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Physical and soil water properties of technosols developed from lignite fly ash

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Abstract: The aim of this study was to determine the influence of reclamation on selected soil water properties in soils developed from lignite fly ash, deposited as a dry landfill, twenty years after forest reclamation was initiated. Five soil profiles, classified as technogenic soils (Technosols) within the fly ash disposal site of the Adamów (central Poland) power plant, were selected for this study. Disturbed and undisturbed samples ($V=100\ cm^3$) were collected from depths of 5–15 cm and 30–60 in each soil profile. The following physical properties were determined: particle size distribution, particle density, bulk density, soil moisture, hygroscopic water content, and the soil-water potential. Readily available water (RAW; difference of water content at pF=2.0 and at pF=3.7) and total available water (TAW; difference of water content at pF=2.0 and at pF=4.2) were calculated based on soil moisture tension (pF) values. The following chemical properties were determined: soil reaction, total organic carbon, total nitrogen content, carbonate content. Statistical analyses were conducted using the GenStat 18 statistical software package. The soils under study were characterized by very low bulk density, high total porosity, high field water capacity and maximum hygroscopicity. The RAW/TAW ratio values indicate very effective water retention in the soils, thereby ensuring a satisfactory water supply to the plants. However, statistical analysis did not show any clear trends in variability of any determined properties. The small differences in observed outcomes probably resulted from the original variability of the fly ash deposited on the studied landfill. Obtained results show the strong similarity of fly ash derived soils and Andosols in respect of physical and soil-water properties.

Introduction

The proportion of electricity produced by coal-fired power plants accounts for about 38% of its total global production (World Coal Association 2019). Bituminous coal and lignite are among the most important fuels for the production of electricity globally (Kavouridis 2008, Mohr and Evans 2009, World Coal Association 2019). This process is accompanied by the continuous generation of significant amounts of coal combustion products, e.g. fly (fine-grained) and bottom (coarse-grained) ash (Rosik-Dulewska et al. 2008, Weber et al. 2015, Uzarowicz et al. 2017). These products mostly consist of non-combusted lignite mineral admixtures (clay minerals, quartz, carbonates, sulfides etc.) that are high temperature transformation products (Vassilev and Vassileva 1996). Despite their potential use as a source of nutrients in forestry and agriculture, and use in the construction industry, the vast proportion of these solid wastes are stored in dry or wet disposal sites in many countries (Ahmaruzzaman 2010, Ukwattage et al. 2013, Yao et al. 2015) and also in Poland (Gilewska 2006, Weber et al. 2015, Uzarowicz and Zagórski 2015, Uzarowicz et al. 2018b, Gilewska et al. 2020).

Due to the specific physico-chemical properties of fly and bottom ash (high pH values, salinity and low content of nitrogen in general), few plants are able to survive on the soils that develop from these materials (Maiti and Jaiswal 2008, Krzaklewski et al. 2012, Pietrzykowski et al. 2018). Spontaneous plant colonization on fly and bottom ash disposal sites occurs only with difficulty (Żołnierz et al. 2016, Meravi and Prajapati 2019). Therefore, these materials are subjected to reclamation, which is carried out in a variety of ways, but usually faces many obstacles that result from the properties of this material (Gilewska 2004, Strączyńska et al. 2004).

While the basic properties of technogenic soils that develop from fly ash are relatively well known (Maciak et al. 1976, Zikeli et al. 2002, 2004, Gilewska 2006, Uzarowicz et al. 2017, Pietrzykowski et al. 2018, Konstantinov et al. 2018, Uzarowicz et al. 2018a, 2018b, Konstantinov et al. 2020), there are only a few papers presenting their soil water properties, such as hygroscopicity or soil-water constants (Weber et al. 2015), especially for the soils that have developed within dry landfills. Thus, the aim of this study was to analyze the impact of the reclamation process on selected soil-water properties in five technogenic soils developed from lignite power plant fly ash that was deposited as dry landfill, twenty years after forest reclamation.

Materials and methods

Study area

The study area was located within the fly ash disposal site (dry landfill) of the Adamów lignite power plant (Fig. 1). First attempt to study the basic physical properties of soil developed within this spoil heap was carried out by Mocek--Płóciniak (2018). As obtained results were promising authors decided to conduct further studies presented in current paper. The landfill formation developed between 1964 and 1974. Dry ash was transported by a belt conveyor. The transport system influenced the shape (in the form of a convex heap) and architecture of the landfill. It has the shape of a truncated cone, gently sloping to the north and north-east and steep sloping to the south and south-west. Strong insolation of these slopes causes the surface drying and intensifies the erosion processes (Gilewska 2004). It covers an area of about 40 ha and reaches a height of 20 m. The first stage of reclamation was carried out in 1979. It consisted of covering part of the heap surface with peat, and white melilot (*Melilotus albus*) was then planted as a pioneer species. After a period of about 10 years, black locust (*Robinia pseudoacacia*), smallflower tamarisk (*Tamarix parviflora*) and ash-leaved maple (*Acer negundo*) were introduced. Unfortunately, these treatments were unsuccessful (Gilewska 2004). A new and effective reclamation method was introduced from 1993 to 1997 (Gilewska 2004). According to the *target species concept* (Bender 1995), high mineral fertilization (300 kg N + 180 kg P_2O_5 + 120 kg K_2O per ha, once a year for 4 years) was applied. Then, calciphilous plant species, tolerant to high salinity levels, such as Norway maple (*Acer platanoides*), European ash (*Fraxinus excelsior*), green ash (*Fraxinus pennsylvanica*), wild olive (*Eleaganus angustifolia*), caragana (*Caragana arborescens*), common dogwood (*Cornus sanguinea*) and sea-buckthorn (*Hippophae rhamnoides*) were introduced. The plant cover on the surface of the landfill initiated the soil--forming process. Since that time, the heap is considered as completely reclaimed (Gilewska 2006). The mean annual air temperature in the study area in the period 1985–2004 was 8.7°C and mean annual precipitation was 520 mm (Stachowski et al. 2013).

Field sampling

In this study, five soil profiles were arranged in a transect in the central part of the dry landfill heap (Fig. 1). The morphological features of soils under investigation, including soil structure, were described according to the Guidelines for Soil Description (Jahn et al. 2006). Intact samples were collected from depths of 5–15 cm and 30–60 from each soil profile using metal cylinders of known volume (100 cm^3 volume, in 3 replicates). The disturbed samples were collected to plastic bags.

Basic soil properties and soil samples description

The following soil properties were determined in the collected samples: particle size distribution with the sieve method and hydrometer methods (Bouyoucos method, modified by Cassagrande and Prószyński), total organic carbon (TOC) and total nitrogen (TN) using a VarioMax CNS analyzer, while TOC content was calculated by the TC correction due to carbonates content (inorganic C content was subtracted from TC content), reaction of the soil with the soil: solution ratio of 1:2.5 using H_2O and 1M KCl as a suspension medium, and carbonate content with the Scheibler volumetric method. Texture class names were provided in line with the USDA classification

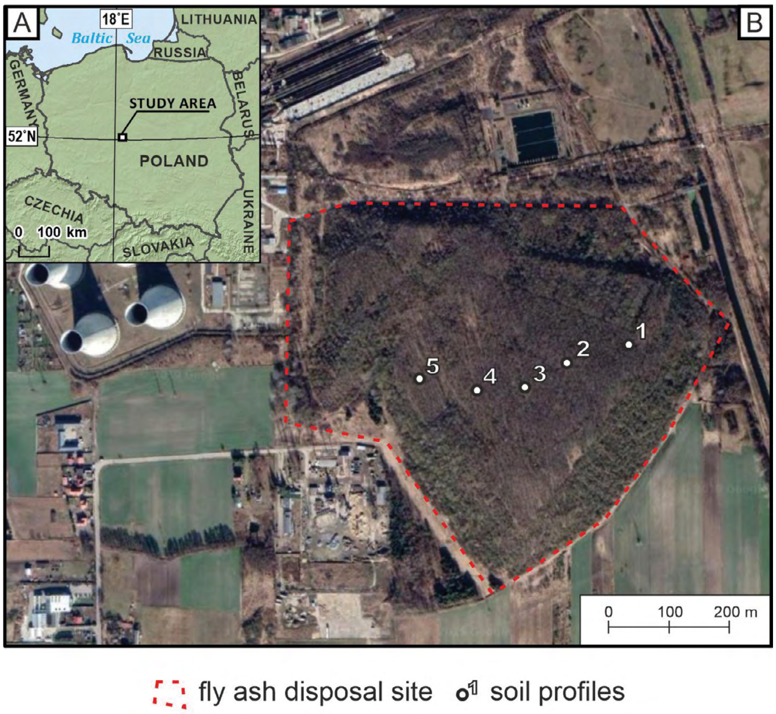


Fig. 1. Location of the study area (A) and the soil profiles within the fly ash disposal site under investigation (B)

(Soil Survey Division Staff 2017). Soil color was described for fresh samples according to the Munsell Soil Color Charts.

Physical and soil water properties

Particle density was determined using the pycnometer method (Soil Conservation Service 2004), and bulk density with the oven-dry method using metal cylinders (100 cm^3 volume). Total porosity was calculated based on particle density and bulk density, soil moisture and hygroscopic water content (H) using the oven-dry weight method, maximum hygroscopic capacity (MH) was determined in a vacuum chamber at 0.8 atm. with a K_2SO_4 saturated solution, the soil-water bond potential was determined with the Richards pressure chamber method (Klute 1986), total available water (TAW; difference of water content at pF=2.0 and at pF=4.2) and readily available water (RAW; difference of water content at pF=2.0 and at pF=3.7) were calculated based on soil moisture tension (pF) values. The soils were classified according to the Polish Soil Classification, 6th edition (Systematyka gleb Polski 2019) and the WRB classification system (IUSS Working Group WRB 2015). The English equivalents for the soil taxa names in the Polish Soils Classification were provided after Kabała et al. (2019).

Statistical analyses

All three replicates of each sample were used for statistical analyses. Firstly, the normality of the distributions of the studied traits were tested using Shapiro-Wilk's normality test. Fisher's test (α=0.05) allows for an assessment of the significance of differences between the obtained values. The analysis of relationships between TC and the other examined traits was carried out with the use of the regression analysis. Coefficients of determination were used to measure how the model fitted the data. The results were also analyzed using multivariate methods. Graphic distribution of the profiles and depth combinations described by the observed traits together were visualized with the use of the principal component analysis (PCA) and presented in the biplot. All the analyses were conducted using the GenStat 18 statistical software package.

Results and discussion

Soil classification, soil morphology and basic soil properties

According to the Polish Soil Classification (Systematyka gleb Polski 2019), all the profiles under investigation were classified as industriosols (calcareous, reclaimed) within Technogenic type soils (Kabała et al. 2019). At the same time, they fulfill the criteria of Spolic Technosols (Arenic, Calcaric, Hyperartefactic, Ochric, Laxic) according to WRB (IUSS Working Group WRB 2015). Most probably the studied soils would also fulfill the criteria for vitric properties. If so, the Vitric supplementary qualifier reported for soils developed from the fly ashes could be used (Uzarowicz et al. 2017). However, it could be considered only after application of additional chemical analyses.

All the soils were characterized by very simple morphology. The process of reclamation (mixing the top layer of ash with the thin organic layer) did not affect profile morphology to more than 5–10 cm below the ground surface. The lack of stratification is a common feature of soils developed within dry deposited ash landfills (Uzarowicz et al. 2017). The samples were collected from the horizons that represent the ACu horizons (5–15 cm) enriched with organic matter, and the Cu horizons composed of the fly ash material without admixture of organic material (30–60 cm). All of the analyzed soil samples were characterized by a relatively dark color that originated from the color of the parent material (Table 1).

The particle size distribution of all tested soil samples was very similar and all were classified as loamy sands (Table 1). The sand fraction was dominant (77–85%) while the contents of silt and clay fractions ranged from 13–21% and 1–2%, respectively. The determined grain size distribution was similar to that found in other ash disposal sites in Poland (Antonkiewicz 2010, Weber et al. 2015, Uzarowicz et al. 2017, 2018a).

Total organic carbon (TOC) content was characterized by relatively large variability. It ranged from 51.5 to 86.3 g kg^{-1} (Table 2). The TOC content distribution in the profiles did not

Table 1. Location, morphological features and texture of investigated soils

Profile No.	Coordinates	Genetic Horizon	Depth of sampling (cm)	Colour*	Structure**		Percentage of fraction with diameter in mm			Texture class**
					Type	Size	2–0.05	0.05–0.002	<0.002	
1	52°00'31" N 18°33'26" E	ACu	5–15	2.5Y3/1	GR	FI	85	13	2	LS
		Cu	30–60	2.5Y3/2	GR	ME	81	18	1	LS
2	52°00'30" N 18°33'21" E	ACu	5–15	5Y3/1	GR	ME	78	21	1	LS
		Cu	30–60	2.5Y3/2	SB	CO	77	21	2	LS
3	52°00'29" N 18°33'17" E	ACu	5–15	2.5Y2/1	GR	ME	78	20	2	LS
		Cu	30–60	2.5Y3/2	GR	ME	79	19	2	LS
4	52°00'29" N 18°33'13" E	ACu	5–15	2.5Y3/1	GR	ME	79	19	2	LS
		Cu	30–60	2.5Y3/2	SB	CO	78	20	2	LS
5	52°00'29" N 18°33'08" E	ACu	5–15	2.5Y3/1	GR	ME	82	16	2	LS
		Cu	30–60	2.5Y3/2	GR	ME	83	15	2	LS

* Colour was determined for fresh samples.
** Structure: GR – granular; SB – subangular blocky; FI – fine; ME – medium; CO – coarse
*** Texture LS – loamy sand

show any clear trend related to depth, which usually occurs in mineral soils (i.e. decrease of TOC with increasing depth). This could be the result of the random presence of unburned lignite remains, which is common in fly ash sites (Strzyszcz 2004, Zikeli et al. 2002, 2004, Weber et al. 2015). These results are in agreement with research conducted by Gilewska (2004) (21.2–149 g kg^{1}) and Antonkiewicz (2010) (28–94 g kg^{-1}), while Bielińska and Futa (2009) obtained lower and less variable results (10–20 g kg^{-1}).

Total nitrogen (TN) content ranged from 1.27 to 2.43 g kg^{-1} in the upper horizons and from 1.11 to 2.03 g kg^{-1} in the endopedons (Table 2). This is in line with research conducted in Poland by Strzyszcz (2004) and Rosik-Dulewska (2015), as well as many studies elsewhere (e.g. Gupta et al. 2007, Jala and Goyal 2006, Haynes 2009) that have reported low or even trace nitrogen content in fly ash. Yao et al. (2015) recommend that Technosols developed from fly ash material should be supplemented with nitrogen. This is due to the fact that fly ash is devoid of humus and N, attributable to the oxidation of C and N during coal combustion (Yao et al. 2015).

The tested soils were alkaline (pH of 7.9–8.5 in H_2O, and 7.2–8.2 in KCl). Similarly, high pH values for fly ash and soils formed from fly ash have been reported by many authors (Zikeli et al. 2002, 2004, Ukwattage et al. 2013, Weber et al. 2015). The high pH of these soils is related to the elevated amounts of calcium carbonate, which ranged from 5.7–9.5% in studied soils (Table 2).

Physical properties

Soil particle density ranged from 2.06–2.15 Mg m^{-3} in the epipedons. The endopedons were characterized, in most cases, by significantly higher values that ranged from 2.14–2.24 Mg m^{-3} (Table 3). The observed values were considerably lower than those found in soils developed from glacial sediments (2.50–2.80 Mg m^{-3}), which are the most common parent material for the northern and central parts of Poland, as well as the surroundings of the study area (Kaczmarek 2011, Kaczmarek et al. 2015, Gajewski et al. 2015). The aforementioned difference is the effect of the hollow ash grains (cenospheres) presence, which lowers the soil particle density (Sokol et al. 2000, Uzarowicz et al. 2017). For this reason the soil particle density values in this study are typical of technogenic soils that have developed from fly ash, as well as from raw ash, as also reported by other authors (Gilewska and Otremba 2010, Rosik-Dulewska 2015, Weber et al. 2015, Uzarowicz et al. 2017).

The bulk density values were also very low in this study. They ranged from 0.76–0.80 Mg m^{-3} in the upper horizons and from 0.69–0.83 Mg m^{-3} in deeper parts of the soil profiles (Table 3). Bulk density values decreased with increasing depth in profiles 1, 2 and 3, however this change was not statistically significant in profile 2 (Table 3). The opposite situation was observed in profiles 4 and 5, where the bulk density of the endopedons was higher (statistically significant only for profile 5). The values were within the range of bulk density values obtained for similar soils in Poland (Weber et al. 2015, Żołnierz et al. 2016) and in Europe (Hartman et al. 2010, Klose et al. 2001, Zikeli et al. 2002, 2004). As was the case with soil particle density, the obtained values were also significantly lower than those found in soils that have developed over glacial sands and tills (0.90–1.90 Mg · m^{-3}) (Kaczmarek 2011, Kaczmarek et al. 2015, Gajewski et al. 2015).

The calculated total porosity values based on particle density and bulk density were relatively high, ranging from 62.20–63.68% v. in the surface horizons, and from 62.27–68.35% v. in the subsurface layers (Table 3). The observed trends were dissimilar between the studied soil profiles. In profiles 1–4, an increase in total porosity with depth was observed (insignificant for profile No. 4, Table 3). Profile 5 was different, as total porosity was not significantly lower in the endopedons than in the upper horizon. These results are in line with Gilewska (2004), who suggested that high porosity values are a characteristic feature of technogenic soils formed from fly ash.

Hygroscopic water content in soils formed from ash has not been studied by any of the authors cited in this paper. This parameter characterizes the ability of the soil material to retain a certain amount of water in air-dry state. The hydroscopic water content varied from 1.69–2.73% of volume (Table 3). A comparison of hygroscopic humidity levels in examined soils with the natural soil formations in this region shows that this parameter exhibits similar values to those reported for cultivated mineral soils composed of loamy sands (Gajewski et al. 2015, Kaczmarek et al. 2017).

Table 2. Chemical properties of investigated soils

Profile number	Depth of sampling (cm)	TOC	TN	$CaCO_3$ [%]	pH	
		[g·kg^{-1}]			H_20	1M KCl
1	5–15	54.2	1.60	8.5	8.5	8.1
	30–60	51.5	1.58	7.9	8.1	7.9
2	5–15	84.5	2.43	8.5	8.5	8.1
	30–60	86.3	2.03	9.5	8.5	8.2
3	5–15	68.3	1.27	7.6	8.1	7.8
	30–60	81.6	1.28	5.7	7.9	7.3
4	5–15	64.9	1.96	7.9	8.0	7.9
	30–60	58.3	1.57	6.7	8.0	7.3
5	5–15	79.0	1.96	6.4	8.1	7.4
	30–60	56.6	1.11	7.2	8.0	7.2

Soil water properties

The maximum water capacity (humidity at pF = 0.0) was about 2–3% lower than the total porosity. Field water capacity (FC) was high, ranging from 36.53–44.39% v (Table 4). This demonstrates that the studied soils could retain a large amount of plant available water in some periods. Weber et al. (2015) obtained similar FC values (above 40% v.) when examining the upper (0–25 cm) horizons of Technosols formed within a fly ash wet disposal site. High water storage capacity was also reported by Gangloff et al. (2000) in the case of sandy soils amended with fly ashes. The water content at pF = 3.7 was unfavorably high, amounting to 18.44–24.04% v., which accounted for a considerable proportion of the hardly available water (HAW). The moisture content at the permanent wilting point (pF = 4.2) was also high and ranged from 10.77–19.20% v.). As all of the examined soil samples were characterized with texture of loamy sands, the maximum hygroscopicity values, corresponding to the water content at pF = 4.5 was surprisingly high (6.91–16.55%, Table 4). In sediments of natural origin, such values are usually found in soils that have developed from clays and heavy clays (Kaczmarek et al. 2015). We assume that these results could arise from binding some amount of water into the porous glass grains with vesicular pores and cenospheres being a vast part of the fly ashes. Even though the water content at pF = 3.7 and 4.2 was critically high, the elevated field water capacity values effectively compensated for this deficiency. The TAW and RAW indices, calculated on the basis of pF determinations, varied from 20.86–32.64% v. for TAW, and from 13.63–29.95% v. for RAW. In comparison to natural, mineral, and agricultural (arable) soils, they are very high, thereby ensuring an optimal water supply to plants, as the water is retained effectively after precipitation. On the other hand, this favorable state of soil moisture is considered as very transient and can disappear in the absence of other forms of hydration (Gangloff et al. 2000). The RAW and TAW values clearly indicate an elevated proportion of readily available water for plants. RAW/TAW ratio ranged from 0.62–0.80% v. and the values were distinctly higher (Table 4) than analogous values obtained in mineral soils with similar texture (Mocek 1989). Weber et al. (2015) obtained slightly different results while examining soil samples taken from a depth of 0–25 cm, within a former fly ash settling pond. They determined the values of RAW (20.5% v.), much higher TAW values (40.0% v.), and similar field water capacity values (43.6% v.). Finally, the RAW/TAW ratio value calculated for that horizon was 0.51, which is very favorable when compared to the fly ash and natural (glacial) sediments (Mocek 1989).

Some authors have highlighted the chemical and morphological similarities of fly ash derived technogenic soils to Andosols (Uehara 2005, Uzarowicz et. al. 2017, 2018a). Moreover, soils developed from fly ash are comparable to volcanic soils in respect of bulk density values (Uzarowicz et al. 2017). The obtained results allow us to state that these specific human-made soils also have much in common with volcanic ash derived soils in terms of physical and soil water properties, e.g., very low bulk density, high total porosity and high plant-available water content (Dorel et al. 2000, Neall 2000).

Statistical analyses

We assumed that the negligible differences in particle size distribution between the examined soil samples can be beneficial for further investigation, e.g., if the soil texture is very similar, then the possible differences in soil-water properties are caused by some others factors. As the organic matter content is known to influence the soil water properties, regression analysis was performed to assess the relationships between TOC content and selected physical parameters (Table 5).

Surprisingly, no correlations were found, although we expected to find the strong expression of TOC impact on soil water content, especially in regard to such a homogenous texture.

In addition, no clear patterns were observed with the PCA results (Fig. 2). The most likely reason is that 20 years is not a sufficient period for the pedogenic processes to differ in the epipedons and endopedons, in such unusual parent material as fly ash.

Conclusions

The soils in this study were characterized by some extraordinary features in terms of the physical and soil water properties encountered: very low bulk density, high total porosity, high field water capacity and maximum hygroscopicity. Elevated field water capacity values compensated for the negative effect

Table 3. Physical properties of investigated soils

Profile No.	Depth of sampling (cm)	Particle density	Bulk density	Total porosity	Hygroscopic water content
		[$\text{Mg}\cdot\text{m}^{-3}$]		[% of volume]	
1	5–15	2.09fg	0.79bc	62.20e	1.77ef
	30–60	2.14cde	0.72de	66.36bc	1.69g
2	5–15	2.06g	0.76cd	63.11de	2.10c
	30–60	2.17bcd	0.72de	66.82ab	1.83de
3	5–15	2.13de	0.80ab	62.44e	2.73a
	30–60	2.18bc	0.69e	68.35a	1.74f
4	5–15	2.12ef	0.77bc	63.68de	1.80def
	30–60	2.24a	0.79bc	64.73cd	2.41b
5	5–15	2.15cde	0.79bc	63.26de	2.09c
	30–60	2.20ab	0.83a	62.27e	1.87d

α = 0.05/values marked with the same letters don't differ significantly

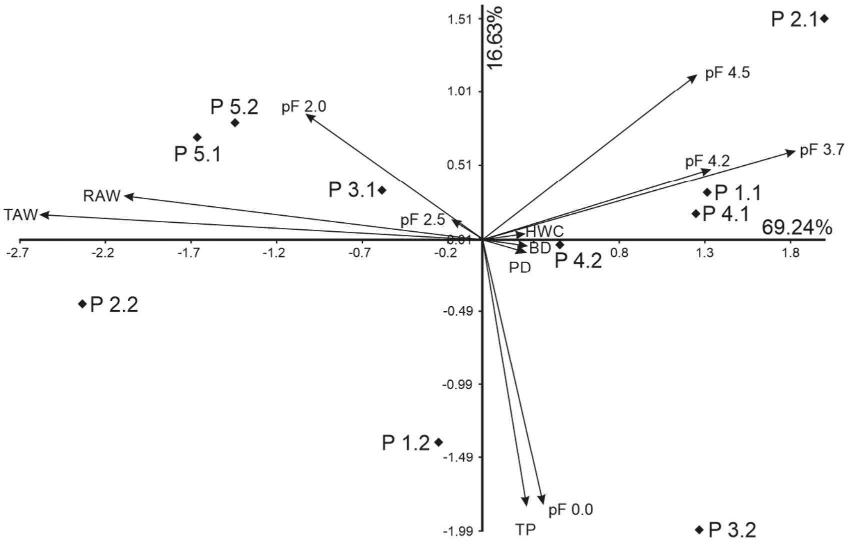
Table 4. Soil water properties

Profile No.	Depth of sampling (cm)	Moisture [%v] at pF:						Water retention [%v]		
		0	2.0	2.5	3.7	4.2	4.5	RAW	TAW	RAW/TAW
1	5 15	59.60ef	36.53f	30.87f	22.90bc	14.56c	8.34cd	13.63d	21.97ef	0.62
	30–60	64.66a	37.72e	33.70b	19.56e	11.08ef	8.76c	18.16d	26.64c	0.68
2	5 15	61.29cd	40.06bc	32.66cd	23.51ab	19.20a	16.55a	16.55e	20.86f	0.79
	30–60	63.34b	44.39a	32.41de	18.44f	11.75e	7.48de	29.95a	32.64a	0.80
3	5 15	59.62ef	39.20cd	32.87bcd	19.65e	12.53d	6.91e	19.55c	26.67c	0.73
	30–60	65.49a	36.66f	31,59ef	21.36c	14.92c	8.24cd	15.30f	21.74ef	0.70
4	5 15	60.70de	38.74de	31.70ef	24.04a	16.16b	8.06cd	14.70f	22.58e	0.65
	30–60	61.57c	38.44de	33.45bc	20.45d	14.19c	10.68b	17.99d	24.25d	0.74
5	5 15	61.43cd	43.50a	35.84a	21.36c	11.44ef	8.72c	22.14b	32.06a	0.69
	30–60	58.72f	40.52b	32.74cd	18.92ef	10.77f	8.20cd	21.60b	29.75b	0.73

α = 0.05/values marked with the same letters don't differ significantly

Table 5. Regression analysis showing the relationships between total organic carbon (TOC) content and soil water properties

Trait (x)		Model	R² [in %]
HWC		$y = -0.0006x^2 + 0.0795x - 0.6428$	9.1
TP		$y = 0.0048x^2 - 0.6171x + 83.303$	19.2
PD		$y = -8E\text{-}05x^2 + 0.0101x + 1.8263$	6.8
BD		$y = -0.0001x^2 + 0.0168x + 0.245$	32.1
Moisture at pF:	0.0	$y = 0.0048x^2 - 0.6121x + 80.104$	21.5
	2.0	$y = 0.1118x + 31.813$	32.5
	2.5	$y = -0.0004x^2 + 0.069x + 29.998$	2.0
	3.7	$y = -0.0013x^2 + 0.1824x + 14.897$	1.4
	4.2	$y = 0.0422x + 10.735$	4.6
	4.5	$y = 0.0023x^2 - 0.2564x + 15.555$	9.9
RAW		$y = 0.0017x^2 - 0.1273x + 18.787$	15.5



P 1.1; P 1.2 etc. - profile No 1: sampling depth 5-15; profile No 1: sampling depth 30-60 etc.
pF 0.0; pF 2.0 etc. - water content at pF=0.0; water content at pF=2.0, etc.
PD - particle density; BD - bulk density; TP - total porosity; HWC - hygroscopic water content

Fig. 2. Principal component analysis (PCA) biplot showing the graphical distribution of the profiles and depths combinations described by the observed traits

of an unfavorably high water content at pF = 3.7 and 4.2. Also, the RAW/TAW values indicate very effective retention of water by the soils, thereby ensuring an optimal water supply to the plants. These values could be highly important for the development of a comprehensive approach to fly ash site reclamation, as these specific soil-water properties may strongly influence plant growth.

On the other hand, statistical analysis did not show any clear trends in the variability of the determined soil properties. The upper horizons differed negligibly from the endopedons. Thus, we can assume that 20 years after reclamation, the pedogenic processes have had a little impact on the physical and soil water properties within the studied soil profiles. Most probably, all the minor differences between the soil profiles and the sampling depths are due to the original variability of the fly ash deposited on the studied landfill.

In addition, we confirmed the similarities of fly ash derived Technosols to Andosols. These results show that these specific human-made soils have much in common with volcanic ash derived soils in terms of physical and soil water properties such as very low bulk density, high total porosity and high plant-available water content.

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