usually divided into two sub-horizons. The transition between sub-horizons was marked by a sharp colour change, and the border has an undulating shape. The transition between sub-horizons is marked by a sharp colour change, and the border has undulating shape. The transition horizon was gray with dark gray or rusty spots. Moist, sandy loam. Unstructured, loose density. There were some roots of bushes and trees. The transition to the next horizon in colour is gradual and indistinct. A few alluvial horizons were found. The first alluvial horizon was light gray with irregularly shaped rusty spots extending mostly horizontally. It was moist, sandy, unstructured, and poorly compacted. Roots of tree species were encountered. The transition to the next horizon was colourless, indistinct, and 2–3 cm wide. The second alluvial sand horizon was wet. It was coloured rusty gray, grayish blue and brownish. The horizon was represented by 0.5–1 cm thick layers of humus material with an interval of 1.5–2 cm of background colour. Darker layers 0.5–1 cm thick alternated with light gray material 1.5–2 cm thick. The horizon was composed of loose sand, unstructured. There were roots of tree species. Transition to the next horizon by colour and moisture content. The alluvial gley sand horizon had grayish-blue, rusty-gray, dark gray colour, which is typical for the restoration conditions. The horizon had a loose density with horizontal dark gray gley

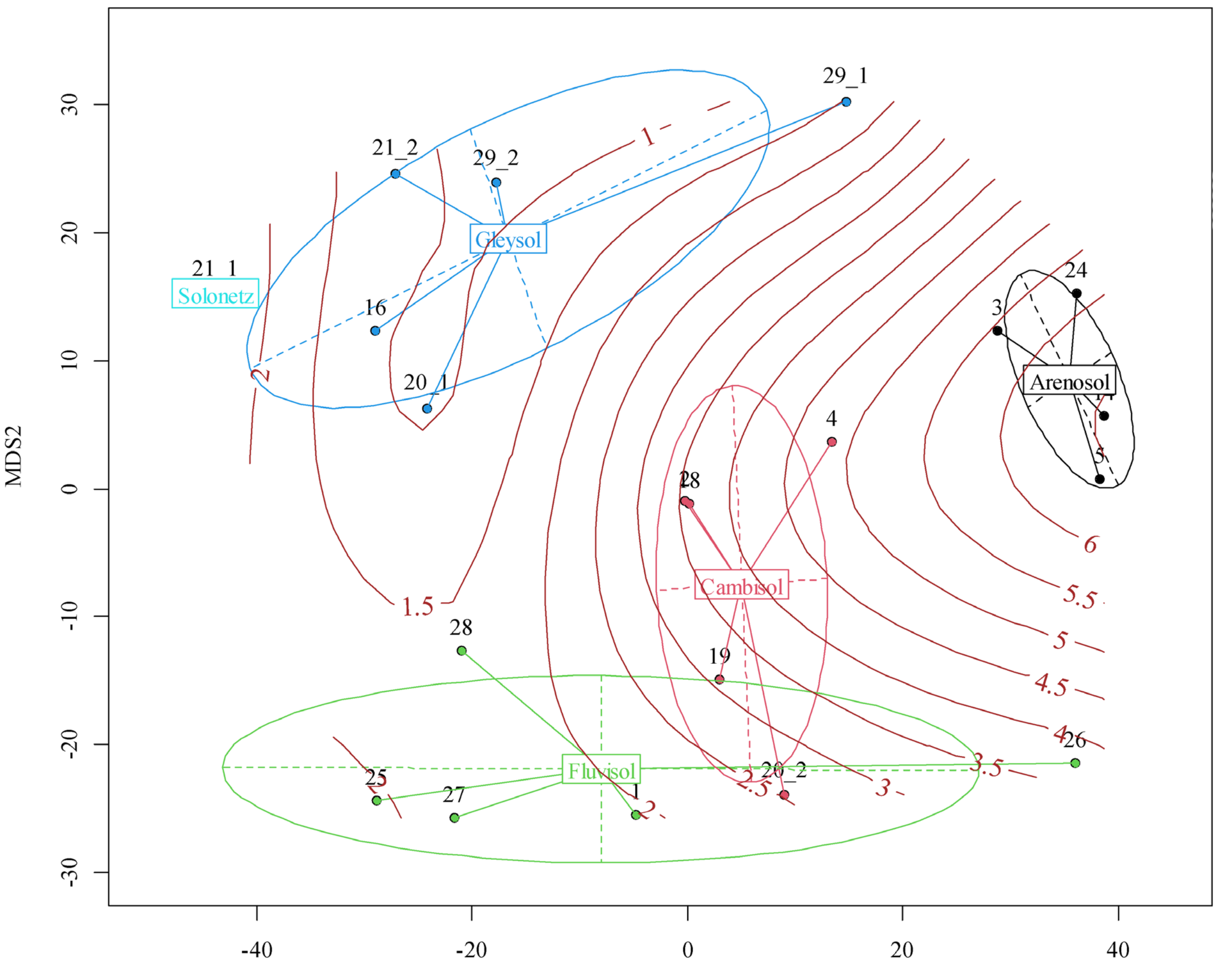


Fig. 4. Positioning of soils in the space of dimensions derived from the results of Nonmetric Multidimensional Scaling. The brown colour indicates the ground water level (m).

spots and rusty layers. Below the horizon was groundwater.

Solonetz

Solonetz was found in the floodplain of the Protoch River. The bedrock is alluvial sand. The revealed water table was 120 cm. There were some traces of soil invertebrates, which did not have a significant impact on the mixing of the horizons. There is a tendency to gleying in the form of red spots at a depth below 98 cm. There were no visible formations, carbonate fragments, or salt accumulation. The soil was dense or cohesive. The genetic type of the profile was eluvial-illuvial-differentiated. Boiling after the application of HCl was from a depth of 31 cm. The Solonetz profile was represented by horizons A, B and alluvial bedrock C. Horizon A with a total thickness of up to 18 cm was differentiated into two sub-horizons. The structure was gray, soddy, granular-dusty, loose, heavily intertwined with root systems of herbaceous plants. Horizon B ranged from 18.0 to 65.0 cm. It was differentiated into saline illuvial clay-humus (dark gray, merged, vertical cracks 0.5 cm wide forming pads 12–15 cm wide), sub-saline carbonate saline and carbonate saline (with spots of glaze) sub-horizons. The alluvial horizon C was differentiated into two sub-horizons based on grain size distribution, colour and intensity of glaze, and groundwater was found from a depth of 115 cm.

Multidimensional scaling

The multidimensional scaling allowed to perform the soil ordination in the space of two dimensions (Fig. 4). The dimension 1 differentiated soils in the gradient of relief height and/or moisture level. The higher values of dimension 1 corresponded to automorphic soils with predominantly atmospheric humidification (Arenosol), and the lower values corresponded to hydromorphic soils with soil water supply (Fluvisol, Gleysol, and Solonetz). The Cambisol occupied a transitional position. The dimension 2 differentiated hydromorphic soils. The higher values of dimension 2 corresponded to Gleysol, and the lower values corresponded to Solonetz and Fluvisol.

Transition of soil properties in a gradient of multidimensional dimensions

In the gradient of dimension 1, the main soil profile rearrangements were related to the B and C horizons or the buried A horizons (Fig. 5). An important interconnected cluster of horizons was made up of horizons with carbonate features. The sequential transition of soils in the gradient of dimension 1 was accompanied by changes in the colour properties of soils. The colour transit matrix was represented by clusters of 'gley' colours, which are represented by different variants of gray colour and a cluster of different variants of brown colour (Fig. 6).

In the gradient of dimension 2, an important factor in the organization of the soil profile is the depth of groundwater, which directly affects the AB and C horizons. A separate cluster of interconnected transitions is formed by horizons A, B, BC and C. Changes in the profile structure were also accompanied by changes in the colours of the horizons. In the gradient of dimension 2, the transformations of brown and gray colours were described as a single cluster.

Discussion

Floodplains and terraces together cover a significant part of the river valley. Floodplains are areas adjacent to the river, formed by the river in its current hydrological re-

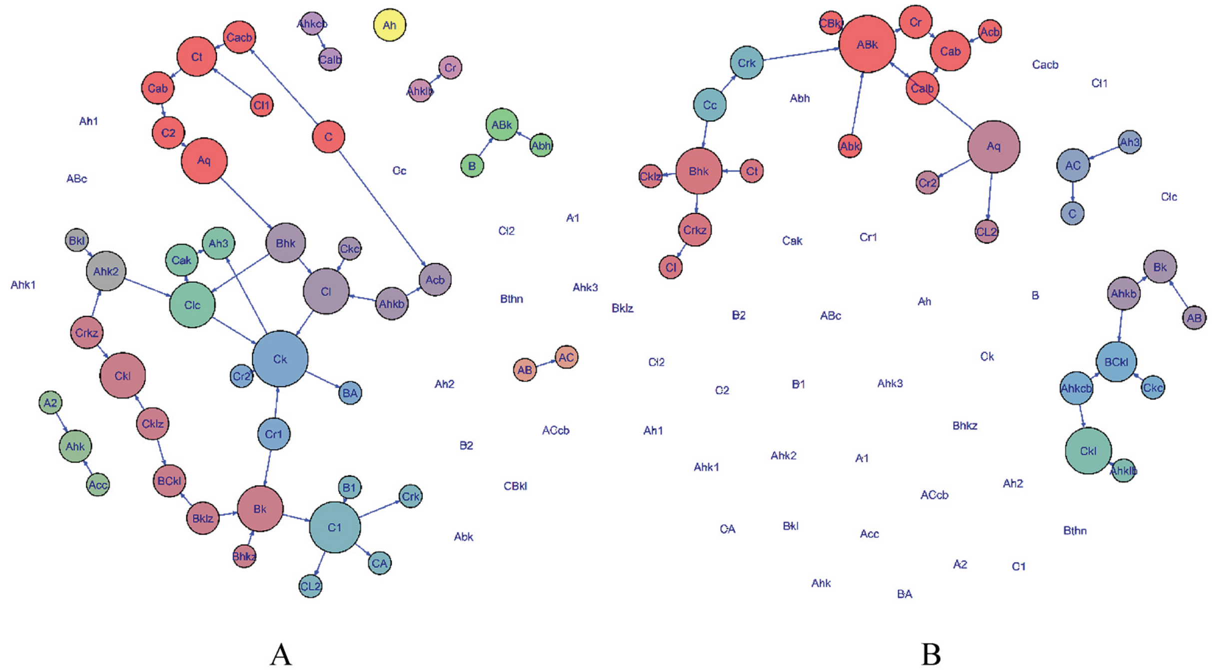
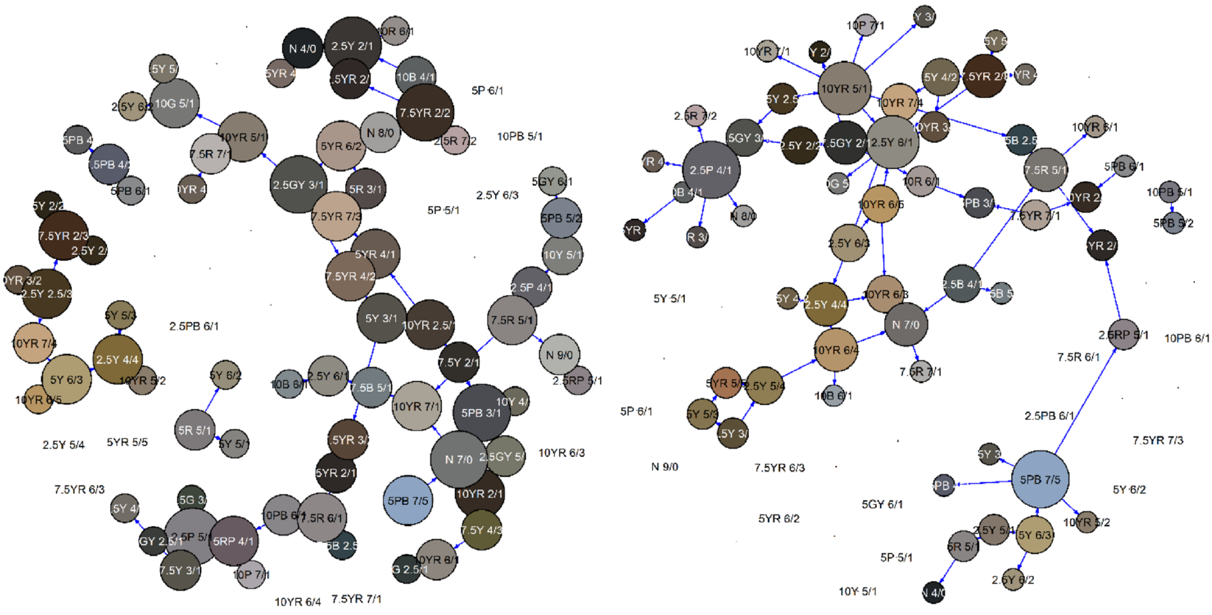


Fig. 5. Graph of relations between soil horizons based on the transition matrix in the gradient of dimensions extracted after multidimensional scaling: A – MDS1 gradient; B – MDS2 gradient.



A B

Fig. 6. Graph of relations between soil colours based on the transition matrix in the gradient of dimensions extracted after multidimensional scaling. Colours are shown close to natural. Colour coding is given according to Munsell: A – MDS1 gradient; B – MDS2 gradient.

gime and flooded during floods (Yan et al., 2018). Terraces are former and abandoned floodplains that are not integrated well into the existing hydrological regime of the river (Pazzaglia and Gardner, 1993). Fluvial terraces are stepped landforms that are at a higher elevation than the current water level and represent the residue of abandoned floodplains, valley bottoms, or channel beds formed by a previous stage of erosion or deposition (Kothyari and Luirei, 2016; Luirei et al., 2018). The topography and alluvial deposits of terraces record long-term geomorphic and hydrological responses to climatic and tectonic history (Pazzaglia, 2013).

The sand and loamy sand texture of alluvial and aeolian sediments is characteristic of the soils of the Dnipro River Valley arena terrace, which determines the underdeveloped and poorly differentiated Arenosols' A-C or A-CA-C profile. WRB Reference Soil Group Arenosols have a sandy texture over the entire depth of the soil profile. Lamellic is defined as a principal qualifier at the second level of classification due to the presence of thin reddish layers in the lower part of the profile, which result in a high content of clay fraction and iron compounds. Lamellae (or pseudofibers) are of pedogenic and petrogenic origin and are a typical element of the morphological structure of sandy soils in various natural zones (Bockheim and Hartemink, 2013; Gus-Stolarczyk et al., 2022; Holliday and Rawling, 2006; Rawling, 2000). Pseudofibers are usual for sandy loam and sandy soils of various natural zones (Blume and Schwertmann, 1969). Pseudofibers can prevent moisture infiltration in the spring (Zaidel'man et al., 2018). The appearance of nodules in the soil profile indicates a contrasting stagnation-percolation regime (Zaidel'man et al., 2018). Pseudofibers occur in all Arenosol profiles studied, but mostly below 100 cm, so they are not necessarily included as a qualifier. Wind activity forms aeolian relief forms on the surface of the original alluvial sandy deposits (supplementary qualifiers Aeolic), which causes the presence of buried humus layers in the profile (supplementary qualifiers Thaptoochric). Fluvial and aeolian actions influence the geomorphic conditions of river valleys (Field et al., 2009; Liu and Coulthard, 2015; Yang et al., 2020), which is one of the factors in the formation of soil cover. WRB Reference Soil Group Cambisols are formed in the erosive elements of the arena, under conditions of sandy loam (or much less often loamy sand) texture of the bedrock with a higher content of clay fraction compared to the conditions where Arenosols are formed. An increase in the content of the clay fraction in combination with other factors leads to a more complex and differentiated structure of the Cambisols' genetic profile: A-B-C or A-AB-C and the formation of the Cambic diagnostic horizon. In some Cambisol profiles, slight accumulations of secondary calcium carbonates are observed, which corresponds to the Protocalcic supplementary qualifier.

Periodic deposition of alluvial material and high groundwater levels is important in the genesis of floodplain soils (Bullinger-Weber and Gobat, 2006; Gerrard, 1987; Kawalko et al., 2021; Kercheva et al., 2017). WRB Reference Soil Group Fluvisols are diagnosed by the presence of fluvic material ≥ 25 cm thick from a depth of ≤ 25 cm from the soil surface. The periodicity of alluvial deposits causes a lithological heterogeneity, layered structure of the Fluvisols' profile and the presence of buried layers. Accordingly, the structure of genetic profiles of alluvial soils is characterized by considerable diversity. The depth of alluvial deposits in the Dnipro floodplain exceeds 100 cm, which is reflected in the Pantofluvic principal qualifiers. Depending on the topography, Fluvisols' profiles can show high water tables and associated gleyic properties starting from a depth of ≤ 75 cm from the soil surface. In some Fluvisols, minor accumulations of secondary calcium carbonates (additional qualifiers Protocalcic) and buried humus layers (additional qualifiers Thaptoochric) are diagnosed.

WRB Reference Soil Group Gleysols are formed under the influence of groundwater (Świtoniak et al., 2022), which leads to the appearance of gleyic properties starting from a depth of 40 cm from the surface and strongly reducing conditions in the lower part of the profile. The genetic profile has a typical structure of A-Bl-Cr, A-CAl-Cr. Most of the studied Gleysols are characterized by the principal qualifiers, Fluvic (presence of fluvic material in the layer starting from a depth of ≤ 75 cm from the soil surface) and Calcic (presence of a calcic horizon with an upper limit of ≤ 100 cm from the soil surface). In some profiles, the salic horizon is diagnosed from a depth of ≤ 100 cm from the surface.

The presence of a diagnostic natric horizon within ≤ 100 cm of the soil surface is a defining characteristic of RSG Solonetz. The classification of the Solonetz samples reflects the influence of saline groundwater and saturation with calcium carbonate (main qualifiers Gleyc and Calcic), alluvial origin and sandy loamy particle size distribution of the parent rock (additional qualifiers Fluvic and Loamic). The genetic profile has the following structure A-Btn-Blz –Crz.

Thus, the position of the Dnipro Valley soils at both levels of classification is determined by the physical and chemical properties and geological youth of the parent rocks. Soils belonging to RSG Arenosols and Fluvisols are diagnosed based on the properties and origin of the parent rock. In the diagnostics of RSG Gleysols, the water regime and gleyc properties are determined by the peculiarities of the river valley relief formed by Quaternary sediments of different age, thickness and lithology. The profile structure and properties of RSG Cambisols are also largely determined by the geological youth and grain size distribution of the parent rocks. Soils of the valley are characterized by saturation with bases (principal qualifiers of the Eutric), which is related to the composition of parent rocks, groundwater chemistry and climatic conditions of the steppe zone of Ukraine. In addition to the texture inherited by the soils from the parent rocks (supplementary qualifiers Arenic and Loamic), a number of other principal (Fluvic, Lamellic, Gleyic, Calcic) and supplementary (Aeolic, Protocalcic, Thaptoochric) qualifiers related to the properties of Quaternary sediments are diagnosed in the valley soils.

The study of the relationship between soil genetic types and soil fauna is of interest for further research. Fragmentary research has been carried out in this direction (Kunakh et al., 2023; Zhukov et al., 2023), but identifying the diversity of soil cover provides a basis for understanding the impact of soils and soil macrofauna communities. It is also important to examine the reverse effect, namely, the contribution of soil animals to the soil formation process of floodplain and terrestrial soils in river valleys.

Conclusions

Quaternary sediments of the Dnipro Valley are shown to be a major factor in shaping the diversity and structure of the soil cover of the Dnipro-Orilsky Nature Reserve. Fluvial and aeolian processes determine the geomorphological features of the valley, in particular the relief and distribution of alluvial, alluvial-deluvial, aeolian, and lake and marsh Quaternary sediments. The key properties of bedrock as a soil formation factor in the Dnipro Valley are geological youth, predominantly sandy and sandy loam texture, layered sediments and features of the relief formed by Quaternary sediments (which determines the groundwater level). The diversity of soils in the valley according to the WRB classification is represented mainly by the Arenosols, Cambisols, Fluvisols and Gleysols reference groups. The properties of Quaternary sediments determine the position of soils at both levels of classification (reference groups, main and additional qualifiers). The distribution of each of the reference groups is clearly related to the geomorphology of the valley. Arenosols and Cambisols form the soil cover of the floodplain terrace, while Fluvisols and Gleysols are found mainly in the floodplain.

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Suppplementary material

Table S1. Soil profile data

FEP*	Landform	Quaternary sediments	Ground water level (m)	Vegetation	Soil horizons Depth (cm) Texture class Structure Mansellcolor									Soil classification according to WRB (2015)
Arenosol														
3	A leveled area on a sandy hill	Aeolian sands	6.4	Artificial Pinus plantation of *Pinus sylvestris* L	0–14 Ah1 SL gr 10R 9/8	14–22 Ah2 LS gr 10YR 8/22	22–34 CA LS sb 7.5YR 9/26	34–87 C/A LS sb 10YR 9/15	87–140 C S sg 5Y 9/16	140–155 Ct S sg 5P 6/1	155–200 C’ S sg 10YR 6/1			Eutric Arenosol (Aeolic, Ochric)
5	A leveled area on a sandy hill	Aeolian sands	12.6	Artificial Pinus plantation of *Pinus sylvestris* LS	0–8 Ah S sg 10GY 9/20	8–25 CA S sg 5YR 9/22	25–36 C S ab 7.5YR 9/26	36–110 Cab S ab 7.5BG 10/1	110–134 C’ S ab 5YR 8/26	134–141 Ct S ab 10YR 7/1	141–181 C’ S sg 2.5Y 6/1	181–200 Ca’b S sg 10YR 5/1	200–210 C’’ S sg 10G 5/1	Eutric Arenosol (Aeolic, Ochric) Thaptoochric)
14	A leveled area on a sandy hill	Aeolian sands	6.4	*Acer tataricum* L. shrubs	0–14 Ah S sg 5PB 8/13	14–52 C1 S sg 5PB 8/14	52–137 C2 S sg 2.5Y 9/24	137–145 Cab S ab 7.5YR 9/19	145–200 C’2 S ab 10B 9/3					Eutric Arenosol (Aeolic, Ochric) Thaptoochric)
24	A leveled area on a sandy hill	Aeolian sands	3.3	Sandy steppe (*Festuca ovina* L. and *Poa glauca* Schkuhr)	0–12 Ah1 S sg 7.5YR 8/15	12–20 Ah2 S sg 7.5Y 9/14	20–81 C/A S sg 2.5Y 9/14	81–100 Ct S sg 5YR 9/19	100–143 Cc S sg 7.5YR 9/17	143–200 C S sg 2.5YR 2/1				Eutric Lamellic Arenosol (Aeolic, Ochric)
Cambisol														
2	Slope of a valley light loam	Alluvial-deluvial	2.4	Oak (*Quercus robur L)* forest L. and *Poa glauca* Schkuhr)	0–3 Ah1 SL gr 7.5GY 9/28	3–26 Ah2 SL sg 5GY 10/22	26–80 Ah3 SL sg 10Y 10/14	80–97 BA SL ab 5GY 10/22	97–127 B LS ab 2.5Y 10/22	127–160 Bk gS ab 2.5GY 3/1	160–200 Ck gS sg 5Y 3/1			Eutric Cambisol (Humic, Loamic)
4	Thalweg of a valley light loam	Alluvial-deluvial	2.6	Meadow (*Limonium gmelinii* (Willd.) and *Poa pratensis* L)	0–4 Ah1 LS gr 5Y 9/23	4–32 Ah2 SL gr 7.5Y 9/22	32–71 B1 SL ab 2.5Y 9/14	71–110 B2 SL abab 2.5Y 9/14	110–140 C1 L sb 10YR 9/15	140–180 C2 LS sg 7.5R 5/1	180–200 Cl S 7.5PB 4/2			Eutric Cambisol (Loamic, Ochric)

Table S1. Continued

FEP*	Landform	Quaternary sediments	Ground water level (m)	Vegetation	Soil horizons Depth (cm) Texture class Structure Mansellcolor								Soil classification according to WRB (2015)
18	Slope of a sandy hill	Aeolian light loam and sandy loam	8.1	Artificial plantation of *Pinus sylvestris* L	0–7 Ah1 SL gr 7.5B 8/14	7–51 Ah2 SL gr 2.5PB 10/2	51–81 Abh SL sb 5PB 10/3	81–100 B SL sb 7.5B 9/2	100–150 C1 SL ab 7.5YR 9/26	150–200 C2 S sg 10PB 6/1			Eutric Arenosol (Humic) Loamic)
19	The floodplain of the Protoch River	Aeolian and alluvial sandy loams	1.6	Oak (*Quercus robur L)* forest	0–7 Ah1 SL gr 5R 8/13	7–17 Ah2 SL ab 2.5B 10/1	17–64 Ah3 LS ab 5PB 9/6	64–105 ABk SL ab 10R 7/11	105–120 Bk SL ab 7.5PB 10/6	120–130 Ckl SL ab 10YR 5/1	130–155 Crk S sg 2.5Y 5/1		Eutric Cambisol (Arenic, Protocalcic, Humic)
20_2	Slope of a valley	Alluvial-deluvial sandy loams	2.5	Elm (*Ulmus laevis* Pall.) oak (*Quercus robur* L.) forest 10R 8/11	0–10 Ahk1 SL gr 5GY 10/14	10–31 Ahk2 SL gr 7.5YR 8/16	31–84 Ahk3 SL gr 10Y 10/14	84–121 Bk LS ab 2.5PB 8/7	121–148 Ckl S sg 5Y 6/2	148–200 Crk S sg			Eutric Cambisol (Arenic Protocalcic, Humic)
Fluvisol													
1	The floodplain of the Protoch River	Alluvial light loamy and sandy soils	2.2	Meadow *(Festuca valesiaca* Schleich. ex Gaudin and 5PB 8/13 *Potentilla anserina* L)	0-7 Ah SL gr 5PB 8/11	7-48 Ahk SL sb 5YR 8/16	48-75 Cak SL ab 5YR 9/23	75-113 Ck SL ab 5YR 8/17	113-136 Cl1 SL ab 2.5B 8/12	136-152 Cl2 LS ab 2.5B 8/12	152-171 Cr1 LS sg 2.5PB 8/14	171-200 Cr2 S sg	Eutric Pantofluvic Fluvisol (Protocalcic, Humic, Loamic)
25	The floodplain of the Protoch River	Alluvial sand	1.2	White poplar (*Populus alba* L) woodland	0-7 Ahk1 LS gr 5GY 9/22	7-35 Ahk2 SL ab 10BG 10/2	35-58 Bk L ab 7.5BG 10/1	58-80 BCkl L ab 7.5R 8/13	80-112 Ckl LS ab 5YR 9/18	112-122 Crk gS sg 2.5Y 6/3			Eutric Gleyic Pantofluvic Fluvisol (Protocalcic, Humic, Loamic, Nechic)
26	Dnipro River floodplain	Alluvial sandy loams and sands	1.7	Elm (*Ulmus laevis* Pall.) *oak* (*Quercus robur* L.) forest 5PB 8/11	0-7 Ah1 LS sb 2.5PB 8/8	7-24 Ah2 LS ab 7.5R 7/10	24-43 Acc LS ab 7.5R 8/12	43-54 Cc S sg 5YR 8/20	54-69 ACcb S ab 2.5PB 10/2	69-94 Cacb S ab 2.5YR 9/3	94-133 Cl1 S sg 7.5YR 8/24	133-171 Cl2 S sg 10BG 9/10	Eutric Gleyic Panthofluvic Fluvisol (Arenic, Ochric, Thaptoochric)

Table S1. Continued

FEP*	Landform	Quaternary sediments	Ground water level (m)	Vegetation	Soil horizons Depth (cm) Texture class Structure Mansellcolor										Soil classification according to WRB (2015)
27	Dnipro River floodplain	Alluvial sandy loams and sands	1.2	Elm (*Ulmus laevis* Pall.) oak (*Quercus robur* L.) forest	0-6 Ah1 L gr 10R 8/12	6-18 Ah2 SL gr 5YR 8/26	18-38 AB SL gr 2.5YR 8/18	38-46 C S sg 2.5YR 8/15	46-62 Ahkb SL ab 7.5YR 8/16	62-73 Ckc S ab 5YR 8/23	73-82 Ahkcb S ab 7.5YR 8/24	82-93 Ckl S ab 5YR 8/24	93-106 Ahklb S ab 7.5PB 10/3	106-117 Crk S sg 10B9/3	Eutric Gleyic Pantofluvic Fluvisol (Protocalcic, Humic, Loamic, Thaptoochric)
28	Dnipro River floodplain	Alluvial sandy loams and sands	1.1	Elm (*Ulmus laevis* Pall.) oak (*Quercus robur* L.) forest	0-10 Ah1 SL gr 2.5B 7/22	10-19 Ah2 SL gr 7.5R 8/13	19-31 AC LS sg 2.5B 10/1	31-44 C S sg 7.5R 9/10	44-55 Acb S sg 7.5R 8/13	55-74 Cl S sg 2.5YR 8/18	74-82 Calb sg 5Y 9/13	82-106 Cr S sg 5YR 7/22			Eutric Gleyic Pantofluvic S Fluvisol (Humic, Loamic, Thaptoochric)
Gleysol															
16	The floodplain of the Protoch River	Alluvial sands	0.2–1.0	Elm (*Ulmus laevis* Pall.) oak (*Quercus robur* L.) forest	0-13 Ahk1 LS gr 2.5GY 5/1	13-38 Ahk2 SL sb 7.5Y 4/3	38-65 ABk SL ab 5G 2.5/1	65-83 CBkl SL ab 5PB 7/5	83-98 Ckl SL ab 7.5YR 2/3	98-101 Crk SL sg 10YR 3/2					Eutric Fluvic Calcic Mollic Gleysol (Humic, Loamic)
20_1	Thalweg of a valley	Alluvial sandy loam	0.2–1.4	Marsh *(Poa pratensis* and L. and *Carex riparia* Curtis)	0-17 Ahk1 *LS* gr 10YR 8/14	17-75 Ahk2 *LS* ab 7.5GY 9/21	75-115 Bhk *LS* ab 10G 9/17	115-135 Crk *gS* sg 5B 8/12							Eutric Calcic Mollic Gleysol (Humic, Loamic)
20_2	The floodplain of the Protoch River	Alluvial sandy loam	0.83	Moist meadow (*Festuca valesiaca* Schleich. ex Gaudin and *Potentilla anserina* L)	0-10 *Ah1* *LS* gr 7.5GY 9/14	10-18 *Ah2* *LS* gr 7.5Y 9/14	18-38 *Bhk* *SL* gr 5YR 9/18	38-68 *Bkl* *LS* ab 5Y 9/23	68-83 *Crkz* *SL* ab 10YR 10/16						Eutric Fluvic Calcic Mollic Gleysol (Arenic, Humic, Salic)
29_1	Dnipro River floodplain	Alluvial sandy loams and sands	1.4	Elm (*Ulmus laevis* Pall.) oak (*Quercus robur* L.) forest	0-2 A1 SL sb 2.5Y 9/24	2-13 A2 SL sb 10YR 9/19	13-23 A/C SL sb 7.5YR 9/25	23-79 C1 S sg 10YR 10/16	79-97 C2 S ab 10YR 10/16	97-116 Cl1 S sg 10YR 10/16	116-140 Cl2 S sg 7.5YR 9/25				Fluvic Gleysol (Arenic, Ochric)

Table S1. Continued

FEP*	Landform	Quaternary sediments	Ground water level (m)	Vegetation	Soil horizons Depth (cm) Texture class Structure Mansellcolor							Soil classification according to WRB (2015)
29_2	Dnipro River floodplain sands	Alluvial sandy loams and	1.1	Elm (*Ulmus laevis* Pall.) oak (*Quercus robur* L.) forest	0-7 A1 SL gr 7.5GY 9/26	7-29 A2 SL sg 2.5Y 10/15	29-41 Acc SL sg 2.5GY 10/14	41-53 Cc S sg 5GY 10/22	53-79 Clc S sg 10Y 10/14	79-110 Cl S sg 7.5G 10/13		Eutric Fluvic Mollic Gleysol (Humic, Loamic)
Solonetz												
21_1	The floodplain of the Protoch River	Alluvial sandy loam	1.2	Salt marsh *vegetation* (*Limonium gmelinii* (Willd.) and *Poa pratensis* L)	0-3 Ah1 LS gr 2.5YR 7/11	3-18 Ah2 SL ab 7.5B 9/2	18-31 Bthn L pr 10B 9/3	31-50 Bhkz L pr 7.5B 9/2	50-65 Bklz L pr 2.5PB 10/2	65-98 Cklz L ab 10R 8/16	98-115 Crkz L ab 7.5PB 10/3	Calcic Mollic Gleyic Solonetz (Fluvic, Humic, Loamic)

*FEP is field experimental polygon.