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Forestry Reforestation vs. Spontaneous Revegetation – Soil Changes in Coal Mining Spoil Heaps Across Bulgaria

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Abstract. The paper presents results of an investigation of forestry reclamation and spontaneous revegetation on Technogenic soils (Technosols) formed as a result of coal mining activities. The soils are located in "Maksim taban" deposit site, Pernik, Bulgaria. Soil samples were taken at twenty-two profiles at representative plots under spontaneous revegetation - herbaceous plant cover (eleven profiles) and under forestry reclamation - black pine (*Pinus nigra* Arn.) (eleven profiles) at a depth of 0-100 cm. The changes in physicochemical properties were investigated under different vegetation and at different soil depths. The results reveal that most soil characteristics, such as bulk density, total porosity, the content of sand, silt, plant available water coefficient, pH, total organic carbon, total Kjeldahl nitrogen and available potassium are statistically significantly different under different vegetation. There are strong positive or negative correlations among soil characteristics and with soil depth.

Key words: coal mining, soil characteristics, plant cover.

Introduction

The mining industry brings drastic changes in the environment which cause a decrease in and/or a complete loss of biodiversity, as well as soil and air pollution (Alekseenko *et al.*, 2017a; b; Giam *et al.*, 2018; Etteieb *et al.*, 2020; Arefieva *et al.*, 2019). For dozens of years, environmental changes and subsequent problems related to the extraction of mineral resources have been a major issue worldwide (Sklenicka *et al.*, 2004; Abakumov *et al.*, 2012; Alekseenko *et al.*, 2017a; b), and no soil formation has begun even after decades (Alekseenko *et al.*, 2017a; b).

Affected areas around mining companies in Bulgaria are a serious environmental problem. The area around the town of Pernik, affected by the mining industry, occupies a territory of about 30 000 ha (Kirilov & Banov, 2017). By destroying the flora and fauna, changing the soil characteristics and limiting the soil microbiocenoses, mining activities bring about dramatic changes in the physical and biological characteristics of the mining areas (Corbett *et al.*, 1996).

Anthropogenically affected areas around mining industry sites in Bulgaria create serious environmental problems, which are particularly conspicuous on the territory of the Pernik coal mines (Kirilov & Banov, 2017; Kachova & Ferezliev, 2018).

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Banov & Pavlov (2014) point out that the nature of the technogenic substrates from coal mines requires a comprehensive approach to reducing their negative impact. The open-pit mining technique involves the removal of the layer above the coal seam with geological materials being accumulated in dump areas outside the mine. After mining activities cease, the geological substrates are returned to the extraction pits and reclamation activities are carried out to restore fertility. The techniques used vary depending on the objectives – whether reclamation is done for agricultural, forestry or recreational purposes (Banov & Pavlov, 2014; Pavlov *et al.*, 2015; Banov & Marinova, 2016).

The soils adjacent to mining industry sites are characterized by high bulk density, low pH, low humus content, poor structure, deterioration of soil physical and hydraulic properties and presence of trace element input by anthropogenic activity (Seybold *et al.*, 2004; Tsolova *et al.*, 2016; Atanassova *et al.*, 2018).

The spontaneous placement of vegetation in post-mining terrains is extremely slow, heterogeneous communities are created in microhabitats (Wheater & Cullen, 1997; Prach & Pysek, 2001; Tropek *et al.*, 2010; Patova *et al.*, 2015).

In various studies of disturbed terrains as a result of mineral extraction the state of the soil after recultivation is examined. In terms of vegetation, the most common tree species is mentioned, e. g black pine (Doichinova, 2008). Often the vegetation is divided only into grass and tree - broad-leaved and coniferous (Hristov *et al.*, 2015), species with slower growth rate and lowered vitality (Alekseenko *et al.*, 2017b). Other studies mention some of the plant species, for example vegetation on old slag-heaps (mining waste dump sites) includes birches and ferns, spare grasses, *Portulaca oleracea* L., *Spergularia rubra* (L.) C. Presl, *Dysphania botrys* (L.) Mosyakin & Clemants and others. The recultivated land has been planted with e.g. red oaks, blue spruces and ornamental shrubs; self-sowing trees such as black locusts have also spread into these areas (Pajurková, 2017).

The purpose of this study is to identify the presence or absence of any differences among the soil characteristics of the technogenic soil formed as a result of coal mining activities under naturally occurring vegetation and under forestry reclamation.

Materials and Methods

The object. Technosols (FAO, 2014) occurring on the territory of "Maksim taban" deposit site, located to the Northwest next to Klepaloto and Baykusheva mahala districts in Pernik, Bulgaria, were the object of the study. The object of study is found in the Lower forest vegetation zone (0-600 m a.s.l.) of the Moesian forest vegetation area of Bulgaria (Zahariev *et al.*, 1979).

*Methods of study***.** Twenty-two profiles at a depth of 0-100 cm were done at representative plots under spontaneous revegetation (herbaceous plant cover – sample plot 1, eleven profiles) and under forestry reclamation (black pine - *Pinus nigra* Arn. – sample plot 2, eleven profiles). A systematic sampling design was used (Petersen & Calvin, 1996). The samples were taken at depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm. The following soil characteristics were analyzed by using the respective methods: Bulk density (BD, $g.cm^{-3}$), according to the DIN ISO 11272:1998, 2001; Total porosity (TP, %) by calculation of bulk density and relative density (Lorraine & Flint, 2002); Soil texture (Sand (2 mm - 63 µm), %; Silt (63 µm - 2 µm), %; Clay (2 µm), %), using the sedimentation method (ISO 11277), the soil texture classes have been determined according to Soil Survey Staff, 1975; Plant available water capacity (PAWC, mm), by a laboratory method, with the calculation of field capacity and permanent wilting point (Donov *et al.*, 1974); Soil acidity (pH in water extraction 1:5) – measured potentiometrically by WTW 720 pH meter (ISO 10390:2002); Total Organic

Carbon (TOC, %) by ISO 14235:1998; Total Kjeldahl Nitrogen (TKN, %) content, with a modified version of the classic Kjeldahl method (ISO 11261:2002); P_2O_5 (mg.100g^{-1}) – according to IVANOV (1984); K_2O (mg.100g^{-1}) also according to IVANOV (1984).

Phytocoenotic relevès with area 4 m^2 for grass communities and 100 m^2 for forest communities were made in typical places in the sample plots. Phytocoenotic relevès include: floristic composition; total coverage of the phytocoenotic horizons; species abundance. Species identification was carried out according to the "Guide of Vascular Plants in Bulgaria" (DELIPAVLOV *et al.*, 2011). The quantity of the species at phytocoenosis was assessed through abundance and cover scale (BRAUN-BLANQUET, 1964).

Data analysis. The data were statistically processed using Numbers (Apple Co., 2018), Excel (Microsoft Co., 2016) and SPSS (IBM Co., 2016) in Mac. The ANOVA test was used to demonstrate statistically significant differences (p-value). The ANOVA test was used to determine the significance (p-value) in regression relationships between soil indicators and depth. The minimum and maximum values (min, max), mean, median, standard deviation (SD) were identified.

Results and Discussion

*Plant cover***.** The first plot is occupied by grass phytocoenosis (spontaneous revegetation), consisting of 22 plant species (Table 1). Most of them (77%) are perennial herbaceous plants, and the annuals and biannuals account for 18% and 5% respectively. There are predominantly representatives of the grasses (family *Poaceae*), as *Poa bulbosa* L. (3), *Poa pratensis* L.(2), *Festuca valesiaca* Scheich. Ex Gaud. (2), *Arrhentherum elatius* (L.) J. et C. Presl. (2). The Asteraceae family is also represented with more species but with low coverage such as: *Cychorium inthybus* L. (1), *Senecio vulgaris* L. (1) and others. The second plot is occupied by forest phytocoenosis (forestry reclamation), consisting of 14 plant species (Table 1). The first phytocoenotic horizon is with coverage 70% and consists mainly of *Pinus nigra* Arn. (5) and single *Fraxinus americana* L. (+). The coverage of the second phytocoenotic horizon is 20% and is represented by the species *Rosa canina* L. (2), *Prunus cerasifera* Ehrh. (2) and *Fraxinus ornus* L. (1). The third phytocoenotic horizon is with 80% coverage. Its composition includes grass species such as: *Geum urbanum* L. (2), *Galium aparine* L. (2), *Ballota nigra* L. (1), *Bryonia alba* L. (+), *Sambucus ebulus* L. (3), *Urtica dioica* L. (3), as well as undergrowth of *Crataegus monogyna* Jacq. (2) and *Quercus frainetto* Ten (1).

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*Soil characteristics***.** The bulk density (Table 2) of the soil under spontaneous revegetation is higher than the one of the soil under forestry reclamation. There is a statistically significant difference (p=0.002) between the bulk density of the soil under spontaneous revegetation and the one of the soil under forestry reclamation. Both bulk densities under forestry reclamation and spontaneous revegetation increase with depth (Fig. 1). These changes are described using linear regressions with a very high degree of probability (p<0.0001 in both cases). Total porosity (Table 2) decreases with depth (Fig. 2, which is described using linear regressions with a very high degree of probability (p=0.001 under both types of plant cover), which is normal due to the increase in bulk density with depth, but the total porosity under herbaceous plant cover is lower than the total porosity under woody plant cover resulting in a statistically significant difference (p=0.0005).

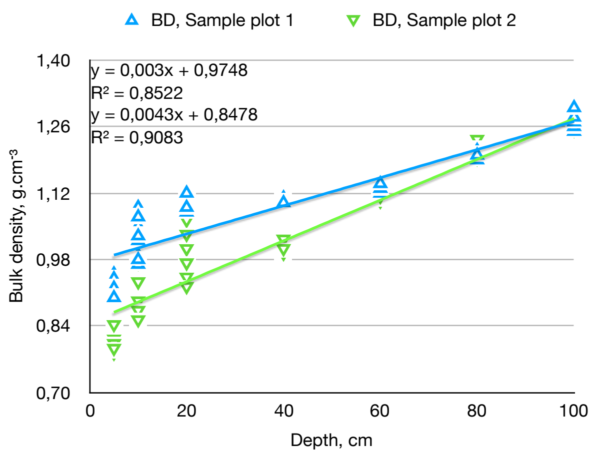

Fig. 1. Relationship between soil depth and BD.

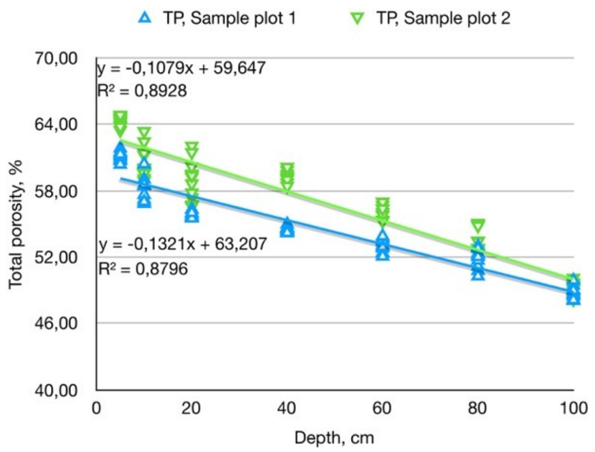

Fig. 2. Relationship between soil depth and TP.

The data on soil texture are shown in Table 2. The texture of the soils spontaneous revegetation ranges from sandy clay loam, through sandy loam, loamy sand to sand, and the soils under forestry reclamation fall within the following texture categories: sandy clay loam, sandy loam to loamy sand. There are statistically significant differences for the sand and silt fractions (p=0.009 and 0.002 respectively) under the different types of plant cover, but there isn't a statistically significant difference for the clay fractions (p=0.515) under forestry reclamation and spontaneous revegetation. The changes in the fractions of the soil texture with depth are shown in Fig. 3.

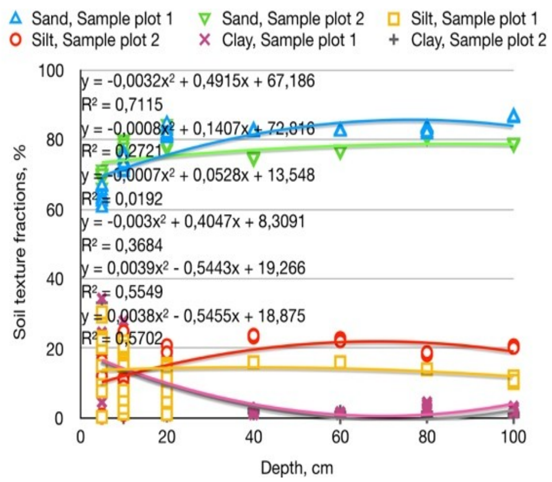

Fig. 3. Relationship between soil depth and Soil texture.

The changes in soil texture with depth are described using second-order polynomial regressions (Fig. 3), which are statistically significant (p<0.0001) for all fractions under the two types of phytocoenoses, with the exception of the silt fraction under spontaneous revegetation (p=0.40). Plant available water capacity (Table 2) is higher in the soils under spontaneous revegetation than in those under forestry reclamation, and the difference is statistically significant (p<0.0001).

The soil acidity (Table 3) of the studied soils under forestry reclamation and spontaneous revegetation ranges from moderately acidic to slightly acidic (according to the von H.-P. Blume classification), and it increases with depth (Fig. 4), which is described by second-order polynomial regressions with a high degree of probability (p<0.0001 under forestry reclamation and spontaneous revegetation).

These data are consistent with the data reported by other authors on the lower pH values in the root zone in soils formed after coal mining (PATOVA *et al*., 2015). The soil acidity data show a statistically significant difference (p=0.03) between the two types

Table 1. Plant species on sample plots.

Plant species on sample plot 1.		Plant species on sample plot 2.		
Plant species	**Abun-dance**	**Phytocoenotic horizon/Species**	**Abun-dance**	**Cover, %**
Potentilla argentea L.	2	I phytocoenotic horizon		70%
Festuca valesiaca Scheich. Ex Gaud.	2	*Pinus nigra* Arn.	5	
Poa pratensis L.	2	*Fraxinus americana* L.	+	
Cychorium inthybus L.	1	II phytocoenotic horizon		20%
Sanguisorba minor Scop.	1	*Rosa canina* L.	2	
Convolvulus arvensis L.	1	*Prunus cerasifera* Ehrh.	2	
Plantago lanceolata L.	2	*Fraxinus ornus* L.	+	
Arrhentherum elatius (L.) J. et C. Presl.	2	III phytocoenotic horizon		80%
Eryngium campestre Vis. Et Pancic	1	*Geum urbanum* L.	2	
Senecio vulgaris L.	1	*Galium aparine* L.	2	
Poa bulbosa L.	3	*Clematis vitalba* L.	2	
Anthemis arvensis L.	1	*Ballota nigra* L.	1	
Achillea millefolium L.	1	*Bryonia alba* L.	+	
Cardaria draba (L.) Desv.	1	*Crataegus monogyna* Jacq.	2	
Hordeum murinum L.	1	*Sambucus ebulus* L.	3	
Vicia grandiflora Scop.	1	*Urtica dioica* L.	3	
Erodium cicutarium (L.) L ,Herit	1	*Quercus frainetto* Ten.	2	
Trifolium incarnatum L.	+			
Cerastium banaticum (Roch.) Heuffel	+			
Scorzonera laciniata L.	+			
Tlaspi arvense L.	+			
Lepidium campestre (L.) R. Br.	+			

Table 2. Physical characteristics of studied soils. Legend: For abbreviations of the names of soil characteristics, see part "Material and Methods". * For the 0-100 cm layer.

	Depth, cm	n		BD, g.cm^{-3}	TP, %	Sand, %	Silt, %	Clay, %	PAWC, mm
Under herbaceous plant cover	0-5	11	Mean	0.92	61.04	64.14	19.16	16.70	
			Median	0.92	61.06	64.03	22.44	13.24	
			SD	0.02	0.47	2.38	9.94	9.99	
			Min	0.90	60.37	60.40	0.30	4.49	
			Max	0.95	61.84	66.91	30.40	34.35	
	5-10	11	Mean	1.02	58.40	72.94	11.43	15.63	
			Median	1.02	58.43	72.37	7.82	20.05	
			SD	0.04	1.21	2.07	7.87	8.54	
			Min	0.97	56.84	70.55	1.24	2.58	
			Max	1.09	60.42	76.33	22.00	27.88	
	10-20	11	Mean	1.10	55.83	82.18	8.73	9.09	
			Median	1.10	55.76	81.79	7.58	9.40	
			SD	0.01	0.28	1.48	4.97	5.18	
			Min	1.08	55.52	80.37	1.08	0.60	
			Max	1.12	56.33	84.79	15.55	18.55	
	20-40	11	Mean	1.11	54.49	82.38	14.64	2.97	152.71*
			Median	1.11	54.49	82.60	16.00	1.40	152.79*
			SD	0.01	0.25	0.30	0.00	0.30	1.79*

			Min	1.10	54.19	82.03	16.00	1.00	150.01*
			Max	1.11	54.98	83.00	16.00	1.97	154.78*
	40-60	11	Mean	1.13	53.09	82.56	16.00	1.44	
			Median	1.13	53.10	82.51	16.00	1.49	
			SD	0.01	0.62	0.24	0.00	0.24	
			Min	1.12	52.08	82.29	16.00	1.08	
			Max	1.14	53.91	82.92	16.00	1.71	
	60-80	11	Mean	1.20	51.94	82.59	14.00	3.41	
			Median	1.20	52.19	82.92	14.00	3.08	
			SD	0.01	0.87	0.86	0.00	0.86	
			Min	1.19	50.29	81.47	14.00	2.21	
			Max	1.21	52.99	83.79	14.00	4.53	
	80-100	11	Mean	1.28	48.76	86.53	10.90	2.57	
			Median	1.27	48.64	86.47	11.00	2.85	
			SD	0.02	0.56	0.31	0.60	0.61	
			Min	1.25	48.07	86.14	10.04	1.42	
			Max	1.30	49.90	86.97	11.96	3.28	
Under woody plant cover	0-5	11	Mean	0.81	64.14	68.88	11.25	19.86	
			Median	0.81	64.23	69.46	10.99	19.39	
			SD	0.02	0.43	1.66	9.36	9.61	
			Min	0.78	63.32	65.88	0.11	0.24	
			Max	0.84	64.69	71.11	29.73	33.12	
	5-10	11	Mean	0.90	60.34	76.80	12.35	10.85	
			Median	0.87	59.84	75.87	11.22	9.79	
			SD	0.06	1.43	2.30	7.58	7.02	
			Min	0.85	58.74	74.28	0.87	0.23	
			Max	1.00	63.22	79.82	24.93	19.31	
	10-20	11	Mean	1.00	58.85	80.32	11.30	8.38	
			Median	1.00	59.07	80.41	11.56	4.25	
			SD	0.05	1.80	2.53	7.14	7.55	
			Min	0.92	56.43	76.98	2.20	0.72	
			Max	1.08	61.89	84.21	20.93	19.13	
	20-40	11	Mean	1.02	59.02	75.44	21.65	2.91	159.84
			Median	1.00	59.34	74.39	23.78	1.90	160.04
			SD	0.01	0.59	0.30	0.25	0.46	2.76
			Min	0.99	58.27	74.00	23.12	1.35	153.78
			Max	1.02	59.99	74.85	23.93	2.60	162.91
	40-60	11	Mean	1.10	56.09	76.49	22.47	1.04	
			Median	1.10	56.20	76.48	22.45	0.99	
			SD	0.00	0.64	0.32	0.39	0.50	
			Min	1.10	55.09	76.07	22.02	0.19	
			Max	1.11	56.85	76.92	23.00	1.74	
	60-80	11	Mean	1.21	53.21	80.50	18.38	1.12	
			Median	1.21	52.67	80.46	18.30	1.23	
			SD	0.01	1.10	0.28	0.33	0.53	
			Min	1.19	52.12	80.12	18.02	0.40	
			Max	1.23	54.92	80.98	18.92	1.79	
	80-100	11	Mean	1.26	48.94	78.53	20.49	0.98	
			Median	1.26	49.16	78.60	20.49	1.03	
			SD	0.01	0.66	0.31	0.28	0.39	
			Min	1.25	48.03	78.09	20.13	0.23	
			Max	1.27	49.97	78.87	20.90	1.58	

of phytocoenoses. Total organic carbon and TKN (Table 3) decrease with depth (Fig. 5) and these relationships are described by polynomial regressions for both indicators with a high degree of probability ($p<0.0001$).

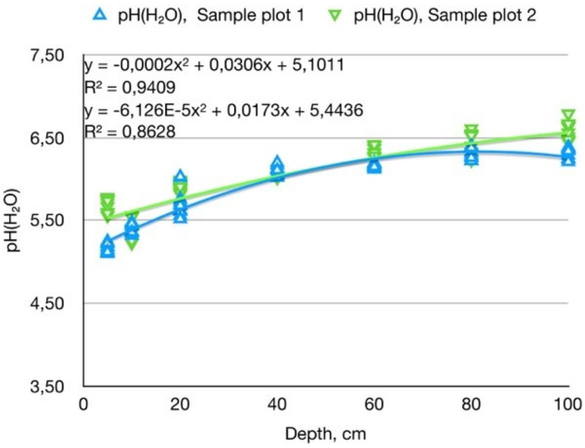

Fig. 4. Relationship between soil depth and $pH(H_2O)$.

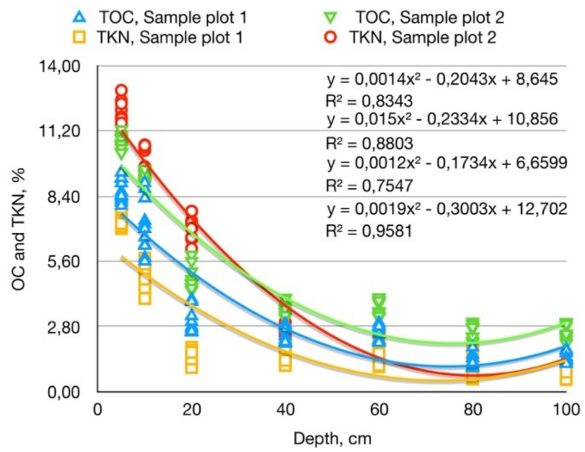

Fig. 5. Relationship between soil depth and TOC and TKN.

However, the TOC and TKN contents are higher under forestry reclamation than under spontaneous revegetation, and the differences are statistically significant ($p=0.003$ and $p<0.0001$ respectively).

Available phosphorus (Table 3) decreases with depth under both types of plant covers (Fig. 6), where the changes in depth are described by second-order polynomial regressions with a high degree of probability ($p<0.0001$ under both types of phytocoenoses). There isn't a statistically significant difference ($p=0.425$) between the content of available phosphorus under forestry reclamation and under spontaneous revegetation.

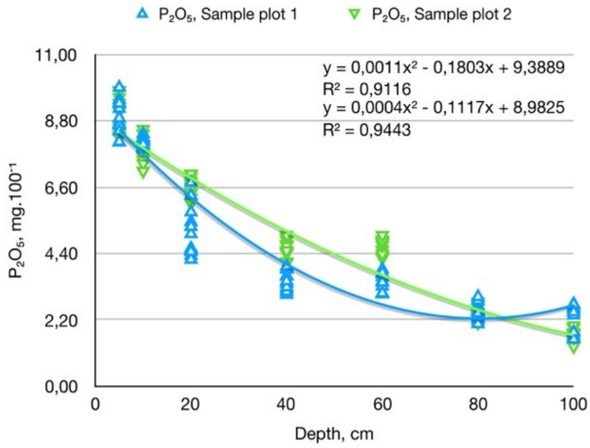

Fig. 6. Relationship between soil depth and P_2O_5.

The availability of potassium (Table 3) in the studied soils under forestry reclamation decreases with depth (Fig. 7, where the decrease with depth is described by second-order polynomial regressions with a high degree of probability ($p<0.0001$ under both types of phytocoenoses). The content of available potassium is different (statistically significant difference $p<0.001$) under forestry reclamation and spontaneous revegetation.

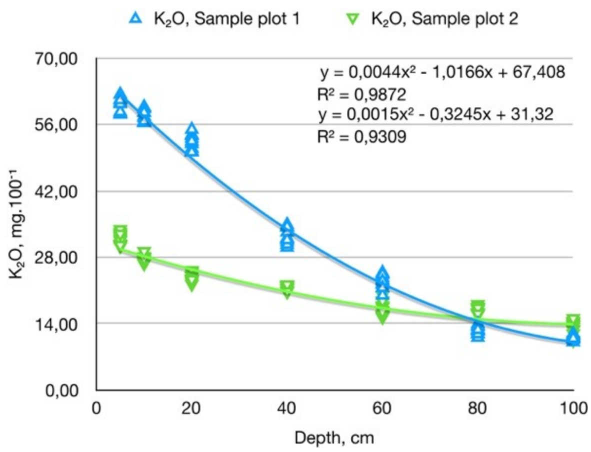

Fig. 7. Relationship between soil depth and K_2O.

Table 3. Chemical characteristics of studied soils. Legend: For abbreviations of the names of soil characteristics, see part "Material and Methods".

	Depth, cm	n		pH(H_2O)	TOC, %	TKN, %	P_2O_5, mg.100g^{-1}	K_2O, mg.100g^{-1}
Under spontaneous revegetation	0-5	11	Mean	5.68	8.63	7.284	8.95	60.24
			Median	5.72	8.46	7.269	8.90	60.73
			SD	0.08	0.48	0.240	0.59	1.52
			Min	5.54	8.00	7.009	8.10	58.22
			Max	5.76	9.43	7.914	9.92	62.45
	5-10	11	Mean	5.36	7.11	4.988	8.11	57.97
			Median	5.33	7.01	5.202	8.11	57.83
			SD	0.12	1.15	0.586	0.14	1.32
			Min	5.21	5.61	4.006	7.89	56.42
			Max	5.54	8.98	5.740	8.38	59.80
	10-20	11	Mean	5.89	3.12	1.477	5.16	52.24
			Median	5.88	3.02	1.620	5.06	52.09
			SD	0.05	0.55	0.317	0.85	1.61
			Min	5.80	2.56	1.036	4.21	50.22
			Max	5.97	3.97	1.904	6.77	55.03
	20-40	11	Mean	6.02	2.45	1.551	3.79	33.62
			Median	6.00	2.23	1.466	3.49	32.16
			SD	0.13	0.32	0.301	0.32	1.70
			Min	5.87	2.07	1.132	3.05	30.14
			Max	6.40	2.92	1.989	3.98	34.94
	40-60	11	Mean	6.31	2.45	1.500	3.42	22.90
			Median	6.30	2.24	1.365	3.45	23.00
			SD	0.05	0.32	0.316	0.31	1.48
			Min	6.24	2.11	1.072	3.06	20.01
			Max	6.40	2.96	1.997	3.88	24.82
	60-80	11	Mean	6.39	1.32	1.059	2.48	12.60
			Median	6.38	1.23	1.105	2.43	12.56
			SD	0.14	0.29	0.358	0.28	0.87
			Min	6.21	1.03	0.551	2.07	11.12
			Max	6.59	1.92	1.774	2.97	14.00
	80-100	11	Mean	6.57	1.54	0.760	2.35	11.25
			Median	6.61	1.49	0.842	2.54	11.27
			SD	0.11	0.22	0.179	0.45	0.52
			Min	6.43	1.20	0.516	1.56	10.17
			Max	6.77	1.83	0.972	2.73	11.93
Under forestry reclamation	0-5	11	Mean	5.17	10.67	11.886	8.89	31.59
			Median	5.18	10.60	11.815	8.63	31.61
			SD	0.05	0.34	0.582	0.61	1.21
			Min	5.10	10.20	11.043	8.20	30.02
			Max	5.25	11.20	12.950	9.77	33.57
	5-10	11	Mean	5.40	9.18	9.823	7.78	27.49
			Median	5.37	9.21	9.642	7.83	27.46
			SD	0.06	0.25	0.587	0.41	0.86
			Min	5.32	8.85	9.069	7.09	26.36
			Max	5.48	9.50	10.606	8.48	28.95
	10-20	11	Mean	5.71	4.78	7.075	6.53	23.47
			Median	5.68	4.57	7.078	6.56	23.10
			SD	0.17	0.49	0.488	0.36	0.95

		Min	5.52	4.29	6.151	6.01	22.05
		Max	6.03	5.81	7.761	7.00	24.93
20-40	11	Mean	6.09	3.71	2.79	4.79	21.15
		Median	6.11	3.50	2.34	4.65	21.06
		SD	0.06	0.76	1.27	0.59	1.54
		Min	6.02	3.10	2.15	4.04	18.52
		Max	6.20	5.81	6.56	6.37	24.93
40-60	11	Mean	6.16	3.58	2.241	4.62	17.00
		Median	6.16	3.73	2.276	4.69	17.10
		SD	0.03	0.34	0.176	0.26	1.45
		Min	6.12	3.12	2.018	4.20	15.07
		Max	6.20	3.98	2.532	4.96	19.63
60-80	11	Mean	6.29	2.49	1.570	2.31	16.52
		Median	6.27	2.64	1.493	2.25	16.66
		SD	0.07	0.30	0.261	0.23	0.73
		Min	6.22	2.03	1.154	2.05	15.63
		Max	6.40	2.93	1.977	2.75	17.75
80-100	11	Mean	6.31	2.43	0.771	1.61	12.98
		Median	6.34	2.38	0.741	1.65	13.29
		SD	0.07	0.29	0.136	0.22	1.31
		Min	6.21	2.01	0.536	1.27	10.18
		Max	6.39	2.92	0.985	1.96	14.79

The data obtained from the physicochemical studies show that technogenic soils do not have the most favourable characteristics. This is consistent with data reported by other authors (ZHELEVA *et al.*, 1995) despite the considerably high values of TKN and TOC, which are most likely due to the nature of soil formation from coal mining spoils. This is also consistent with data reported by other authors (KOSTOVA *et al.*, 2013). The soil physicochemical characteristics could be a limiting factor for plant diversity and normal plant development (BOGDANOV, 2018a; b) which is the reason for the long period of time (up to 25 years) necessary for plant cover restoration (ŘEHOUNKOVÁ, 2007). The forestry reforestation of post-mining territories is a significantly more preferable reforestation method than spontaneous revegetation (PRACH *et al.*, 2011; KRÜMMELBEIN *et al.*, 2012). Nevertheless, spontaneous revegetation results in a greater species diversity (HODAČOVÁ & PRACH, 2003), which was also confirmed by the present study.

Conclusions

The bulk density of the soil under spontaneous revegetation cover is statistically significantly higher than the bulk density under forestry reclamation. The total porosity under spontaneous revegetation is lower than the total porosity under forestry reclamation, where the difference is statistically significant ($p=0.0005$). The components of the soil texture (sand and silt) are statistically different under both types of plant cover. The soils under spontaneous revegetation are characterized by higher PAWC compared to the soils under forestry reclamation ($p<0.0001$).

The phytocenosis dominated by black pine (*Pinus nigra* Arn.) results in a decrease in the soil reaction – pH(H_2O) compared to the herbaceous phytocoenosis, which is statistically significant. The high levels of TOC and TKN are due to the technogenic nature of the soils formed as a result of coal mining activities, but higher levels of TOC and TKN are found in soils under forestry reclamation than in soils under spontaneous revegetation (the difference is statistically significant). The available phosphorus and potassium change (decrease) with depth, which is most likely due to their accumulation (mainly in the surface layer) as a result of the decomposition of organic matter. There aren't any statistically significant differences between the available phosphorus found under the two phytocoenoses. The presence of available potassium is statistically different under both types of plant covers, where it is higher under spontaneous revegetation than under forestry reclamation.

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