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Original Research

Deposol Reclamation along a Canal of the Danube-Tisza-Danube Hydro System

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Abstract

After the excavation of the canals of the main canal network (MCN) of the Danube-Tisza-Danube (DTD) hydro system, specific technological schemes were used to form deposited materials. In 1958 an experiment with forest plantings was set up on the deposols of the Odžaci-Sombor Canal. Its purpose was the protection and reclamation of the newly-formed dikes. The main aim of this paper is to point to the speed of the process of reclamation and changes in soil properties in the course of a 54-year-long experiment, on the basis of a years-long study of the experimental area.

Keywords: deposol reclamation, technogenic substrates, forest plantings, soil properties, the Danube-Tisza-Danube hydro system

Introduction

The processes of soil and land damage have affected large areas all over the world [1-3] and they have a tendency for further expansion [4, 5]. Products of destruction of natural soils and the accumulation of large amounts of waste materials serve as a substrate for the development of new soil formations. A special place among these new soil formations belongs to technogenic substrates [6-9]. Technogenic surface formations differ in their genesis, morphology, and physicochemical properties [10-13]. Technogenic materials draw the attention of researchers interested in regaining the suitability of substrates for biomass production through the process of reclamation. The establishment of plant cover on technogenic substrates depends primarily on the type of substrate, the content of fine earth in the surface layer, and the distance from natural plant complexes [14].

Loess and loess-like materials are the basis of the substrate formed during the construction of the main canal network (MCN) of the Danube-Tisza-Danube (DTD) hydro system, in the northern Serbian province of Vojvodina. This process involved a mass of 126.7 million m^3 of material originating from different depths [15]. The excavated material for canal formation was built into 1.75-10.0 m-high dikes. After construction of the MCN, the area of canals and deposited materials amounted to 10,800 ha, of which the canal area accounted for 2,600 ha (24%) and an area of

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8,200 ha (76%) was covered by deposited materials [16]. Biological protection of the deposols along the MCN of the DTD hydro system is an important component of its maintenance. Special attention was paid to the establishment of forest plantings on the dikes within the MCN in order to reinforce and reclaim the deposited materials [17].

The process of natural soil formation is predetermined by a number of pedogenetic factors. The time needed for the full effect of these factors to be manifested in the process of deposol reclamation is short, but long enough for the dynamics of the process of reclamation to be perceived. Given the importance of forest plantings on the deposols of the MCN in terms of protection and amelioration, the aim of this paper is to point to the speed of the process of reclamation and the changes in the basic properties of the newly-formed soil, as well as to predict future development of this soil on the basis of a 54-year-long study in the experimental site.

Materials and Methods

Site Description

The DTD hydro system is an amelioration system whose primary function is to evacuate early spring surplus water from 762,000 ha of agricultural land [15]. Its purpose is also to convey sufficient quantities of water for the irrigation of about 510,000 ha of agricultural land in the province of Vojvodina in summer. The regulation of the water regime was performed by building a network of canals within the DTD hydro system. This network was connected to form a single hydro-technical unit. In a functional sense, the canal network of the DTD hydro system includes the MCN, a detailed drainage canal network, and a detailed canal network for irrigation. The MCN of the DTD hydro system consists of 20 major canals and watercourses covering a total length of 960 km. The length of new canals and canals and watercourses that were subjected to either a radical reconstruction or a major or minor construction intervention is 773 km. The total length of completely new canals is 310 km [15].

In 1958 an experimental site was established by the Odžaci-Sombor Canal, near the town of Sombor (Fig. 1), immediately after the formation of dikes along the new canals [17]. This experiment was aimed at determining the extent to which these deposited materials can be used as a substrate for the application of certain forest tree species and learning about their effects in the process of deposol reclamation. The experimental site is located in northwestern Vojvodina Province (Fig. 1), at an altitude of 89 meters above sea level (m.a.s.l.) and approximately 45º36'34" N (north latitude) and 19º10'20" E (east longitude). Since the establishment of the experimental plots, investigations were performed in several stages: 1958, 1978, 1989, and 2011. The area of the Odžaci-Sombor Canal belongs to the Bačka loess terrace. The basic form of bedrock on which the soils developed on the loess terrace is partly hydromorphic terrace loess, mainly formed by wind and partly by fluvial accumulation [18]. The main soil type in the study area is Calcaric chernozem on loess terrace [19, 20].

The investigated area has a moderate continental climate, with a mean annual air temperature of 10.6ºC and total annual precipitation of 573.3 mm, on the basis of observations from 1961 to 2011 [21]. In the period from 1985 to 2005 the mean annual temperature amounted to 11.4ºC, and mean annual precipitation amounted to 604.6 mm [22]. According to the ET/ETO ratio (ET – actual evapotranspiration, ETO – referential evapotranspiration) and the limit values for certain periods, the number of days with

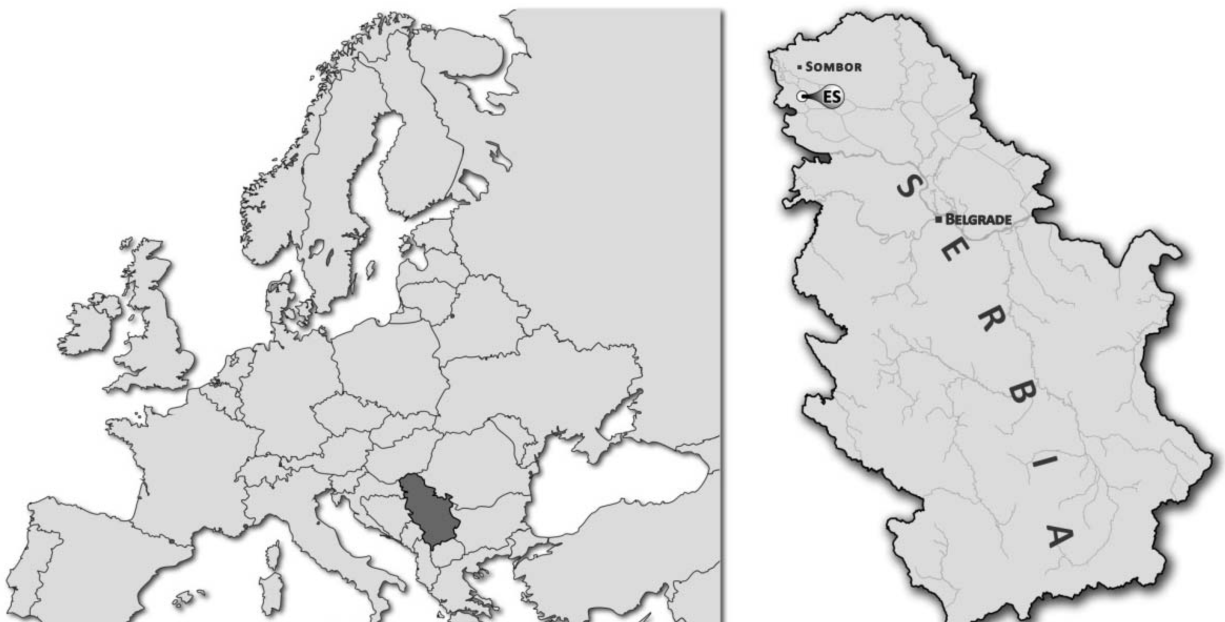

Fig. 1. Location of the experimental site (ES).

an ET/ETO ratio <0.5, which indicates the beginning of a dry period, during the April-May-June (AMJ) and June-July-August (JJA) periods was 41 and 61 days, respectively [22]. In the same periods, the number of days with the ET/ETO ratio that indicates intense, extreme, and very extreme drought was 69 and 103, respectively.

The Reclamation Experiment

The reclamation experiment was established by the Directorate of the DTD hydro system in cooperation with the Poplar Institute from Novi Sad in 1958 [16]. The excavation of the canal, transportation of the excavated material, its incorporation into the dikes, and final shaping of canal slopes were performed in accordance with the presented technological scheme (Fig. 2). The terrain elevation was 85.5 m.a.s.l. and the elevation of the canal bottom was 77.5 m.a.s.l., i.e. the depth of the excavation was 8.0 m. The deposited material from the excavation was a yellowish, highly calcareous fine-grained material (loess powder). The soil was excavated with dragline excavators, transported, and finally built into the dikes on both sides of the canal by means of bulldozers and scrapers.

The experimental site was formed on the material deposited over a 220-meter-long section by the left and right banks of the canal. The surface area of the deposited materials was divided into 10×20 m plots (200 m^2 each). After parceling out the terrain, the researchers obtained 32 plots, i.e. 16 per each side of the canal, totaling 6,400 m^2 (Fig. 3).

The experimental plots were treated in different conditions, including sandy and loamy substrates, as well as conditions both with and without irrigation and both with and without humification. In all cases the experiment was performed in two replicates. Planting at 2.5 m spacing between rows and 1.25 m spacing between seedlings was applied in all experimental plots and it included the following species: *Populus nigra* L. (10 seedlings), *Robinia pseudoacacia* L. (12 seedlings), *Ulmus effusa* Willd. (16 seedlings), *Fraxinus oxicarpa* Willd. (8 seedlings), *Tilia grandifolia* Ehrh. (5 seedlings), and *Pinus nigra* Arn. (8 seedlings). Fifty-nine seedlings were planted in each plot for a total of 1,888. During 2008/09, stems of all tree species were cut down in the left section of the experimental site and reforestation with Siberian elm (*Ulmus pumila* L.) was initiated in 2010. The stems of all species except black locust were cut down in the right section of the experimental site.

Sample Collection

The studies of the experimental plots were carried out during four periods. The basic physical and chemical analyses of the deposited substrate at 10 profiles were performed in 1958, on a 0-20 cm layer in the phase of establishment of the experimental plots. During 1978 reconstruction of the experimental area was performed, along with a soil survey and planted trees estimation [23]. On the basis of these parameters, the percentages of the remaining tree species and their impact on the reclamation of deposols were inves-

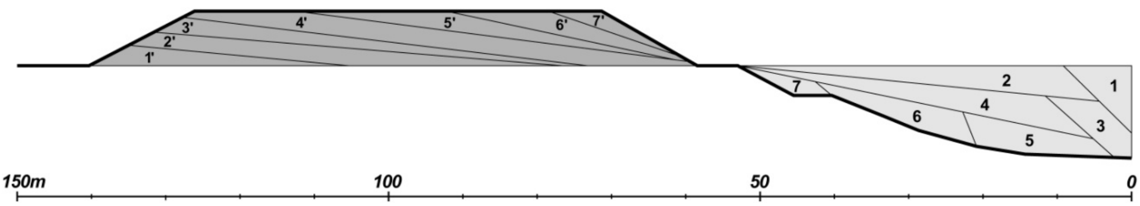

Fig. 2. Technological scheme of canal excavation and substrate deposition.

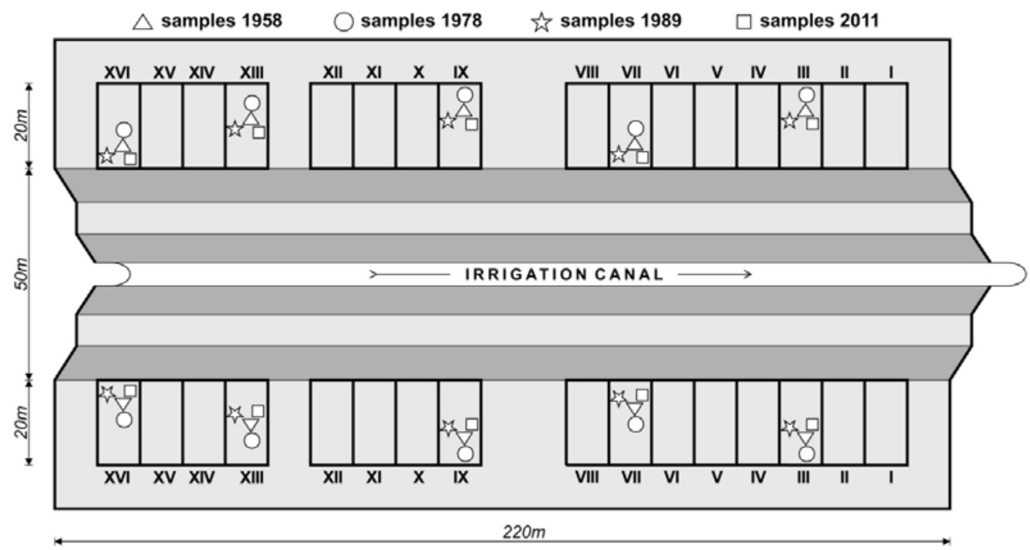

Fig. 3. Scheme of the experimental site.

tigated. Ten soil profiles were opened, i.e. five in the left and five in the right section of the experimental site (Fig. 3). Substrate samples were taken from the depths of 0-6, 6-30, and 30-80 cm. The sampling of forest litter for the analysis of elemental composition was performed at four locations. During 1989, field and laboratory surveys of the soil were conducted on the samples from 10 different soil profiles, five from the left and five from the right section of the experimental site (Fig. 3). The sampling of forest litter was performed in 1992 [16]. In spring o 2011 soil sampling was once again performed at 10 different soil profiles (Fig. 3), and the studies investigated morphological, physical, and chemical properties of the soil.

Analytical Methods

The analyses of the deposited substrate were performed for the establishment of the experimental plots, including the analyses of mechanical composition using pyrophosphate B-pipette method, pH (H_2O and KCl), bulk density (BD), carbon and nitrogen content, and the concentration of easily accessible P_2O_5, K_2O, and $CaCO_3$ [15]. In addition, an investigation of planting success was performed in the experimental plots. Later on (in 1978, 1989, and 2011), the studies involved analyses of morphological as well as basic physical and chemical properties of the soil. In 1978 an estimation of forest species in the experimental plots was carried out in addition to the soil survey.

In 2011, randomized sampling was performed at 10 different locations, as in the previous research periods. Soil pits were excavated at each sampling site to collect samples for the analyses of physical and chemical properties. For each pit, soil samples were collected at depths of 0-6, 6-30, and 30-80 cm (in 1978), 0-9 and 9-30 cm (in 1989), as well as at depths of 0-16 and 16-30 cm (in 2011). The soil granulometric fractions were separated using the combined method of sieving with 0.2 mm mesh sieves and pyrophosphate pipette B-method [24, 25]. BD samples were obtained for each layer using a standard container with a volume of 100 cm^3 (55.50 mm in diameter and 41.40 mm in height) and weighed to the nearest 0.1 g [26]. Measurement of the pH value was performed in water and $CaCl_2$ using a 1:3 soil solution ratio. Soil organic carbon (SOC) was measured using the Tyurin method [27], total Nitrogen by the Kjeldahl method [28], the available P and K after extraction by the Egner-Riehm method [29], and $CaCO_3$ by the volumetric method [30]. All the analyses were performed in two replicates.

Soil organic carbon densities (SOCD) were calculated for each soil profile using the following equation [31]:

$$SOCD = \sum_{i=1}^{n} Ti \cdot BD_i \cdot SOC_i \cdot (1 - \frac{C_i}{100})$$

...where: *SOCD* ($kg \cdot m^{-2}$), *Ti* – soil layer thickness (cm), BD_i – soil layer bulk density ($g \cdot cm^{-3}$), SOC_i – soil layer content of organic carbon ($g \cdot kg^{-1}$), C_i – volume percentage of the fraction >2 mm at layer i.

Table 1. Percentages of the remaining tree species in the sample plots in comparison to the initial state [23].

Tree species	Number of stems	Percentage, (%)	Mean stem diameter, ds (cm)	Mean stem height, hs (m)
Black poplar	74	23	21.0	15.0
Locust	146	38	13.7	14.0
Elm	67	13	8.2	7.5
Narrow-leaved ash	36	14	9.4	9.1

Table 2. Quantities and elemental composition of forest litter (1978, 1992, 2011).

Average amount of forest litter ($kg \cdot m^{-2}$)	Elemental composition ($g \cdot kg^{-1}$ of dry matter)				
	N	Ca	Mg	P	K
0.265	14.7	29.75	3.80	0.70	1.30

Statistical analyses were performed using the StatgraphicsPlus program. The data were analyzed using descriptive statistics, correlation and regression analyses, and the analysis of variance (ANOVA test). Research data from 1958, 1978, and 1989 were systematized, statistically analyzed, and presented along with the results from 2011.

Research Results

State of Forest Plantings

At the end of the growing season in the autumn of 1958, the number of remaining trees in the experimental plots was 1,119 [16], i.e. 59.27% of the number of trees planted (1888), including the following species: black poplar, locust, elm, narrow-leaved ash, and linden.

The percentages of the remaining tree species were determined by the 1978 forest estimation. It was found that only four of the included tree species remained in the site, and these were black poplar, locust, narrow-leaved ash, and elm. Measurements of stems (height and diameter of all stems) were carried out and the obtained values are shown in Table 1.

The number of trees recorded in the 1989 estimation did not change compared to the 1978 state. During 2008/09, stems of all tree species in the left section of the experimental site were cut down, and reforestation with Siberian elm (*Ulmus pumila* L.) was performed in 2010. Stems of all species, except black locust, were cut down in the right section of the experimental site.

Mean values of the elemental composition and quantity of forest litter in the experimental site are shown in Table 2. The results are based on former measurements [16] and measurements performed in spring 2011. The forest litter

Table 3. Summary statistics of soil properties for the studied periods.

Summary statistics	1958 (Radanović, 1959)						
	pH_{H2O}	BD	Humus (%)	TN (%)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)	C/N
Count	10	10	10	10	10	10	10
Average	8.63	1.81	0.16	0.027	2.35	10.02	11.25
Variance	0.03	0.00	0.000234	0.000522	0.07	1.17	0.858
St. dev.	0.18	0.05	0.015	0.023	0.27	1.14	0.93
Minimum	8.34	1.72	0.12	0.00	1.7	8.30	9.72
Maximum	8.84	1.89	0.21	0.06	2.7	12.00	12.89
CV (%)	2.09	2.76	9.56	84.63	11.49	11.18	8.23
	1978 [23]						
Count	10	10	10	10	10	10	10
Average	8.12	1.42	1.99	0.12	2.45	10.10	10.44
Variance	0.04	0.01	0.34	0.00	0.26	1.32	5.75
St. dev.	0.20	0.08	0.61	0.04	0.54	1.21	2.53
Minimum	7.85	1.28	3.19	0.07	1.80	7.50	8.43
Maximum	8.40	1.57	1.02	0.21	3.40	12.00	16.00
CV (%)	2.46	5.63	30.65	33.33	21.26	11.98	24.23
	1989 [16]						
Count	10	10	10	10	10	10	10
Average	7.96	1.40	2.55	0.15	3.1	16.80	9.83
Variance	0.01	0.00	0.05	0.00	0.34	5.86	0.68
St. dev.	0.10	0.04	0.23	0.01	0.62	2.51	0.87
Minimum	7.80	1.34	2.34	0.13	2.00	13.70	8.35
Maximum	8.20	1.46	3.10	0.17	3.90	22.30	11.21
CV (%)	1.26	2.86	9.02	6.67	20.00	14.94	8.85
	2011						
Count	10	10	10	10	10	10	10
Average	7.90	1.38	3.26	0.205	4.10	18.10	9.21
Variance	0.02	0.00	0.08	0.00	0.84	12.00	0.54
St. dev.	0.13	0.04	0.30	0.02	0.97	3.65	0.77
Minimum	7.72	1.32	2.75	0.17	2.30	14.00	7.43
Maximum	8.05	1.46	3.75	0.4	5.80	25.50	10.00
CV (%)	1.65	2.90	9.20	9.76	23.66	20.17	8.36

CV (%) – coefficient of variation

contained the foliar litterfall of black poplar, American ash, and elm.

State of the Soil in the Experimental Site

Compared to the state of the substrate deposited in 1958, the 1978 study found the formation of the initial humus layer (A) with an average depth of 6 cm. The 1989 study revealed that the depth of the initial humus layer increased to 9 cm on average. Furthermore, a humus layer with an average depth of 16 cm could clearly be distinguished in early 2011. The results of this study were systematized and statistically analyzed for certain periods, and the summaries of statistical analyses of the soil properties are shown in Table 3 (pH_{H2O}, BD, humus content, total nitrogen-TN, P_2O_5, K_2O, C/N). Fig. 4 shows soil profile

Table 4. Physical properties of the characteristic soil profiles of deposols (2011).

Horizon	Depth (cm)	BD (g/cm³)	Moisture (%)	Texture of deposol (%)						Total	
				2.0-0.2 (mm)	0.2-0.06 (mm)	0.06-0.02 (mm)	0.02-0.006 (mm)	0.006-0.002 (mm)	<0.002 (mm)	Sand (%)	Clay+Silt (%)
Left section of the experimental site											
A	0-13	1.35	1.21	0.50	60.60	15.30	8.60	6.70	8.30	76.40	23.60
I	13-30	1.46	0.52	0.50	64.70	10.80	9.20	3.00	11.80	76.00	24.00
II	>30	1.64	1.51	0.50	63.70	10.60	12.2	3.50	9.50	74.80	25.20
Right section of the experimental site											
A	0-19	1.32	1.60	0.40	35.30	22.20	21.30	6.50	14.30	57.90	42.10
I	19-30	1.41	1.02	0.40	33.60	22.70	19.40	6.60	17.30	56.70	43.30
II	>30	1.85	2.18	0.40	33.30	18.90	20.00	6.90	20.50	52.60	47.40

descriptions from 1978 and 2011, with the clearly apparent anthropogenic A horizon in the soil profile (Fig. 4b).

On the basis of the 2011 study, Tables 4 and 5 show the soil properties (physical and chemical) of the deposols in two characteristic soil profiles in the left and right sections of the experimental site.

Soil color was determined using Munsell Soil Color Charts [32]:

- A-10YR 5/2 crumb (crumby), silt loam/sandy loam, calcareous
- I - 10YR 6/4 silt loam/sandy loam, moist, calcareous
- II - 10YR 6/6 loess, silt loam/sandy loam, moist, calcareous.

Fig. 5 graphically presents the mean values of basic deposol properties (profile depth, humus content, pH_{H_2O}, TN, C, C/N, K_2O, P_2O_5) since the establishment of the experimental plots.

Table 6 shows the density of organic carbon in the deposol by soil layers on the basis of the results of soil texture analysis, BD, and organic carbon content.

Correlation analysis with the dependent variable pH, as a function of humus content (*H*), is shown by the logarithmic model:

$$pH = 8.17957 - 0.181176 \ln H$$

...where: correlation coefficient R =-0.789327, and R^2=0.623036, with the standard deviation Sd=0.188983, $p < 0.01$. Fig. 6 shows correlation between pH and humus content in a deposol.

An analysis of variance of the changes in deposol properties (total sand content, total clay content, pH_{H_2O} and BD) during the study period was performed in order to analyze the impact of forest plantings on the changes of these properties. These results are shown in Table 7.

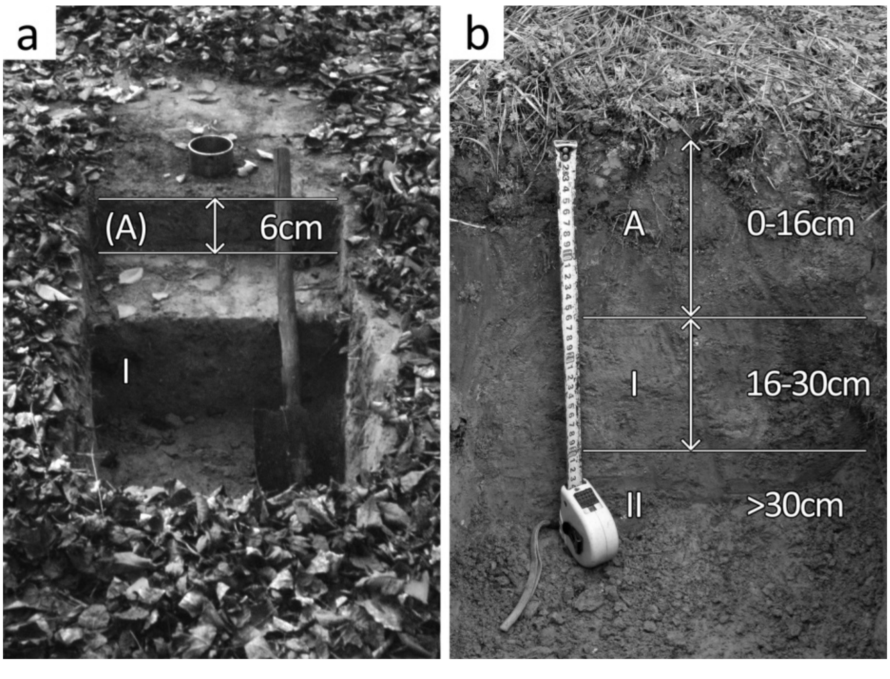

Fig. 4. Soil profiles from 1978 (a) and 2011 (b).

Table 5. Chemical properties of the characteristic soil profiles of deposols (2011).

Horizon	Depth (cm)	pH_{H_2O}	$CaCl_2$	$CaCO_3$ (%)	Humus (%)	C (%)	TN (%)	C/N	Available P_2O_5 (mg/100g)	Available K_2O (mg/100g)
Left section of the experimental site										
A	0-13	7.90	7.45	20.93	3.43	1.99	0.22	9.0	5.80	21.30
I	13-30	8.05	7.55	27.20	0.44	0.26	0.029	8.97	2.20	9.00
II	>30	8.65	-	27.90	-	-	-	-	-	-
Right section of the experimental site										
A	0-19	7.73	7.24	25.96	2.75	1.99	0.18	8.9	2.30	14.00
I	19-30	8.02	7.52	28.50	0.64	0.37	0.028	13.21	1.40	9.20
II	>30	8.43	-	28.60	-	-	-	-	-	-

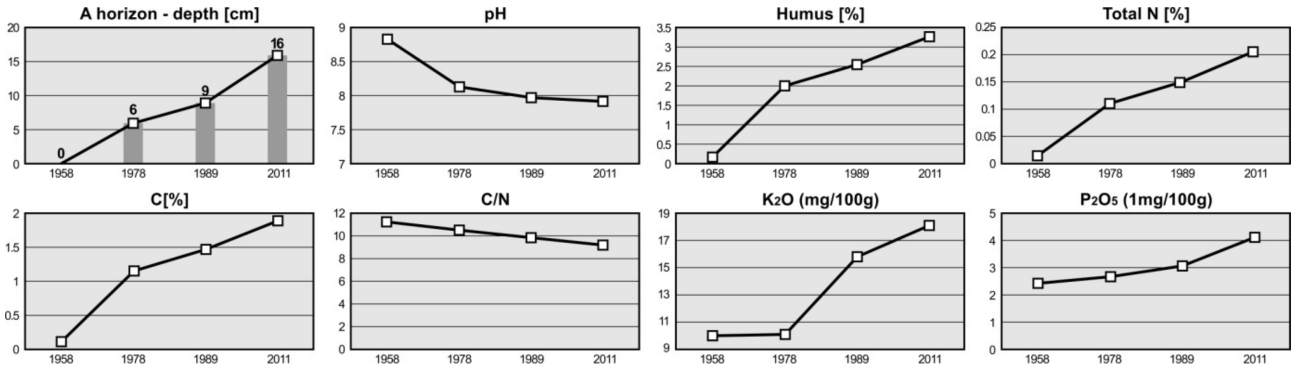

Fig. 5. Changes in the basic physical and chemical properties of the Deposols.

Discussion

The reclamation of deposols using forest plantings by the Odžaci-Sombor Canal had significant ameliorative effects, because loess and loess-like substrates are highly suitable for reclamation [33]. The impact of forest tree species on the soil substrates is the result of an interaction among all ecosystem components [34, 35]. Forest tree species affect soil directly and indirectly, both through their root systems and above-ground parts [36].

Nutrient content in biomass is the result of a balance between the adoption of nutrients, plant growth, movement, and losses of these substances. These processes depend on the plant species and soil fertility status, as well as other site conditions [37]. Foliar litterfall of various forest species is the main source of organic matter for soil and the basic source of energy for soil microorganisms that trigger the processes of transformation of organic matter into humus and its mineralization to the end products of decomposition. It also implies that the mineral substances taken by these species from the soil are rapidly involved in the process of biological circulation, returning to the soil in a short time. In this way, the soil in the experimental site was annually enriched with 3.90 $g \cdot m^{-2}$ of nitrogen, 7.88 $g \cdot m^{-2}$ of calcium, 1.01 $g \cdot m^{-2}$ of magnesium, 0.19 $g \cdot m^{-2}$ of phosphorus, and 0.34 $g \cdot m^{-2}$ of potassium.

The total annual litterfall (563 $g \cdot m^{-2} \cdot year^{-1}$) in the floodplain forest of the Middle Ebro River (NE Spain) for the 6 dominant tree species (*Fraxinus angustifolia*, *Populus alba*, *Populus nigra*, *Salix alba*, *Tamarix* spp., and *Ulmus minor*) contains 5.9 $g \cdot m^{-2} \cdot year^{-1}$ of N, and 0.53 $g \cdot m^{-2} \cdot year^{-1}$ of P [38]. Nitrogen concentrations in freshly fallen leaf litter of narrow-leaved ash in the Mediterranean forests amount to 1.00% (10 $g \cdot kg^{-1}$) of dry matter (dm) and 1.08% (10.8 $g \cdot kg^{-1}$) of dm in partially decomposed leaf litter [39]. The results of the research of interclonal variability of black locust (*Robinia pseudoacacia*) in Vojvodina show foliar concentrations

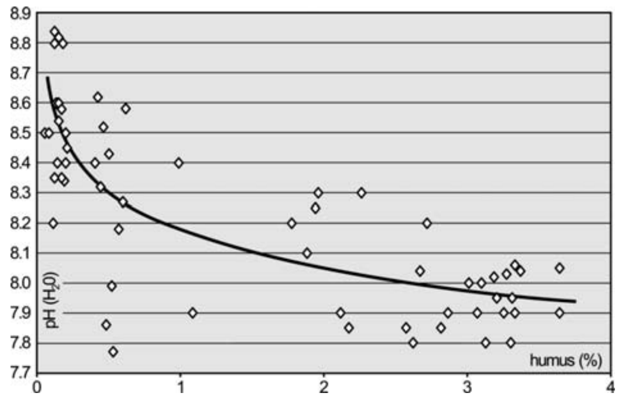

Fig. 6. Correlation of pH and humus content.

Table 6. Density of organic carbon by deposol layers.

Year	Soil layer (cm)	BD ($g\cdot cm^{-3}$)	SOCD ($kg\cdot m^{-2}$)
1958	0-20	1.81	0.0362
1978	0-6	1.42	0.988
1989	0-9	1.40	1.865
2011	0-16	1.38	4.173

Table 7. Results of the analysis of variance of changes in deposol properties.

pH		BD	
F	p-value	F	p-value
44.50	<0.001	148.93	<0.001
Method: 95% LSD		Method: 95% LSD	
Year	Average value	Year	Average value
1959	8.63^{a}	1959	1.809^{a}
1978	8.12^{b}	1978	1.420^{b}
1989	7.96^{c}	1989	1.398^{b}
2011	7.90^{d}	2011	1.377^{b}

a, b, c, d – homogeneity of sample groups

($mg\cdot g^{-1}$ of dm) of N, P, K, and Ca: N – 28.67, P – 0.55, K – 4.75, and Ca – 22.00 [40]. The nutrient content (%) of the leaves of black locust in Hungary amount to: N – 3.90, P – 0.19, K – 0.23, Ca – 2.06, and Mg – 0.29 [41]. Phosphorus input through litterfall is 0.81 $g\cdot m^{-2}$ for black poplar in non-fertilized conditions [42]. The quantity of nutrients that reach the soil with the annual fall of organic remains in the Hybrid 275 plantation is (in $kg\cdot ha^{-1}$): N – 81, P – 5, K – 41, Mg – 27, and Ca – 67, and in the *Populus robusta* plantation: N – 79, P – 3.6, K – 26, Mg – 27, and Ca – 96 [43]. The foliar litterfall of European ash (*Fraxinus excelsior*), black poplar (*Populus nigra*), and the species of the genus Ulmus (*Ulmus* sp.) on the deposols in urban settings of the Netherlands contains less than 18-20 $g\cdot kg^{-1}$ of dm of nitrogen, less than 1.0 $g\cdot kg^{-1}$ dm of phosphorus, and less than 5.0-6.5 $g\cdot kg^{-1}$ dm of potassium [44].

Significant ameliorative effects were achieved in the experimental site due to the production of organic waste that reaches the soil over the year. However, the concentrations of mineral nutrients, i.e. the concentrations of nitrogen, phosphorus and potassium in the foliar litterfall on the deposols, are perceived as deficient, whereas magnesium values belong to the optimal category. Compared to the 1958 state of the deposited substrate, the formation of the initial humus (A) horizon, with an average depth of 6 cm, was observed as early as in 1978. The depth of the average initial humus horizon was 9 cm in 1989 and 16 cm in 2011. According to Table 4, mean humus content increased from 0.16% (1958) to 1.99% (1978), and from 2.55% (1989) to 3.26% (2011). It should be pointed out that humus content in the lower layers increased as follows: 6-30 cm (1978) – 0.24%, 9-30 cm (1989) – 0.36%, and 16-30 cm (2011) – 0.54%.

According to the total nitrogen (TN) content at the time of the establishment of the experiment (0.027% in 1958), the substrate belonged to the soil class with limited silvicultural prospects. However, in 1978 and 1989 it belonged to the class of soils with a sufficient nitrogen supply (0.1-0.2%) [45]. The mean TN concentration of 0.205% (in 2011) indicates a transition to the type of soil with a high concentration of nitrogen (0.2-0.3%). In terms of supply with readily available forms of phosphorus, the values in all periods were within the limits of 0-10 mg of P_2O_5 per 100 g of soil, i.e. typical for the class of soils with an insufficient supply. According to the concentration of K_2O, this soil belonged to the class of soils with a nearly sufficient supply (10-20 mg of K_2O per 100 g of soil).

The observed changes of the properties of deposol are related to the process of humification. Humus is actively involved in almost all pedogenetic processes in soil and numerous physical and chemical properties of the soil are dependent on it. Humic acids and intermediates in the process of decomposition of organic residues affected the chemical reactions in the soil, so that there was a change in soil pH. In 1958 the deposited soil material had a strong alkaline reaction (8.63 pH), and in 2011 a weak alkaline reaction of the humus horizon was observed (7.90 pH).

On the basis of the analysis of variance, the changes of certain soil properties in the process of deposol reclamation were determined. Table 7 shows that the results of the analysis of variance ($F=44.5$; $p<0.001$) reveal statistically significant differences between the mean soil pH values in all measurement periods. Also, the analysis of variance ($F=148.9$; $p<0.001$) revealed statistically significant differences between the mean BD values of these soils measured in 1958 compared to the mean values measured in 1978, 1989, and 2011. Mild acidification of strong alkaline soils is a positive process, which suggests both a higher biological activity of the substrate and a greater accessibility of plant assimilatives. Humic substances are involved in the aggregation of primary soil particles, and thus they indirectly affect water and air properties of the substrate. The percentage of nitrogen increased along with the increase in the percentage of humus. The percentage of nitrogen in the deposited soil material was on the verge of detection (0.027%) in 1958. According to the percentage of nitrogen recorded in 2011, the humus horizon belongs to the class of soils with a sufficient supply of nitrogen. The content of physiologically active forms of phosphorus and potassium also increased in comparison to the values from 1958.

The morphology of the profiles and the analytical values of the studied soil properties suggest that the evolution of a deposol as a technogenic soil type develops towards the formation of a rendzina on a deposol. Also, deposol is a soil type within the class of technogenic soils on mixed natural geologic materials [6]. It can also be defined as technosol (calcaric) [19].

Conclusion

During 54 years of investigations, from 1958 to 2011, in the experimental site by the Odžaci-Sombor Canal, significant ameliorative effects were found on the deposited materials. The establishment of forest plantings accelerated the biological circulation of the elements, formed the forest litter layer, and contributed to the process of humification. The initial humus (A) horizon developed from 0 cm (in 1958) to the average depth of 16 cm in 2011, while mean humus content increased from 0.16% (in 1958) to 3.26% (in 2011). In addition, pH of the humus horizon was reduced from 8.63 (a strong alkaline reaction) in 1958 to 7.90 (a weak alkaline reaction) in 2011.

The biomass of organic residues that reach the soil and its surface had a key role in the pedogenetic processes and the revitalization of the deposol in the experimental site. The character of the humus horizon, formed in a deposol, depends on the amount and chemical properties of organic residues. The evolution of a deposol in the experimental site develops toward the formation of a rendzina on a deposol (technosol).

The reclamation of deposols through reforestation helped the establishment of protective forest functions and conditions for natural revitalization of the soil, and thus revitalization of the area as a whole. The results of this 54 year-long experiment provide guidelines for further amelioration activities, i.e. the reforestation of 8,200 more ha of dikes by the MCN in the DTD hydro system. In addition, the results obtained in the experimental site in the northern Serbian province of Vojvodina are important for other Danube countries that are faced with the problem of maintenance of dense canal and dike networks.

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References

1. GISLADOTTIR G., STOCKING M. Land Degradation Control and its global environmental benefits. Land Degrad. Dev. **16**, 99, **2005**.
2. BAKKER M., GOVERS G., KOSMAS C., VANACKER V., OOST K., ROUNSEVELL M. Soil erosion as a driver of land-use change. Agr. Ecosyst. Environ. **105**, 467, **2005**.
3. ANANDA J., HERATH G. Soil erosion in developing countries: a socio-economic appraisal. J. Environ. Manage. **68**, 343, **2003**.
4. BAI Z.G., DENT D.L., OLSSON L. SCHAEPMAN M.E. Global assessment of land degradation and improvement – Identification by remote sensing. Report 2008/01, ISRIC-World Soil Information, Wageningen, **2008**.
5. STOCKING M. Land Degradation as a Global Environmental Issue: A Synthesis of Three Studies Commissioned by The Global Environment Facility to Strengthen the Knowledge Base to Support The Land Degradation Focal Area. Report for GEF Council (Report prepared for Scientific and Technical Advisory Panel, Global Environment Facility, Washington DC), December **2006**.
6. RESULOVIĆ H., ĆUSTOVIĆ, H. Technosols – Development, Classification and Use. Agriculturae Conspectus Scientificus **72**, (1), 13, **2007**.
7. RISTOVIĆ M.I., STOJAKOVIĆ P.M., MILIVOJ I., VULIĆ I.M. Recultivation and Sustainable Development of Coal Mining in Kolubara Basin. Thermal Science **14**, (3), 759, **2010**.
8. YU J., LIU J., WANG J., ZHANG X. The evaluation of reclamation effects for the methods of covering soils in a coalmine reclamation area. Journal of Agricultural Extension and Rural Development **2**, (7), 116, **2010**.
9. ROHOŠKOVA M., PENIŽEK V., BORUVKA L. Study of Anthropogenic Soils on a Reclaimed Dumpsite and their Variability by Geostatistical Methods. Soil and Water Research **1**, (2), 72, **2006**.
10. SHUGALEI L.S., CHUPROVA V.V. Soil Formation in the Technogenic Forest – Steppe Landscapes of the Nazarovskaya Depression in Western Siberia. Eurasian Soil Sci+. **45**, (3), 246, **2012**.
11. SCHONSKY H., PETERS A., LANG F., ABEL S., MEKIFFER B., WESSOLEK G. Sulfate transport and release in technogenic soil substrates: experiments and numerical modeling. Journal of Soils and Sediments **13**, (3), 606, **2012**.
12. PEREVERZEV V. N., EVDOKIMOVA G. A., ZENKOVA I. V., KORNEYKOVA M.V., REDKINA V.V. Evolution of technogenic landscapes by the example of apatite-nepheline ore concentration wastes. Natural Science **2**, (6), 600, **2010**.
13. SHLYAKHOV S. A., OSIPOV S. V. Technogenic Surface Formations in the Areas of Placer Gold Mining (the Bureya Upland, Far East). Eurasian Soil Sci+. **37**, (10), 1106, **2004**.
14. PUGACHEV A. A., TIKHMENEV E. A., TIKHMENEV, P. E. Natural Recovery of Technogenic Landscapes in Open Larch Forests in Northeastern Russia. Russ. J. Ecol+. **36**, (6), 391, **2005**.
15. MILOVANOV D. Main Canal Network of the Danube-Tisza-Danube hydro sistem – Hydro sistem Danube-Tisza-Danube (Novi Sad: Public Enterprise Danube-Tisza-Danube), **1972** [In Serbian].
16. KADOVIĆ R., KNEŽEVIĆ M., KARADŽIĆ D. Biological measures of deposol protection along the main canal network of the hydrosistem Danube-Tisza-Danube. (In M. Šestović, N.K. Nešković, & I. Perić (Eds.), Plant Protection, Today and Tomorrow (pp. 629-636). Belgrade: Serbian Society for Plant Protection.), **1994** [In Serbian].
17. RADANOVIĆ R. An experiment of deposol greening in Doroslovo. Institute for Agriculture Design and Economy, Novi Sad, Serbia, **1959** [In Serbian].
18. TRIFUNOVIĆ S., STOJADINOVIĆ M., ČANOVIĆ M., KEMENCI R. Geological booklet of Basic Geologic Map 1:100.000 for Odžaci area. Institute of Geology, Belgrade, **2010** [In Serbian].
19. WRB IUSS International Working Group. World reference base for soil resources 2006 – A framework for international classification, correlation and communication. World Soil Res Reports 103 (Rome: Food and Agriculture Organization of the United Nations - FAO), **2006**.

20. NEJGEBAUER V., ŽIVKOVIĆ B., TANASIJEVIĆ Đ., MILJKOVIĆ N. Soil booklet of Basic Soil Map 1:50.000-Section: Sombor 4. Institute for Soil Research, Belgrade Serbia, **2010** [In Serbian].
21. Republic Hydrometeorological Office of Serbia: Meteorologic annual reports (1961-2011), Belgrade, Serbia, **2012** [In Serbian].
22. LALIĆ B., MIHAILOVIĆ T. D., PODRAŠČANIN Z. Future climate conditions in Vojvodina and influence on crop production. Field and Vegetable Crops Research **48**, 403, **2011**.
23. KADOVIĆ R. Investigation of ammeliorative-protective effects of some forest tree species in forest belts beside the canals of the Danube-Tisza-Danube hydro system. Master thesis, University of Belgrade Faculty of Forestry, **1978** [In Serbian].
24. Yugoslav Society for Soil Research. Study Methods for Soil Physical Properties, Novi Sad, Serbia, **1997** [In Serbian].
25. ISO 11277. Soil Quality-Determination of particle size distribution in mineral soil material, Method by sieving and sedimentation, International Organization for Standardization, Switzerland, **1998**.
26. ISO 11272. Soil Quality – Determination of dry bulk density. International Organization for Standardization, Switzerland, **1993**.
27. NELSON D.W. , SOMMERS L.E. Total carbon, organic carbon, and organic matter. (In D. L. Sparks (Ed.), Methods of soil analysis. Part 3 - Chemical Methods, 961, Madison: SSSA), **1996**.
28. ISO 11261. Soil quality-Determination of total nitrogen, modified Kjeldahl method, International Organization for Standardization, Switzerland, **1995**.
29. ČAKMAK D., SALJNIKOV E., MRVIĆ V., JAKOVLJEVIĆ M., MARJANOVIĆ Ž., SIKIRIĆ B., MAKSIMOVIĆ S. Soil Properties and Trace Elements Contents Following 40 years of Phosphate Fertilization. J. Environ. Qual. **39**, (2), 541, **2010**.
30. ISO 10693. Soil Quality-Determination of carbonate content, Volumetric method, International Organization for Standardization, Switzerland, **1994**.
31. VLADIMIR S., MONTANARELLA L., FILIPPI N., SELVARADJOU S., GALLEGO J. Soil Sampling Protocol to Certify the Changes of Organic Carbon Stock in Mineral Soils of European Union, Office for Official Publications of the European Communities, Luxembourg, **2005**.
32. Munsell Soil Color Charts. X-Rite World Headquarters, Grand Rapids, Michigan, USA, **2009**.
33. RESULOVIĆ H., ĆUSTOVIĆ H. Properties of Technogenous Substrates and Assessment of their Suitability for Recultivation – Technosol Development Projection. Agriculturae Conspectus Scientificus **76**, (1), 8, **2011**.
34. FANG H.Y., LI Q.Y., CAI Q.G. A study on the vegetation recovery and crop pattern adjustment on the Loess Plateau of China. African Journal of Microbiology Research **5**, (12), 1414, **2011**.
35. REMEŠ J., ŠÍŠA R. Biological activity of anthropogenic soils after spoil-bank forest reclamation. Journal of Forest Science **53**, (7), 299, **2007**.
36. NORRIS E.J., STOKES A., MICKOVSKI B.S., CAMMERAAT E., VAN BEEK R., NICOLL C.B., ACHIM A. (Eds.). Slope Stability and Erosion Control: Ecotechnological Solutions. Dordrecht: Springer, **2008**.
37. HAGEN-THORN A., ARMOLAITIS K., CALLESEN I. STJERNQUIST I. Macronutrients in tree stems and foliage: a comparative study of six temperate forest species planted at the same sites. Ann. For. Sci. **61**, 489, **2004**.
38. GONZALES E. Seasonal patterns of litterfall in the floodplain forest of a large Mediterranean river. Limnetica **31**, (1), 173, **2012**.
39. OLIVEIRA DE T., HATTENSCHWILER S., HANDA I.T. Snail and millipede complementarity in decomposing Mediterranean forest leaf litter mixtures. Funct. Ecol. **24**, 937, **2010**.
40. ORLOVIĆ S., PAJEVIĆ S., KRSTIĆ B., MERKULOV Lj., NIKOLIĆ N., PILIPOVIĆ A. Variability of anatomical-physiological traits in Black locust clones (*Robinia pseudoacacia* L.), Proc. Nat. Sci. Matica Srpska **106**, 65, **2004** [In Serbian].
41. BARNA T. Experimental use of controlled mycorrhization in afforestations in Hungary, Annals of the Faculty of engineering Hunedoara – Journal of engineering **1**, (V), 171, **2007**.
42. KHAN F., LUKAC M., TURNER G., GODBOLD D. Elevated atmospheric CO_2 changes phosphorus fractions in soils under a short rotation poplar plantation (EuroFACE), Soil Biol. Biochem. **40**, 1716, **2008**.
43. JONCZAK J., DZIADOWIEC H., KASPROWICZ K., CZARNECKI A. An Assessment of the Influence of Poplar Clones Hybrid 275 and Robusta on Soil Cover Based on the Characteristics of their Plant Litter Fall, Polish Journal of Soil Science **43**, (1), 9, **2010**.
44. KOPING J., VAN DEN BURG J. Using soil and foliar analysis to diagnose the nutritional status of urban trees. Journal of Arboriculture **21**, (1), 17, **1995**.
45. KNEŽEVIĆ M., KOŠANIN O. Soil Science Handbook (Belgrade: University of Belgrade Faculty of Forestry), **2011** [In Serbian].