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Technogenic soils (Technosols) developed from fly ash and bottom ash from thermal power stations combusting bituminous coal and lignite. Part I. Properties, classification, and indicators of early pedogenesis

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ABSTRACT

Large amounts of fossil fuel combustion wastes (e.g. fly and bottom ash) are discharged on land surface all over the world. The uppermost layer of disposal sites is subject to soil-forming processes after the development of plant cover due to natural succession or reclamation works. The present study presents the analysis of technogenic soils (Technosols) developed from ashes after combustion of bituminous coal and lignite. The study involved the determination of their properties, their classification, and discussion of the indicators of early pedogenesis. Technosols located on the surface of settling ponds and landfills of selected thermal power stations in Poland combusting both bituminous coal and lignite were examined. Standard pedological methods for the determination of soil morphology and physical-chemical properties were applied. Dithionite and oxalate extractions of Fe, Al, Si, and Mn were used in order to determine transformations of soil substrate during pedogenesis. Moreover, optical microscope observations permitted finding microscale effects of soil-forming processes in the studied Technosols. The properties of the analysed Technosols are primarily influenced by the properties of the parent material (i.e. ash from thermal power stations) which in turn are strongly dependent on (1) the type of ash (fly ash vs. bottom ash), (2) the kind of fuel (bituminous coal vs. lignite), as well as (3) the mode of ash deposition and type of disposal site (settling pond vs. dry landfill). Properties of the studied soils are also controlled by the following soil-forming factors: vegetation (input of soil organic matter), human (acceleration of soil-forming processes by reclamation), and climatic/weather conditions (leaching of soluble compounds by water from precipitation). The most important morphological and physical-chemical indicators of pedogenesis of the studied Technosols over several decades of soil formation are as follows: (1) the development of soil structure in A horizon related to the accumulation of soil organic matter, (2) the decrease in pH (a change in reaction from strongly alkaline towards less alkaline or acidic), (3) the formation of pedogenic carbonates and their subsequent leaching from the topsoil after several dozen of years of pedogenesis, and (4) the release of oxalate-extractable Al and Si during the pedogenesis. The studied soils were classified according to WRB as Spolic Technosols (or Leptic Spolic Technosols) with various supplementary qualifiers (Alcalic or Eutric, Arenic and/or Loamic, Calcic or Protocalcic, Fluvic, Hyperartefactic, Laxic, Relocatic, Tephric or Vitric). Certain suggestions to improve the WRB soil system are discussed in the paper.

1. Introduction

Bituminous coal and lignite are still among of the most important fuels for the production of electric power all over the world. The activity of thermal power stations (TPSs) generates a variety of coal combustion products (CCPs), with the highest contribution of fly ash and bottom ash. For example, in the United States approximately 63 million Mg of fly and bottom ash was produced in 2014 (ACAA, 2014),

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Table 1
Location, approximate age, and field settings of the investigated soils.

Soil profile	Geographical position (GPS)	Field setting and topography	Type of disposal site	Vegetation and predominating plants	Approximate age of soil	General description of parent material and morphology of soil profiles
L1	Gardawice village N 50°06′42,9″ E 18°48′34,4″ alt. 279 m a.s.l.	Reclaimed embankment located in one of the quarters of the Gardawice settling pond; a slope slightly inclined (1°) towards the north	Settling pond	Meadow; grasses, clover, mosses	< 5 years	Very weakly developed soil profile built of ashes. In the upper part of the profile (down to 110 cm), the ash material is mixed (no stratification visible in the profile; presence of fragments of several centimetres large aggregates of crushed ash layers). Below 110 cm, ashes slightly stratified.
L2	Gardawice village N 50°06′27,0″ E 18°48′37,9″ alt. 281 m a.s.l.	Abandoned, unreclaimed quarter of the Gardawice settling pond; a flat surface	Settling pond	Meadow; grasses (mainly reed grass), mosses and lichens, single pine seedlings and perennials	~20 years	Very weakly developed soil profile built of layered ashes. Rusty material enriched in magnetite occurring in the topsoil at a depth of approximately 5 cm. Coarse grain (gravels, sand) stratified material predominating in the upper part of the profile (down to 110 cm). Fine grain (silt) well stratified material predominating below 110 cm.
L3	Gostyń village N 50°07′32,4″ E 18°50′35,1″ alt. 268 m a.s.l.	Reclaimed surface of the Gostyń settling pond; a flat surface	Settling pond	Meadow; grasses (mainly reed grass), mosses, single thistles, seedlings of snowberries, walnuts, and birches	~35 years	Very weakly developed soil profile built of ashes. In the upper part of the profile (down to 57 cm), the ash material is mixed. No stratification visible in that part of the profile. Presence of fragments of several centimetres large aggregates of crushed ash layers (previously compacted). Well stratified material with alternating coarse grain (gravel, sand) and fine grain (silt) layers predominating below 57 cm.
L4	Łaziska Górne town N 50°08′08,5″ E 18°50′28,7″ alt. 317 m a.s.l.	Old landfill; a slope slightly inclined (5°) towards the south	Dry landfill	Sparse birch and aspen forest with grasses (mainly reed grass) and thistles in groundcover	~60 years	Weakly developed soil profile built of ashes which were not stratified. A humus horizon with a thickness of approximately 30 cm developed in the topsoil. Presence of hard aggregates (size up to 2 cm) consisting of cemented ash material throughout the profile.
K2	Kazimierz Biskupi village N 52°17′59,2″ E 18°12′05,4″ alt. 88 m a.s.l.	Abandoned, unreclaimed quarter of the settling pond near the Pątnów TPS; after closure used as a place for evaporation of alkaline waters from TPS; a flat surface	Settling pond	Meadow; grasses (mainly reed grass), young seedlings of birch, willow, and white poplar	~40 years	Very weakly developed bipartite soil profile. Presence of a layer of yellowish laminated calcareous material in the topsoil (down to 16 cm). Well stratified ash material with alternating coarse grain (gravel, sand) and fine grain (silt) layers predominating below 16 cm.
K3	Konin town N 52°16′53,6″ E 18°14′55,9″ alt. 82 m a.s.l.	Abandoned, unreclaimed quarter of the Gosławice settling pond; a flat surface	Settling pond	Sparse meadow with patchy plant cover; grasses, lichens, single seedlings of willow, white poplar, and birch	~40 years	Very weakly developed bipartite soil profile. Presence of a layer of yellowish laminated calcareous material in the topsoil (down to 7 cm). Well laminated ash material with sandy texture predominating below 7 cm, showing very firm consistency. Presence of a cemented layer built of fine material, containing vast amounts of unburned lignite below 50 cm.
K5	Konin town N 52°16′39,7″ E 18°16′35,6″ alt. 85 m a.s.l.	Abandoned, reclaimed settling pond near the Konin TPS; a flat surface	Settling pond	Young sparse forest consisting of birch, Scots pine, and willow; groundcover: grasses, mosses, clover and other perennials	~40 years	Weakly developed tripartite soil profile. The O and A horizon developed in the topsoil (0–7 cm) due to accumulation of soil organic matter. Presence of brownish loamy material containing hard fragments of ash layers (previously cemented) crushed due to reclamation processes between 7 and 60 cm. Presence of a layer of cemented, well stratified, whitish and light-grey calcareous ash material below 60 cm.