https://doi.org/10.17221/435/2020-PSE

Changes in selected physico-chemical properties of floodplain soils in three different land-use types after flooding

Ivan Suchara, Julie Sucharová, Marie Holá*

Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Průhonice, Czech Republic

**Corresponding author: suchara@vukoz.cz*

Citation: Suchara I., Sucharová J., Holá M. (2021): Changes in selected physico-chemical properties of flooding soils in three different land-use types after flooding. Plant Soil Environ., 67: 99–109.

Abstract: This article provides information on selected physico-chemical properties, including soil colour, texture, electrical conductivity, pH_{H_2O}, pH_{CaCl_2}, content of total carbon and $Q_{4/6}$ quotient, of the topsoil and subsoil of former flood sediments at three diverse vegetation plots in a floodplain and in two reference plots unaffected by floods, and changes of some soil properties caused by a new subsequent flood. Aggradation of flood sediments in the area was controlled both by local terrain morphology and vegetation type cover. Differences in the properties of sediments in the individual plot types were caused by the different production of litter, root biomass and carbon cycling before the new flood. Vertical distributions and inventories of ^{137}Cs in soils revealed the position and proportion of modern sediments in soil profiles, man-made filling of former erosion grooves and ploughing depths. The new flood of a lower hydrological power aggraded a thin layer of organo-clay sediment on the soil surface but showed minor effects on the investigated soil properties. The lowest dry bulk density and highest total porosity values were found in the topsoil of woody and grassy plots after the flood implying no substantial break down of soil aggregates by the flood. The highest dry bulk density values in the subsoil of fields indicated soil compaction from agricultural machinery. No increased soil salinity was found after the flood. The flood did not significantly affect the pH_{H_2O} of the topsoil and subsoil; however, a significant increase in pH_{CaCl_2} was found for the topsoil of grassy plots and for all topsoil samples from the park. No significant increases in total carbon (C_{tot}) contents were found in topsoils of any plot types after the flood in spite of an accumulation of thin organo-clay material on the soil surface after the flood. However, significant increases in C_{tot} in subsoils of all plot types indicate the vertical migration of colloidal and dissolved organic carbon in soils during the flood. C_{tot} contents positively correlated with electrical conductivity values and negative correlated with pH values. The relatively minor changes in soil physico-chemical properties found after the flood can be explained by the short duration and small dynamic power of the flood, and the timing of sampling when the flood had receded and soil aeration was already being restored.

Keywords: flood condition; contaminated soil; geomorphology; soil structure; alluvial plain

Recently, there has been an increased frequency of catastrophic floods caused by changes in global climate and land-use, including urbanisation, extensive agriculture and landscape deforestation (Ulbrich et al. 2003, Langhammer and Vilímek 2008, Váňová and Langhammer 2011, Gvoždíková and Müller 2017). Floodplain sediments of large rivers are among the most contaminated soil covers, containing potentially toxic elements and compounds and various types of modern pollutants, posing potential threats to the health and stability of agricultural and seminatural bank ecosystems (Vink et al. 1999, Kanzari et al. 2014). The inundation of soil covers leads to many alterations, including the breaking up of soil aggregates, changes soil pH values towards neutral, decreasing soil redox potentials, the microbial anaerobic decomposition of orgnic matter, changes in the metabolism of plants under flood conditions

Supported by the Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Project No. VUKOZ-IP-00027073.

https://doi.org/10.17221/435/2020-PSE

(e.g. Ponnamperuma 1984, De-Campos et al. 2009). Knowledge of the physico-chemical properties of deposited flood materials is needed because they play a major role in the transport, distribution, fate and environmental and health risk of pollutants present in flood sediments.

The aim of our study was to investigate the properties of flood sediments as a basis for the reconstruction and safe use of a floodplain park on the Vltava River after a devastating flood in 2002, and obtain detailed information about the flood sediment properties of this important agricultural floodplain area. A further flood in spring 2013 provided an opportunity to investigate and compare sediment properties at the same sites in three land-use types immediately before and after this second flood.

MATERIAL AND METHODS

Studied area. The investigated landscape park (298 ha), a former demesne of the castle at Veltrusy (50.2776°N; 14.3298°E), was established on the eastern bank of the lower reaches of the Vltava River before 1730 (Figure 1). Initially, the park area used to be a river island that emerged during floods in 1712 and 1714, when a new lateral river arm appeared delimiting the island to the east. The entrance of the river arm was gradually blocked by the accretions of subsequent floods in 1783, 1784 and 1785. Between 1785 and 1790, a new excavated channel about 2–3 m wide and 6-km long and a side channel branch were constructed in the bed of the dried river arm for boat rides (Figure 2, www.veltrusy park.cz/historie.php).

The total length of the Vltava is 430 km and the mean outflow near the confluence with the Labe River is about 150 m^3/s. The river catchment (28 090 km^2) drains the southern half of Bohemia. The geological wholes of the Vltava catchment, the Moldanubicum and the Bohemicum, are created mainly of varied silicate magmatic and metamorphic rocks, and in much lower amounts carbonate rocks (CGS 2019). The studied area was repeatedly affected by at least 22 recorded floods between 1118 and 1900, and about seven significant floods have occurred since 1900 (Brázdil et al. 2005, Kozák et al. 2007). After a flood in 1947 the Vltava floodplains were protected by a series of dams on the upstream reaches. Terrestrial soil development in the park was interrupted by a catastrophic flood in August 2002, with a local flow rate of about 5 000 m^3/s. This flood excavated deep ditches and accumulated piles of gravel-sand sediments up to 1.5–2 m in height close the river and the soil cover was saturated by water for more than two weeks. Subsequently, damaged sites along the river were levelled or backfilled using various flood sediments from elsewhere. A subsequent flood with weaker hydrological power (3 000 m^3/s) flooded the park in spring 2013.

Old maps of the park show a stable non-random arrangement of the main vegetation compartments (woody plots 45%, fields 38%, and meadows 12%) for at least the last three centuries (Brzák 2012). The present woody plots comprise mainly adult common deciduos species. The fields are located mainly in higher central parts of the park and are used for the production of usual crops. The grassy plots with common grass and meadow species cover mainly a terrain depression along the former lateral river arm (Figure 2). The relative variability in elevation of the soil surface in most of the park is about 5–6 m (Figure 3). The ordinary river water level is more than 4 m lower than the park bank, and water in the channels is about 0.6 m below the surrounding soil surface.

Collecting of samples. Soil samples were collected in woody (32), field (21) and grassy (12) plots and from mounds of remaining flood sediments from 2002 at woody and bare plots by the river in May, 2013 (Figure 2). Soil material of volume 20 × 20 × 10 cm was cut out from upper 0–10-cm layer (the topsoil) and the bottom 30–40-cm layer (the subsoil) of soil pits. In parallel, visible soil characteristics were observed elsewhere using cores extracted by a 1-m long soil probe. During the sampling campaign the park was inundated by another flood by up to 1–5 m (2–11, June 2013). Starting on 17th June, resampling of soil samples started immediately adjacent to the

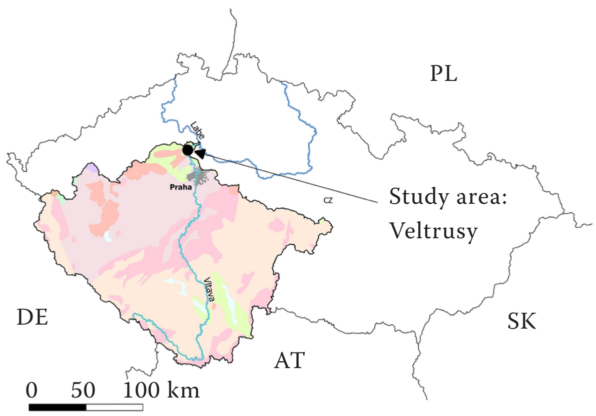
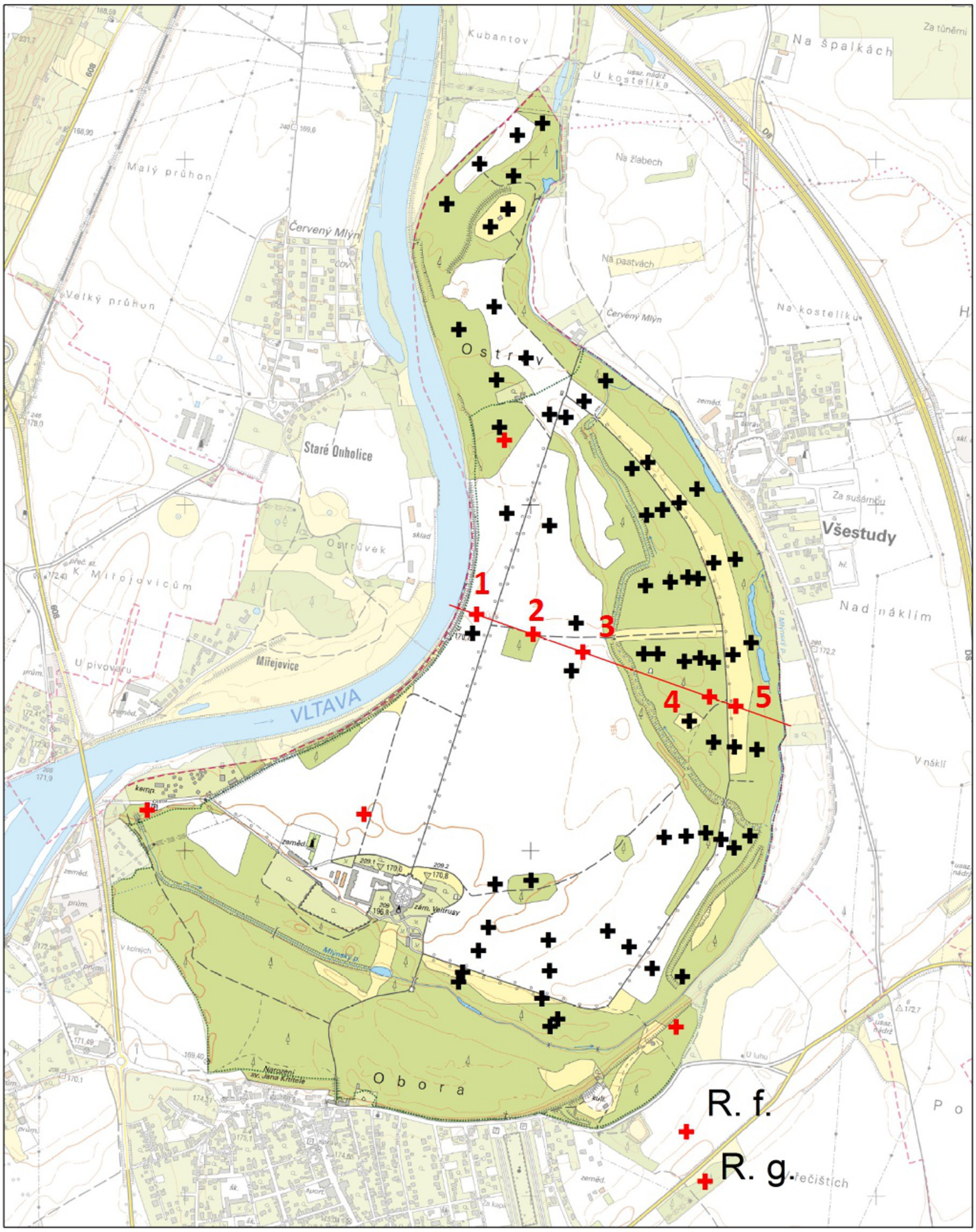


Figure 1. The Vltava River, catchment geology (legend in CGS 2019) and location of the study area

https://doi.org/10.17221/435/2020-PSE



Legend

✚ sampling sites before and after the flood

✚ sampling sites after the flood

R.f. reference field

R.g. reference grove

0 250 500 km

Figure 2. The position of the soil cover sampling sites within the park before and after the flood in 2013 and the position of the cross-section transect (Figure 3)

https://doi.org/10.17221/435/2020-PSE

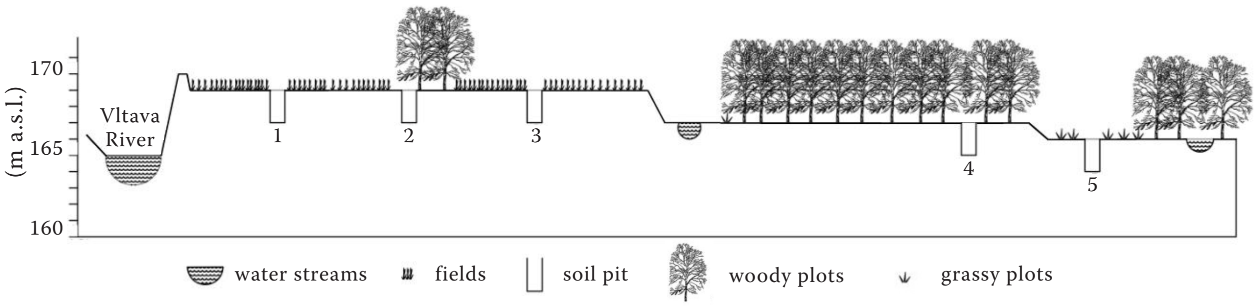


Figure 3. The cross-section in central part of the park and the position of five soil probe pits in various vegetation after the flood in 2013

former sampling sites. However, the water level had already dropped about 1 m below the soil surface and soil aeration had partly been re-established. The soil surface in the park was covered by a 0.5–2 cm-layer of organo-clay flood sediment. Additionally, soil samples were collected from 5 pits covers situated along a linear transect crossing the park (Figure 3) and in a reference grove (50.271569°N; 14.343531°E) that has been shown at the same site in maps for 300 years, and in a field (50.273808°N, 14.343204°E) located outside Q_{500} (Figure 2). Specimens of compact soil layers were cut out using steel cylinders with volume 100.0 cm^3 at selected sampling sites to determine water capillary capacity and dry bulk density (DBD) after weighing water-saturated and subsequently dried soil in the cylinders. Using a steel frame of 10 × 10 × 10 cm soil samples were collected up to a depth of 60 cm at 11 sites for gammascopic determination of the specific ^{137}Cs and ^{210}Pb activities (Bq/kg) in an accredited laboratory of the National Radiation Protection Institute in Prague and for subsequent calculation of ^{137}Cs inventories (Bq/m^2).

Analysis of samples. The samples were air dried and sieved through a 2.0 mm sieve. Soil colour was estimated by a colour chart (MCC 1994); measurements of the grain size distribution used a simplified pipette method (Kettler et al. 2001), pH_{H_2O}, pH_{CaCl_2} and total electrical conductivity were determined in deionised water suspensions of 10 g:50 mL using a combined glass electrode and a WTW platinum conductivity electrode with measuring systems adjusted by commercial buffers and reference KCl solutions, respectively, and for detection of colour quotient $Q_{4/6}$ was measured according to Pospíšil (1981). The grain size distribution was also checked by laser diffraction. The total pore space was calculated from DBD values using an average soil particle density of 2.55 g/cm^3. The humic and fulvic acid ratios in the topsoil after the flood were calculated using $Q_{4/6}$ (Tan 2011) and the formula HA:FA = 17.2 × $Q_{4/6}^{-2.19}$ (Pospíšil 1971). Total C contents were determined directly in samples pulverised in an agate dish using a LECO TruSpecC-N instrument (LECO, St. Joseph, USA) and checked *via* analyses of standard reference materials (LECO Soil LCRM and NIST 1646a).

Basic statistics, pair *t*-tests, analysis of variance, and Tukey-Kramer test and correlation analyses of raw and log-transformed data were done in Statistica (StatSoft, Inc., Tulsa, USA). Medians and median absolute deviations (MAD) are preferentially used in the following text. The map of the park was adopted from a cadastral map by the State Administration of Land Surveying and Cadastre, and the geology of the Vltava catchment (Figure 1) from a geological map of the Czech Republic (CGS 2019).

RESULTS AND DISCUSSION

Colour and texture. The typical colour of soil covers from reference plots and vegetative plot types in the park are shown in Tables 1 and 2. No visible changes in colour or textural symptoms of redoximorphic or illuviation processes were observed in the subsoil or along soil probe cores. Sieved soil samples (4 000 cm^3) did not show perceptible colour changes after the flood, though a thin layer of flood sediment, very dark brown to very dark grey when wet, was deposited on the soil surface in 2013.

The contents of cobbles and boulders were about 10% and 15% by volume in the topsoil and subsoil, respectively, and larger buried boulders were found elsewhere below the subsoil. An increased accumulation of coarse sand and pebbles (~60%) was found between 35 cm and 50 cm in the reference grove. A pale ochre coarse sandy layer occurred deeper than 60 cm at the reference field and the same sediment material was found below the 75–95-cm depth in the eastern and northern parts of the park. The

https://doi.org/10.17221/435/2020-PSE

Table 1. Medians ± median absolute deviations (MAD) of the basic parameters of soil covers at the reference plots

Soil depth (cm)	Soil colour (if fresh)	Bulk density (g_{DW}/100 cm)	Clay (%)	Silt (%)	Sand (%)	Water capillary capacity (%)	Total porosity (%)	pH_{H_2O}	pH_{CaCl_2}	C_{tot} (%)
n	1	1	2	2	2	1	–	3	3	3
Reference oak grove (Loam – Silt loam)										
0–10	10YR 3/2	94.5	8.9	41.8	49.3	48.2	63	4.41 ± 0.00	3.59 ± 0.01	4.28 ± 0.03
10–20	10YR 4/4	na	na	na	na	na	na	4.38 ± 0.01	3.65 ± 0.02	1.67 ± 0.01
20–30	10YR 4/4	117.4	12.1	37.4	50.5	37.1	55	4.39 ± 0.01	3.65 ± 0.00	1.44 ± 0.08
30–40	10YR 3/3	129.6	12.2	32.5	55.3	36.0	48	4.47 ± 0.02	3.73 ± 0.00	0.93 ± 0.07
40–50	10YR 3/3	na	na	na	na	na	na	4.60 ± 0.00	3.90 ± 0.00	0.71 ± 0.01
Reference field (Sandy loam)										
0–10	10YR 3/3	130.7	10.3	38.7	51.0	36.5	49	6.56 ± 0.02	6.25 ± 0.03	1.65 ± 0.10
30–40	10YR 3/3	156.4	12.8	34.6	52.6	29.5	38	6.75 ± 0.01	6.26 ± 0.01	1.55 ± 0.01

na – not available; DW – dry weight; C_{tot} – total carbon

texture analysis found (Tables 1–3) clay contents between 8% and 18%. The median clay content was significantly different in the topsoil of woody and grassy plots, and decreased in the order: grassy plots > fields > woody plots. Sand formed about half the topsoil matrix across the park. Significantly higher sand contents were found in woody and field plots by the river, where remain remnants of coarse-sized sediments from 2002 in pales and strips were deposited in the direction of the flood flow behind tree trunk bases. These sediments from 2002 contained clay, silt and sand in amounts of 1.5–2.5, 3.0–5.0

Table 2. Medians ± median absolute deviations (MAD) of basic parameters of the topsoil and the subsoil for the plots situated along the cross-sectional transect of the park (Figure 3), (0.00 = < 0.005)

Soil depth (cm)	Soil colour (if fresh)	Bulk density (g_{DW}/100 cm)	Clay (%)	Silt (%)	Sand (%)	Water capillary capacity (%)	Total porosity (%)	pH_{H_2O}	pH_{CaCl_2}	C_{tot} (%)
n	1	1	2	2	2	1	–	3	3	3
1. Field at a river bank with levelled flood sediments, arable soil (Sandy loam)										
0–10	10YR 4/3	133.9	12.2	30.2	57.6	34.1	47	7.11 ± 0.01	6.43 ± 0.03	1.69 ± 0.02
30–40	10YR 4/3	164.4	14.5	30.7	54.8	29.8	36	7.31 ± 0.01	6.85 ± 0.01	1.59 ± 0.01
2. Smaller old grove in fields (Sandy loam)										
0–10	10YR 3/2	89.3	9.6	32.3	58.1	41.5	62	5.21 ± 0.01	4.19 ± 0.01	9.51 ± 0.12
30–40	10YR 3/2	118.2	12.9	31.6	55.5	37.2	53	4.87 ± 0.01	3.84 ± 0.00	1.23 ± 0.00
3. Field in central part of the park, arable soil (Sandy loam)										
0–10	10YR 4/3	137.1	12.4	31.1	56.5	31.8	45	6.63 ± 0.03	6.23 ± 0.01	1.17 ± 0.01
30–40	10YR 3/3	161.6	13.3	29.6	57.1	28.3	37	7.04 ± 0.02	6.07 ± 0.01	0.81 ± 0.01
4. Woody belt along a lateral channel (Silt loam)										
0–10	10YR 3/2	90.1	10.4	33.8	55.8	47.3	60	6.46 ± 0.02	5.63 ± 0.01	7.12 ± 0.10
30–40	10YR 4/4	112.7	12.2	34.1	53.7	36.4	52	4.90 ± 0.01	4.01 ± 0.02	0.97 ± 0.02
5. Grassy plot in bed of the former river arm (Silt loam)										
0–10	10YR 4/3	129.6	15.6	38.7	43.4	37.6	49	5.08 ± 0.03	4.52 ± 0.02	3.68 ± 0.01
30–40	10YR 4/3	148.7	17.5	41.1	41.4	33.0	42	5.40 ± 0.02	4.70 ± 0.02	0.88 ± 0.02

DW – dry weight; C_{tot} – total carbon

https://doi.org/10.17221/435/2020-PSE

Table 3. Medians ± median absolute deviations (MAD) of selected soil properties in the topsoil and subsoil for the reference plots, flood sediments from 2002 and various plot types in the park after the flood in 2013

	Reference grove		Reference field		Remaining flood sediment 2002		Woody plots		Fields		Grassy plots	
Depth (cm)	0–10	30–40	0–10	30–40	0–10	30–40	0–10	30–40	0–10	30–40	0–10	30–40
Clay (%)	8.9	12.2	10.3	12.8	1.7	4.4	10 ± 3	12 ± 3	13 ± 3	14 ± 4	17 ± 4	20 ± 5
Silt (%)	41.8	32.5	38.7	34.6	3.6	8.2	33 ± 5	34 ± 4	35 ± 4	36 ± 5	39 ± 4	35 ± 4
Sand (%)	49.3	55.3	51.0	52.6	94.7	87.4	57 ± 6	54 ± 7	52 ± 4	50 ± 4	44 ± 5	45 ± 6
DBD (mg/100 cm^3)	94.5	129.6	130.7	156.4	na	na	91.9 ± 3.2	98.2 ± 4.3	132.1 ± 2.8	160.7 ± 3.5	112.1 ± 2.9	145.0 ± 4.5
EC (μS/cm)	49.6	27.3	45.8	32.5	10.6	27.5	na	na	na	na	na	na

na – not available; DBD – dry bulk density; EC – electrical conductivity

and 93–95%, respectively. Thus, the accumulation processes of various grain sized sediments in the park were affected both by local geomorphology and by the type of vegetation, as also published in other studies (Thonon et al. 2007, Rodríguez et al. 2019).

The topsoil texture of woody plots, fields and grassy plots can be classified (USDA 1987) as sandy loam or loam, sandy loam, and loam or silt loam, respectively. The soil covers of the park can be termed Dystrict/Eutric Fluvisol according to the international soil classification system (FAO 2015) or modal Fluvisol (FLm) and anthropic Fluvisol (FLa) using a local soil classification system (Němeček et al. 2008).

Dry bulk density. DBD values (Tables 1–3) significantly increased in the order: woody plots < grassy plots < fields and in the topsoil and subsoil. A maximal value of 1.68 g/cm^3 in the field subsoil indicates compaction of the soil from agricultural machinery. The critical DBD limit of 1.60 g/cm^3 for silty soils was exceeded in the subsoil of fields. However, no site exceeded the critical value 1.80 g/cm^3 for the restriction of monocot root growth in compressed sandy soils (Reichert et al. 2009, Wilson et al. 2013). Significantly lower DBD in the topsoil and subsoil of woody and grassy plots was caused by increased contents of humus, as documented below, and the positive rhizosphere effect of permanent vegetation on the formation of soil porosity (Yu et al. 2018), which is higher than the effect of the low soil texture variability in the park.

Porosity. Porosity (Tables 1 and 2), which controls the retention of water and speed of the spatial transport of mobile organic colloids, increased with decreasing DBD values. Capillary capacity was higher in the subsoil than in the topsoil, and reached 66–80% of the total porosity. Higher total porosity and lower DBD values in the topsoil of woody and grassy plots after the flood imply higher aggregate stability and a minor effect of the flood on the breaking down of aggregates in these land-use types (Menon et al. 2020).

Specific activities of radionuclides. The vertical distribution and inventory of post-Chernobyl ^{137}Cs (after 1986) and atmogenic ^{210}Pb in soils are used to assess erosion or sedimentation rates of soil covers (Zapata 2002). The exponential decrease of ^{137}Cs and ^{210}Pb specific activities with soil depth (Figures 4 and 5) indicates undisturbed soil layers in the reference grove and woody plots situated at a promontory in the southeastern corner of the park that has not been recently inundated. The grove in the fields, and the woody and grassy plots along the transect, showed an initial faster decrease in radionuclide activities with soil depth, which may imply a mild accretion of modern sediments in the topsoil. The nearly constant activities of ^{137}Cs and ^{210}Pb in the whole upper 30–45-cm layer of the reference field and of a field in the southwest corner of the park are due to the homogenisation of the soil by ploughing. Constant radionuclide activities in the 0–60-cm soil layer at the field near the river reflects the extensive human infilling of the damaged area by a mixture of flood materials after the flood in 2002. Remnants of the flood sediments from 2002 showed a peak of radionuclide activities at the depth of 10–15 cm, likely due to some vertical shifting of clay particles carrying the radionuclides. The vertical distributions of radionuclides did not indicate a significant relocation of the topsoil in 2013.

The inventory of soil ^{137}Cs in the reference grove reached 1 996 ± 325 Bq/m^2, but in the nearby reference field only 1 329 ± 218 Bq/m^2, probably due to the higher content of ^{137}Cs in throughfall deposi-

https://doi.org/10.17221/435/2020-PSE

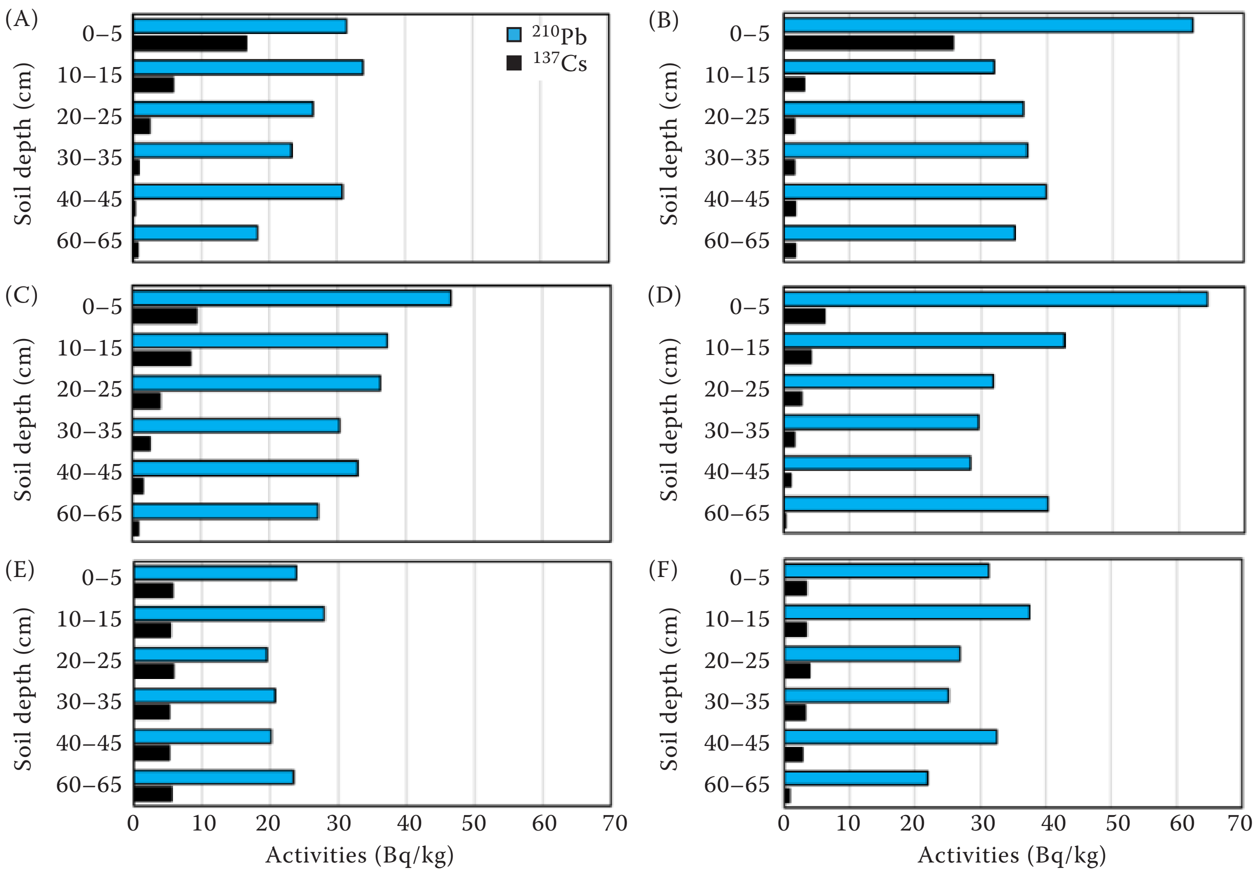


Figure 4. Vertical distribution of total ^{137}Cs and ^{210}Pb activities in soil covers of a woody plot at an upland in the southeastern corner of the park (A); sites along the transect in a field grove (B); a woody plot (C); a grassy plot (D) and a field near the river (F) and in a field in the southwestern corner of the park (E), all after the flood

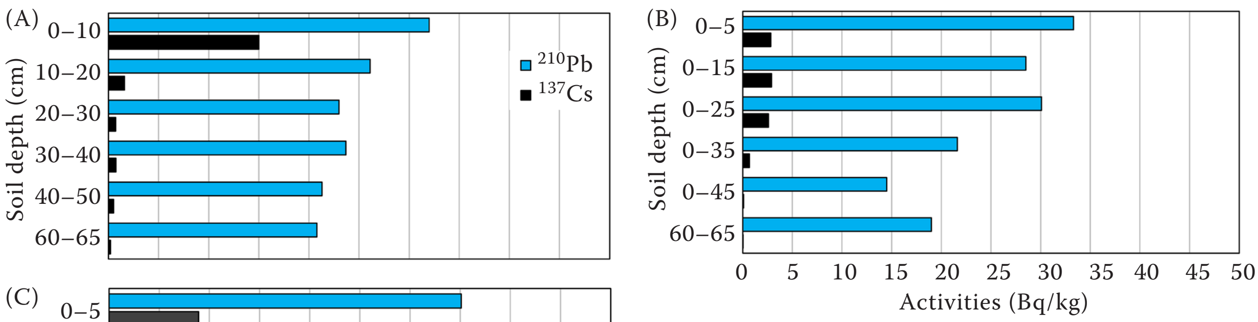
tion under the oak canopy and the annual removal of adsorbed ^{137}Cs (chemical analogue of K) in harvested crops. The ^{137}Cs inventory in the field grove in the park (2 831 ± 513 Bq/m^2) and in two nearby fields (2 287 ± 464 and 2 388 ± 335 Bq/m^2) indicate a moderate accumulation of modern sediments in the central part of the park. The respective inventories in two fields by the river (2 665 ± 431 Bq/m^2 and 5 666 ± 797 Bq/m^2) reflected a high accumulation of flood sediments in 2002 and a considerable amount of modern sediments used in the extensive backfill. The least accumulation intensity of modern sediment material was found at the woody plot (27%) and the grassy plot (48%) in the eastern part of the park. The inventories for two woody plots in the protruding promontory in the southeastern corner of the park unaffected by modern floods gave very similar numbers (2 087 ± 464 and 2 116 ± 335 Bq/m^2) as the nearby reference grove.

Total electrical conductivity (EC). EC (data available only for the topsoil after the flood) ranged between 11 and 192 µS/cm (Table 3), and EC medians for the topsoil of woody plots, fields and grassy plots were not significantly different. Similar respective EC medians of 36.8 ± 10.2 and 22.6 ± 6.2 µS/cm were found for the topsoil and subsoil (n = 8) in the southeastern part of the park in summer 2012.

The EC values detected in the park are equivalent to EC reference values of 0.1–0.7 dS/m for saturated soil paste (Slavich and Petterson 1993). The limit EC value for planting crops of extreme sensitivity to soil salinity are between 1.0 and 18 dS/m (Shannon and Grieve 1998), which is one order of magnitude higher than found in the park topsoil after the flood.

pH_{H_2O} and pH_{CaCl_2}. Detected pH_{H_2O} and pH_{CaCl_2} values (Tables 1, 2, 4, 5 and 6) tightly correlated (r = 0.85–0.99***) in the topsoil and subsoil of all types of plots. The topsoil at the reference oak grove was classified as extremely acid, while the reference field was slightly acid in the topsoil and neutral in the subsoil (MZe 2017). Generally, both the topsoil and subsoil acidity in the park significantly increased

https://doi.org/10.17221/435/2020-PSE



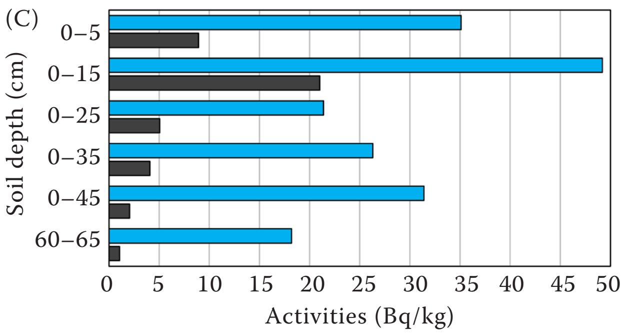


Figure 5. The vertical distribution of ^{137}Cs and ^{210}Pb activities in the soil covers of the reference grove (A); the reference field (B), and in a mound of remaining gravel-sandy sediments in a woody site near the river (C) after the flood

in the order: fields < grassy plots < woody plots, and the soil of fields was significantly less acid than soil covers of woody and grassy plots (Tables 5 and 6) due to significantly different humus contents in soils of these plot types. For grassy plots in particular, there was a higher difference between pH_{H_2O} and pH_{CaCl_2} in the subsoil than in the topsoil implying a possible increased desorption of base cations by acidic compounds from decomposed organic matter. Moderate acid reactions, pH_{H_2O} 6.02–6.21 and pH_{CaCl_2} 5.36–5.72 with lower acidity in the subsoil were found for sediments from 2002. pH values insignificantly increased with sand contents in soil. The highest, neutral, reactions were found (Table 4) for the fresh flood sediments from 2013. After the flood in 2013, pH values mostly slightly increased or decreased insignificantly, but a significant increase (P = 0.003) of pH_{CaCl_2} was found in the topsoil of grassy plots (Table 5). When comparing all topsoil samples from the park (n = 65), a significant increase (P = 0.007) of pH_{CaCl_2} was found. Differences between pH_{H_2O} and pH_{CaCl_2} increased, chiefly in field topsoil after the flood. Increases in pH even 24 h after the inundation of acidic soils are due to chemical and microbial reduction processes releasing hydoxyl radicals (Ponnamperuma 1972). However, there is a very fast recovery of soil reaction when flood waters recede (Ding et al. 2019).

Table 4. Medians ± median absolute deviations (MAD) of pH_{H_2O} and pH_{CaCl_2} for soil covers of the investigated plot types in the park before and after the flood in 2013 (n = 3)

	Before the flood									
	Reference grove		Reference field		Woody plots		Fields		Grassy plots	
Depth (cm)	0–10	30–40	0–10	30–40	0–10	30–40	0–10	30–40	0–10	30–40
pH_{H_2O}	4.41 ± 0.00	4.47 ± 0.02	6.56 ± 0.02	6.25 ± 0.03	5.09 ± 0.31	4.80 ± 0.20	6.05 ± 0.69	6.36 ± 0.52	5.43 ± 0.16	5.84 ± 0.20
pH_{CaCl_2}	3.59 ± 0.01	3.73 ± 0.00	6.25 ± 0.03	6.26 ± 0.01	4.39 ± 0.26	4.04 ± 0.15	5.25 ± 0.77	5.59 ± 0.46	4.74 ± 0.23	4.97 ± 0.21

	After the flood								
	fresh flood sediment 2013	remaining flood gravel-sand sediment 2002		woody plots		fields		grassy plots	
Depth (cm)	0–1	0–10	30–40	0–10	30–40	0–10	30–40	0–10	30–40
pH_{H_2O}	6.68 ± 0.09	6.66 ± 0.19	6.07 ± 0.13	5.05 ± 0.22	4.83 ± 0.15	6.77 ± 0.72	6.15 ± 0.64	5.71 ± 0.22	5.61 ± 0.19
pH_{CaCl_2}	6.36 ± 0.08	6.54 ± 0.17	5.96 ± 0.16	4.48 ± 0.27	4.21 ± 0.27	5.85 ± 0.55	5.34 ± 0.63	5.06 ± 0.27	4.82 ± 0.20

https://doi.org/10.17221/435/2020-PSE

Table 5. Differences of the topsoil and subsoil means of pH_{H_2O}, pH_{CaCl_2} and C_{tot} in the individual plot types before and after the flood

	Woody		Grassy		Field	
	topsoil	subsoil	topsoil	subsoil	topsoil	subsoil
pH_{H_2O}						
Before flood	5.22	4.92	4.48	5.83	6.41	6.34
After flood	5.14	4.89	5.62	5.58	6.52	6.50
P-value	0.358	0.740	0.106	0.057	0.396	0.317
pH_{CaCl_2}						
Before flood	4.51	4.17	4.64	4.91	5.63	5.64
After flood	4.59	4.26	5.05	4.79	5.93	5.82
P-value	0.441	0.335	**0.003**	0.307	0.077	0.289
C_{tot}						
Before flood	4.416	1.913	2.879	1.641	1.980	1.561
After flood	4.023	2.499	3.749	1.980	2.049	1.902
P-value	0.205	**< 0.001**	0.180	**< 0.001**	0.118	**< 0.001**

Significant differences (P <0.05) are highlighted in bold; C_{tot} – total carbon

The reaction of park soils did not differ substantially from the reactions of agricultural soils in the region. However, Prášková and Němec (2016) reported a decrease in soil pH_{H_2O} and pH_{CaCl_2} of about 0.5 unit for fields and nearly one pH unit for grassy plots between 1995 and 2013, implying a territorial acidification of soil covers before 2013.

Tighter relations were found for pH_{CaCl_2} and EC in the topsoil, especially in woody plots (r = 0.64***) and fields (r = 0.57**) of the park. For example, the following linear relationship was valid for all park topsoil samples (n = 65): pH_{CaCl_2} = 4.446 + 0.0151EC, (r = 0.32*).

Total carbon (C_{tot}) and $Q_{4/6}$. C_{tot} contents in soil samples (Tables 1, 2, 5 and 6) represent mainly organic C,

Table 6. Differences of the individual plot types in means of pH_{H_2O}, pH_{CaCl_2} and C_{tot} in the topsoil and subsoil before and after the flood

	Before the flood		After the flood	
	topsoil	subsoil	topsoil	subsoil
pH_{H_2O}				
Woody plots	5.22[a]	4.92[a]	5.14[a]	4.89[a]
Grassy plots	5.47[a]	5.83[b]	5.62[b]	5.58[b]
Field plots	6.41[b]	6.34[b]	6.52[c]	6.50[c]
P-value	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
pH_{CaCl_2}				
Woody plots	4.51[a]	4.17[a]	4.59[a]	4.26[a]
Grassy plots	4.64[a]	4.91[b]	5.05[a]	4.78[a]
Field plots	5.63[b]	5.64[c]	5.93[b]	5.82[b]
P-value	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
C_{tot}				
Field plots	1.980[a]	1.561[a]	2.049[a]	1.902[a]
Grassy plots	2.879[a]	1.641[a]	3.749[b]	1.980[a]
Woody plots	4.416[b]	1.913[a]	4.023[c]	2.449[b]
P-value	**< 0.001**	0.075	**< 0.001**	**< 0.001**

Means marked by different letters are significantly different at P < 0.05; C_{tot} – total carbon

https://doi.org/10.17221/435/2020-PSE

because pH values indicate a low content of carbonates. Before the flood, C_{tot} ranges of 1.41–8.01% and 1.22–8.33% and C_{tot} medians 2.98 ± 0.97 and 1.58 ± 0.23% were found in the topsoil and subsoil (*n* = 65), respectively. Medians of C_{tot} content in the topsoil and the subsoil of the park decreased both before and after the flood in the sequence of: woody plots > grassy plots > fields, and the C_{tot} content in fields was insignificantly lower compared to woody and grassy plots (Table 6). Different contents of soil C_{tot} were caused mainly by different interruptions to multiannual C cycling at different types of plots before the flood. The aggradation of a 1-cm layer of organo-clay sediment with a C_{tot} content of about 3.90% added 3.12 g of C_{tot} per 400 cm^2 of soil surface, or into a total topsoil block of 20 × 20 × 10 cm with 5.6 kg average dry weight. However, the C_{tot} content in the topsoil insignificantly increased in fields and insignificantly decreased in woody and grassy plots after the flood (Table 5) corresponding to the aggradation or erosion of organic matter in the topsoil by flooding. Significantly increased C_{tot} contents were found in the subsoil of all plot types (Table 5) and for the whole park (*n* = 65, *t* = –5.74, $P < 1 \times 10^{-6}$). This was caused by the penetration of a substantial amount of fine particulate and soluble C in the subsoil during the flood (Mayer et al. 2019). The remaining flood sediments from 2002 contained C_{tot} in amounts 2.8–6.4 in the topsoil and 0.9–1.9 g/kg in the subsoil. After the flood, C_{tot} contents in the sediment heaps decreased by about 21% and 4% in the topsoil and subsoil, respectively.

C_{tot} contents were tightly correlated with EC mainly in the soil covers of woody ($r = 0.50^{**}$) and field ($r = 0.78^{***}$) plots after the flood. The pH of the topsoil and subsoil significantly negatively correlated with C_{tot} contents for woody plots and the topsoil of all samples before the flood. After the flood, pH and C_{tot} relationships became more negative in grassy plots and more positive in the remaining plot types. However, for all samples (*n* = 65) respective significant and negative correlations were found for C_{tot} – pH_{H_2O} and C_{tot} – pH_{CaCl_2} in the topsoil ($r = -0.43^{***}$ and $r = -0.39^{**}$) and the subsoil ($r = -0.35^{**}$ and $r = -0.28^{*}$).

Estimations of HA:FA gave significantly different median values of 0.485 ± 0.100, 0.554 ± 0.065 and 0.428 ± 0.075 in the topsoil of woody, field and grassy plots, respectively, after the flood, reflecting rather long-term differences in the quality and available amounts of litter and different decomposition speeds of organic matter than a different quality of C_{tot} accumulated at different plot types by the flood. Ratios lower than about 0.830 imply a low proportion of C condensed in aromatic humic structures, and were found mainly in grassy and woody plots with slower litter decomposition rates and due to repeated removing of organic material during floods.

In conclusion, our study showed that aggradation of flood sediments in the area was controlled by both local surface geomorphology and vegetation type. Differences in most investigated soil properties between individual plot types before the flood can be explained by the effects of various amounts of litter mass entering in the carbon cycle and root production supporting mainly soil structure and stability. Soil properties of woody and grassy plots were usually more similar compared to field plots. The relatively minor effects of the new flood on the investigated soil properties was due to the small power of the flood, its short duration and the timing of soil sampling after the flood, when soil aeration was being restored. No substantial effects of the flood were found for EC and soil texture. Significantly increased pH_{CaCl_2} were found only in the topsoil of grassy plots. However, C_{tot} content in the subsoil showed a significant increase in all plot types, indicating a substantial vertical migration of moveable carbon species in soil covers during the flood. The physico-chemical properties of the investigated plot types can serve as the basis for reconstruction of the park after recent floods and keeping soil healthy for long-term use of the park. The data on soil properties along with element content distributions in park soils will be the subject of a future paper.

REFERENCES

Brázdil R., Dobrovolný P., Elleder L., Kakos V., Kotyza O., Květoň V., Macková J., Müller M., Štekl J., Tolasz R., Valášek H. (2005): Historical and Recent Floods in the Czech Republic. Brno, Masaryk University. (In Czech)

Brzák K.K. (2012): History of the Veltrusy park. Prague, Theresiae RTM. (In Czech)

CGS (2019): Geological Map of the Czech Republic 1:500 000 online. Prague, Web Map Services, Czech Geological Survey.

Ding C.F., Du S.Y., Ma Y.B., Li X.G., Zhang T.L., Wang X.X. (2019): Changes in the pH of paddy soils after flooding and drainage: modelling and validation. Geoderma, 337: 511–513.

FAO (2015): World Reference Base for Soil Resources 2014. International Classification System for Naming of Soils and Creating Legends for Soil Maps. Updated 2015. Rome, Food and Agriculture Organisation of the United Nations, World Soil Resources Reports, No. 106, 192.

Gvoždíková B., Müller M. (2017): Evaluation of extensive floods in western/central Europe. Hydrology and Earth System Sciences, 21: 3715–3725.

Kanzari F., Syakti A.D., Asia L., Malleret L., Piram A., Mille G., Doumenq P. (2014): Distributions and sources of persistent organic pollutants (aliphatic hydrocarbons, PAHs, PCBs and pesticides) in surface sediments of an industrialized urban river (Huveaune), France. Science of the Total Environment, 478: 141–151.

Kettler T.A., Doran J.W., Gilbert T.L. (2001): Simplified method for soil particle-size determination to accompany soil-quality analyses. Soil Science Society of America Journal, 65: 849–852.

Kozák J.T., Státníková P., Munzar J., Janata J., Hančil V. (2007): Floods in the Czech Countries. Prague, Professional Publishing. (In Czech)

Langhammer J., Vilímek V. (2008): Landscape changes as a factor affecting the course and consequences of extreme floods in the Otava river basin, Czech Republic. Environmental Monitoring and Assessment, 144: 53–66.

Mayer S., Kölbl A., Völkel J., Kögel-Knabner I. (2019): Organic matter in temperate cultivated floodplain soils: light fractions highly contribute to subsoil organic carbon. Geoderma, 337: 679–690.

Menon M., Mawodza T., Rabbani A., Blaud A., Lair G.J., Babaei M., Kercheva M., Rousseva S., Banwart S. (2020): Pore system characteristics of soil aggregates and their relevance to aggregate stability. Geoderma, 366: 114259.

MCC (1994): Munsell Soil Color Charts. Revised ed. Munsell Color, New Windsor, Macbeth Division of Kollmorgen Instruments.

MZe (2017): Regulation of Ministry for Agriculture (MZe) No. 335/2017 Sb. (Coll.), on Agrochemical Testing of Agricultural Soils and Determination of Properties of Sylvan Plots. Collection of Laws 115/2017, 3578–3589. (In Czech)

Němeček J., Rohošková M., Macků J., Vokoun J., Vavříček D., Novák P. (2008): Taxonomic Classification System of Soils of the Czech Republic. Prague, Czech University of Life Sciences. (In Czech)

Ponnamperuma F.N. (1972): The chemistry of submerged soils. Advances in Agronomy, 24: 29–96.

Ponnamperuma F.N. (1984): Effects of flooding on soils. In: Kozlowski T.T. (ed.): Flooding and Plant Growth. Orlando, Academic Press Inc., 9–46. ISBN: 978-0-12-424120-6

Pospíšil F. (1971): Humic acids, their properties and effect on phytase hydrolysis. In: Novák B., Macura J., Kutílek M., Pokorná-Kozová J., Tichý V. (eds.): Humus et Planta V. Prague, Transactions of the International Symposium, Prague, 343–350.

Pospíšil F. (1981): Group- and fractional composition of the humus of different soils. In: Transactions of the 5th International Soil Science Conference. Prague, Research Institute for Soil Improvement, 1: 135–138.

Prášková L., Němec P. (2016): Basal Monitoring of Agricultural Soils. Content of Available Micro-elements B, Cu, Fe, Mn, Mo and Zn 1995–2013. Brno, Central Institute for Supervising and Testing in Agriculture. (In Czech)

Reichert J.M., Suzuki L.E.A.S., Reinert D.J., Horn R., Håkansson I. (2009): Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. Soil and Tillage Research, 102: 242–254.

Rodríguez M., Steiger J., Rosales J., Laraque A., López J.L., Castellanos B., Guerrero O.A. (2019): Multi-annual contemporary flood event overbank sedimentation within the vegetated lower Orinoco floodplain, Venezuela. River Research and Applications, 35: 1241–1256.

Shannon M.C., Grieve C.M. (1998): Tolerance of vegetable crops to salinity. Scientia Horticulturae, 78: 5–38.

Slavich P.G., Petterson G.H. (1993): Estimating the electrical conductivity of saturated paste extracts from 1:5 soil, water suspensions and texture. Australian Journal of Soil Research, 31: 73–81.

Tan K.H. (2011): Principles of Soil Chemistry. 4th Edition. Boca Raton-New York, CRC Press. ISBN 9781439813928

Thonon I., Middelkoop H., van der Perk M. (2007): The influence of floodplain morphology and river works on spatial patterns of overbank deposition. Netherlands Journal of Geosciences, 86: 63–75.

Ulbrich U., Brücher T., Fink A.H., Leckebusch G.C., Krüger A., Pinto J.G. (2003): The central European floods in August 2002: Part 2 – Synoptic causes and considerations with respect to climate change. Weather, 58: 434–441.

USDA (1987): Soil Mechanics Level I, Module 1 – Unified Soil Classification System. Study Guide. Washington, United States Department of Agriculture (USDA), Soil Conservative Service.

Váňová V., Langhammer J. (2011): Modelling the impact of land cover changes on flood mitigation in the upper Lužnice basin. Journal of Hydrology and Hydromechanics, 59: 262–274.

Vink R., Behrendt H., Salomons W. (1999): Development of the heavy metal pollution trends in several European rivers: an analysis of point and diffuse sources. Water Science and Technology, 39: 215–223.

Wilson M.G., Sasal M.C., Caviglia O.P. (2013): Critical bulk density for Mollisol and a Vertisol using least limiting water range: effect on early wheat growth. Geoderma, 192: 354–361.

Yu B.Q., Xie C.K., Cai S.Z., Chen Y., Lv Y.P., Mo Z.L., Liu T.L., Yang Z.W. (2018): Effects of tree root density on soil total porosity and non-capillary porosity using a ground-penetrating tree radar unit in Shanghai, China. Sustainability, 10: 4640.

Zapata F. (ed.) (2002): Handbook for the Assessment of Soil Erosion and Sedimentation Using Environmental Radionuclides. Dordrecht, Kluwer Academic Publishers. ISBN 978-0-306-48054-6

Received: August 19, 2020
Accepted: January 5, 2021
Published online: January 22, 2021