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The effects of temporary occupation of agricultural land by gravel deposits and construction on selected soil properties

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Abstract: We addressed the condition of restored soil on alluvial plain in the south-eastern Slovenia after they have been given for the gravel deposit easement during construction. According to pre-investigation using soil probes, two soil profile pits were dug: Profile 1 on the area where excavated soils were deposited over original soils; and Profile 2 on the area where topsoil had been removed before gravel deposition and reapplied after the easement. Undisturbed and disturbed soil samples were collected and analyzed for physical and chemical properties. The results show that chemical properties were generally not the limiting factor for soil fertility. Compaction of the soil reduced hydraulic conductivity and resulted in water stagnation. The bulk density on the area where the material was deposited directly on the soil surface ranged from 1.41 to 1.77 g cm^{-3}. The hydraulic conductivity of the saturated soil was practically impermeable at depths of 10, 20, and 30 cm, indicating compaction due to high mechanical load. At the area where topsoil was removed before deposition and restored after easement the hydraulic conductivity of the saturated soil was low to moderate. Removal of the topsoil before construction began was an appropriate action, but reclamation measures are also required.

Key words: fluvisols; soil degradation; soil restoration; soil physical properties; soil chemical properties

Vpliv začasne zasedbe kmetijskih zemljišč z deponijo gramoza ob gradbenih posegih na lastnosti tal

Izvleček: Namen raziskave je bil preveriti lastnosti tal na območju spodnje Save po rekultivaciji zaradi začasne zasedenosti zemljišč za deponijo gramoza. Po pregledu območja (sondiranje) smo na dveh mestih izkopali talna profila; profil 1 na delu, kjer je bila na obstoječa tla odložena odstranjena rodovitna zemljina; profil 2 na delu, kjer je bil vrhnji sloj tal pred deponiranjem gramoza odstranjen in nato ponovno vzpostavljen. Odvzeli smo neporušene in porušene talne vzorce za merjenje fizikalnih in kemijskih lastnosti tal. Izmerili smo teksturo, volumsko gostoto tal, nasičeno hidravlično prevodnost, pH, vsebnost organske snovi, parametre kationske izmenjalne kapacitete in rastlinam dostopna hranila. Ugotovili smo, da kemijske lastnosti v splošnem niso ovirale rodovitnosti tal. Zbitost tal je omejevala hidravlično prevodnost in povzročila zastajanja vode. Na območju, kjer je bil deponiran material neposredno na površino tal, je bila gostota tal od 1,41 do 1,77 g cm^{-3}. Tla so bila na tem delu praktično neprepustna na globinah 10, 20 in 30 cm, kar kaže na veliko zbitost zaradi mehanskih obremenitev. Tla, na območju, kjer je bila vrhnja plast tal odstranjena in po odstraniti začasne deponije ponovno nanesena, so bila manj zbita. Odstranitev zgornje plasti tal pred deponiranjem gramoza je bil ustrezen ukrep, vendar so potrebni tudi melioracijski ukrepi po zaključku gradbenih del.

Ključne besede: obrečna tla; degradacija tal; rekultivacija tal; fizikalne lastnosti tal; kemijske lastnosti tal

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1 INTRODUCTION

Alluvial plains are important agricultural areas due to favourable soil properties, topography and the vicinity of water resources. Even though several soil types occur, Fluvisols and Cambisols are the most important. Fluvisols are young soils formed by frequent deposition of sediments along river courses and streams. In the upper reaches of the channel, the sediments are usually dominated by large boulders and angular stones, but downstream the particles increase in roundness, become smaller and represent a good basis for soil development. Soils of alluvial plains (Fluvisols, Cambisols) of the lower reaches of rivers or along streams are mostly under agricultural land use, less commonly under forest. The sediments are fine-grained (silty or clayey), and the epipedon may be thick and rich in humus (Vidic et al., 2015, Vrščaj et al., 2017). The lower part of a soil profile may contain gravel and sand; if finer, we usually find reductimorphic features as evidence of gleying, such as grey-brown mottling, which is a consequence of a changing levels of groundwater table and alternating reduction and oxidation processes. Alternation of these processes results from alternating wet and dry phases in the soils, which are associated with a seasonal distribution of precipitation. In Slovenia, wet autumn and spring periods lead to stagnant water in the soil profile alternating with dry winter and summer periods when soil pores fill with air and cause oxidation of Fe substances on the walls of pores and surface of soil aggregates. However, permanent water stagnation in Fluvisols and Cambisol is rare and occurs only in lower soil horizons, which can express predominantly grey color. The alluvial plains are typical for their distinct hydraulic properties (e.g. by higher hydraulic conductivities ranging from 2 to 180 m day^{-1} in the subsoil) compared to upper laying parts of the watershed (Miller et al., 2016; Šípek et al., 2019). Soils are usually enriched with nutrients and characterized by high vertical and horizontal heterogeneity, which is explained with the varying characteristics of alluvial sediments, regime of deposition, age of formation (distance to the river), and land use (Kercheva et al., 2017). In some cases, Fluvisols may be subjected to contamination of deposits (Antić et al., 2006; Schwartz et al., 2006; Mabit et al., 2012).

The predominant land use of alluvial plains is agricultural, where high quality arable land for intensive crop and vegetable production (Maršić et al., 2012; Vrščaj et al., 2017) alternates with grassland (for livestock). The latter is more often found in areas with clayey soils and stagnating water. Fluvisols are of high importance because of their broad ecosystem functions, not only for agricultural production but also for their role in soil water (Zupanc et al., 2011; Zupanc et al., 2012, Zupanc et al., 2020) and flood water retention (Glavan et al., 2020; Bezak et al., 2021). The agronomic significance provokes long-standing interest in determining and mapping of soil physical and chemical properties for designing either drainage or irrigation system (Kercheva et al., 2017, Matičič and Steinman, 2007).

Alluvial plains are very often the subject of different interests of land use planners (Zupanc et al., 2011). Beside agricultural land use, the construction of urban and industrial infrastructure pose negative effects on soil resources (Grčman and Zupanc, 2018), not only directly with soil sealing but also due to the indirect influence of construction work on nearby land and siting of meliorative measures necessary for compensating natural habitats (e.g. flood protection measures, Bezak et al., 2021). As Fluvisols are young soils, soil morphological properties, namely soil structure aggregates are unstable and weakly expressed. Such soils are susceptible to compaction and their structure is not easily re-established after the disturbance (Zupanc et al., 2016, Schomburg et al., 2019), which leads to water logging and hampers soil tillage (Grčman and Zupanc, 2018).

As the areas of Fluvisols are very limited in Slovenia (5 % of Slovenian territory; Vrščaj et al, 2017), we have to pay attention to soil sealing and other degradation processes caused by construction works, which often require easement of the surrounding area. The aim of this study was to evaluate the soil properties on the alluvial plain of the lower Sava River, to assess its possible degradation after the construction of a hydropower plant, for which an easement for gravel deposits was required. We evaluated chemical and physical parameters crucial for soil fertility to establish possible degradation and causes of water stagnation.

2 MATERIALS AND METHODS

The study area is located in the alluvial plains of the lower Sava and Krka rivers (Figure 1). The area was affected by the construction of the Brežice hydropower plant, as part of the agricultural land was used for gravel deposition during the construction works. After the construction works were completed, the gravel deposits were removed and the land was returned to agricultural use (Figure 1). However, stagnant water was seen in some parts of the area, raising questions about the quality of the earthworks used to restore the land.

After detailed surface inspection and soil probing, two sites were selected for excavation of the soil profile pits (Fig. 1). One on the area where the excavated fertile topsoil was deposited directly on the agricultural land (Profile 1), and the other on an area where the fertile topsoil was removed before the gravel was deposited up to the height of 2 - 6 meters and later restored (Profile 2).

The description of morphological properties was done according to the Guidelines for soil description (FAO, 2006) and disturbed soil samples were taken from each recognized horizon. Undisturbed soil samples (V = 100 cm^3) were taken in 10 cm increments. The soil samples were analysed for soil physical properties, i.e., texture, soil bulk density, and saturated hydraulic conductivity, as well as chemical properties, i.e. pH, plant available nutrients organic matter content and parameters of cation exchange capacity. Texture was measured by sedimentation pipette method (SIST ISO 11277), bulk density of soil was determined gravimetrically (ISO 11272, 1993). Saturated hydraulic conductivity was measured using a Darcy apparatus. Five measurements of water flow under saturated conditions were made for each sample and the average was calculated. Results for saturated hydraulic conductivity were interpreted using Bear's (1972) permeability classes (< 0.001 m day^{-1} practically impermeable, 0.001–0.01 very low permeability, 0.01–1m day^{-1} low permeability and from 1m day^{-1} permeable soils). Organic matter content was measured by SIST ISO 14235 – modified method after Walkely-Black, total nitrogen after dry combustion (ISO 13878), cation exchange capacity according to Soil survey laboratory methods manual (1992), pH in extraction with $CaCl_2$ after SIST ISO 10390, and plant available phosphorous and potassium after ÖNORM L 1087 – modification – amonlactate extraction.

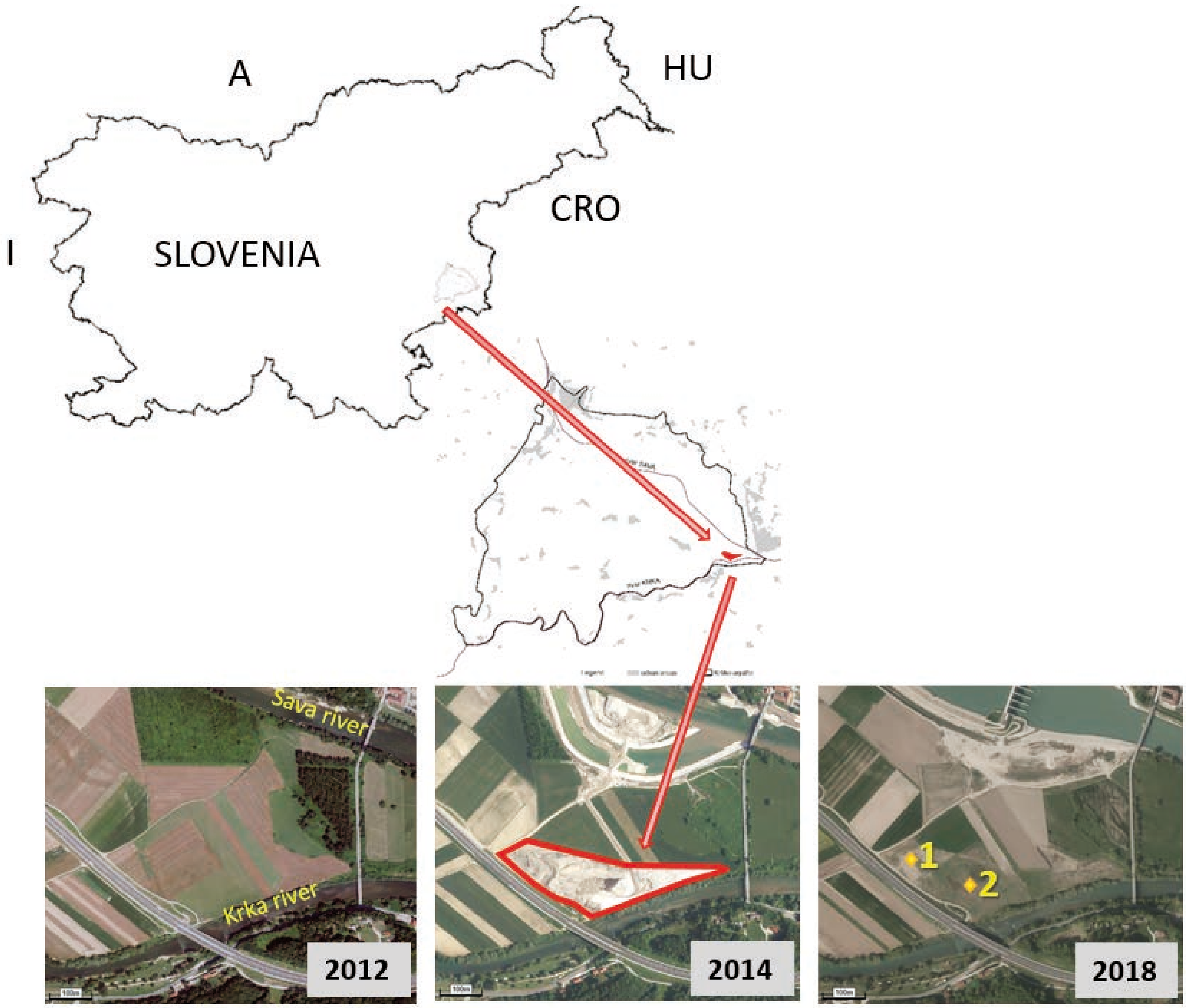

Figure 1: The land use on alluvial plain between the Sava River and the Krka River before, during and after hydropower plant construction; the location of two soil profile pits are marked on the right picture
Slika 1: Raba tal na aluvijalni ravnini med Savo in Krko pred, med in po izgradnji hidroelektrarne; na desni sliki sta označeni lokaciji profilov 1 in 2

3 RESULTS AND DISCUSSION

Both soil profiles were deep and had an anthropogenic influence. The soils on the western part of the formerly occupied land (Profile 1) have a sequence of horizons typical of the Fluvisols of the lower Sava River (Prus, 2000; Prus et al. 2015; Vidic et al., 2015; Vrščaj et al., 2017). Textural differences between the soil horizons were typical of sedimentation processes, but the structural aggregates which were angular-blocky in shape and weak in grade indicating that pedogenetic processes had already started, leading to the development of eutric brown soils (Eutric Cambisols). Morphological evidence of stagnant water, i.e. grey-brown mottling, was found throughout soil profile 1 and in two layers of profile 2, although to a small extent. No water occurred at the bottom of the profiles, although sampling was conducted several days after heavy rain, suggesting that textural discontinuities and soil compaction may be affecting water movement through the soil profile (Figure 2, Table 1).

Soil properties vary horizontally and vertically. These differences occur mainly in texture, which is a result of the different alluvial sediments. Variation in chemical properties was less pronounced (Tables 2 and 3). In =Profile 1, the soil texture varies, silt particles are the predominant soil texture fraction, after which the sand fraction increases to over 80 %. Cation exchange capacity reflects clay content and decreases with depth. Base saturation is high, greater than 90 %, with calcium being the predominant cation. The pH is high, ranging from 7.6 to 7.9. Organic matter decreases with depth, which is typical of undisturbed automorphic soil profiles. The soils are poor in plant-available phosphorus and potassium, indicating that the soils were extensively farmed in the past without the use of fertilizers.

In Profile 2 greater textural variability through the depth was measured. Organic matter content is much higher compared to Profile 1, with concentrations greater than 4 % to a depth of 89 cm. The texture, organic matter content, and soil color indicate that approximately 90 cm layer was removed and later reapplied as topsoil. The cation exchange capacity reflects the clay and organic

Figure 2: Two soil profile pits were dug;Pprofile 1 on the area where the excavated fertile topsoil was deposited directly on the agricultural land (left); Profile 2 on the area where the fertile topsoil was removed before the gravel was deposited and later restored (right)

Slika 2: Izkopana sta bila dva pedološka profila; profil 1 na območju kjer je bila začasno deponirana izkopana zemljina neposredno na površino kmetijskih tal (levo); profil 2, na kasneje rekultiviranem območju, kjer so pred začasno deponijo gramoza odstranili zgornji sloj tal (desno)

Table 1: Morphological characteristics of soil
Preglednica 1: Morfološke lastnosti tal

Area/Profile	Hori-zon*	Soil depth (cm)	Colour***	Structure	Consistency when moist	Roots	Pedogenetic forms
Topsoil was not removed	Ap	0 - 22	2.5Y 4/2	Angular blocky	Very firm	very few	few mottles
Profile 1	II	22 - 46	10YR 4/4	Angular blocky	Firm	very few	few mottles
	III	46 - 82	10YR 4/3	Angular blocky	Firm/Friable	very few	few mottles
	IV	82-102	10YR 4/4	Angular blocky	Friable	very few	few mottles
	V	102-138	10YR 5/3	Angular blocky	Friable/Loose	very few	few mottles
	VI	138-179	10YR 6/4	Single grain	Loose	no	-
Topsoil was removed and later restored	I**	0-45	2.5Y 3/3	Angular blocky	Friable	few	no
	II**	45-89	2.5Y 3/2	Angular blocky	Firm/Friable	few	few mottles
Profile 2	III	89-119	10YR 5/3	Angular blocky	Firm/Friable	very few	few mottles
	IV	119-160	10YR 5/4	Angular blocky	Friable	no	no
	V	160-175	10YR 6/6	Single grain	Loose	no	no

*according to Slovenian national classification, horizons of Fluvisols and Technosols are marked with roman number (Prus et al., 2015)
**replaced layers
***soil colour was identified using Munsell soil colour chart

Table 2: Soil texture and chemical soil characteristics
Preglednica 2: Tekstura in kemijske lastnosti tal

Area/ Profile	Hori-zon*	Soil depth	Sand	Silt	Clay	Texture	pH	Org. matter	C	N	C/N	P_2O_5	K_2O
		cm		%				%				mg/100 g	
Topsoil was not removed	A	0-22	16.0	62.6	21.4	SL	7.6	2.6	1.5	0.16	9.4	0.7	7.9
	II	22-46	5.5	71.5	23.0	SL	7.7	1.8	1.0	0.13	7.7	< 0.5	5.5
Profile 1	III	46-82	6.4	70.9	22.7	SL	7.8	1.3	0.8	0.09	8.9	< 0.5	4.7
	IV	82-102	20.6	64.5	14.9	SL	7.8	0.9	0.5	0.06	8.3	< 0.5	3.5
	V	102-138	62.1	30.2	7.7	Sl	7.8	0.5	0.3	0.02	15.0	< 0.5	2.1
	VI	138-179	87.4	8.0	4.6	S	7.9	0.2	0.1	0.01	10.0	0.6	1.6
Topsoil was removed and later restored	I**	0-45	50.8	34.5	14.7	L	7.5	4.5	2.6	0.14	18.6	1.4	6.1
	II**	45-89	43.0	41.4	15.6	L	7.6	4.2	2.4	0.14	17.1	1.4	6.4
	III	89-119	17.4	67.1	15.5	SL	7.7	1.2	0.7	0.07	10	< 0.5	4.1
Profile 2	IV	119-160	20.9	64.6	14.5	SL	7.8	0.9	0.5	0.06	8.3	< 0.5	3.4
	V	160-175	62.1	30.7	7.2	PL	7.8	0.3	0.2	0.02	10	< 0.5	2.7

*According to Slovenian national classification, horizons of Fluvisols and Technosols are marked with roman number (Prus et al., 2015)
** replaced layers

matter content and decreases with depth. Base saturation is high, greater than 90 %, with calcium being the predominant cation. The pH is high, ranging from 7.5 to 7.8. Similar to profile 1, the soils are poor in plant-available phosphorus and potassium.

The results show that chemical properties are generally not the limiting factor for soil fertility, especially high base saturation, high pH and high organic matter content were favorable characteristics. However, nutrient content could be increased by intensive fertilization.

The bulk density of the soil in Profile 1 (area, where topsoil has not been removed) ranged from 1.41 to 1.77 g cm^{-3}. Notable is a large difference between the soil density of the uppermost 30 cm and the depth from 40 cm, where soil bulk density was from 1.41 to 1.54 g cm^{-3}) (Figure 3). Soil bulk density of the upper 30 cm exceeds

Table 3: Parameters of cation exchange capacity
Preglednica 3: Izmenljivi bazični kationi in kationska izmenjalna kapaciteta

Area/Profile	Hori-zon*	Soil depth	Ca	Mg	K	Na	H	CEC	Base saturat.
		cm			$mmol_C$ 100 g^{-1}				%
Topsoil was not removed	Ap	0-22	25.07	2.01	0.19	0.07	1.40	28.7	95.1
Profile 1	II	22-46	27.14	2.17	0.12	0.12	1.05	30.6	96.6
	III	46-82	27.00	1.99	0.11	0.10	0.85	30.1	97.2
	IV	82-102	23.22	1.33	0.07	0.06	0.10	24.8	99.6
	V	102-138	18.89	0.70	0.04	0.04	0.10	19.8	99.5
	VI	138-179	17.60	1.41	0.03	0.03	0.10	19.2	99.5
Topsoil was removed and later restored	I**	0-45	27.25	1.44	0.15	0.06	1.85	30.8	94.0
	II**	45-89	25.58	1.41	0.15	0.05	1.65	28.8	94.3
Profile 2	III	89-119	23.29	1.06	0.09	0.07	0.10	24.6	99.6
	IV	119-160	23.92	1.15	0.07	0.08	0.10	25.3	99.6
	V	160-175	19.71	0.68	0.05	0.05	0.10	20.6	99.5

*According to Slovenian national classification, horizons of Fluvisols and Technosols are marked with roman number (Prus et al., 2015)
** replaced layers

values, commonly found in the soils of alluvial plains (Kercheva et al., 2017). These results confirm the findings from the field, namely that the uppermost soil layer is highly compacted, hindering the flow of water to depth. The bulk density in profile 2 (area with removed and restored soil) ranged from 1.47 to 1.37 g cm^{-3} (Table 3). In addition to the removal of topsoil prior to the placement of gravel, soil texture could also influence the bulk density. Soils with higher sand content are less susceptible to compaction.

Since hydraulic conductivity below 0.001 m day^{-1} indicates practically impermeable soils (Bear, 1972), the top 30 cm layer was practically impermeable (Figure 4). This could also imply that no water would be infiltrating and percolating vertically and replenishing water storage below the root zone without meliorative measures (deep plowing, plant cover) potentially indefinitely.

In the area where topsoil was removed before deposition and later soils were restored (Profile 2), there were differences in the hydraulic conductivity of the saturated soil within individual soil layer and between soil layers (e.g. 10, 30 and 40 cm depth, Fig. 4). When the hydraulic conductivity of the upper layer is much larger compared to the hydraulic conductivity of the lower layer (factor 10 or larger), the effect of impervious layer occurs. This may cause water stagnation even between more permeable layers. However, large differences were observed between soil profiles at different depths, most likely due to the different soil texture typical for Fluvisols and heterogeneous consolidation of soil mass after soil restoration.

After construction and restoration works are completed, the soil must be rehabilitated to improve the physical properties of the soil (Krümmelbein et al., 2010; Krümmelbein et al., 2012). Generally, restoration cannot be done with construction measures alone (Krümmelbein et al., 2010; Zupanc et al., 2016), necessary time for soil rehabilitation depending on the extent of disturbance to the soil profile (Grčman and Zupanc, 2018). The reasonable approach is to leave the last phase to land users (farmers), who are better able to adapt to weather conditions and optimal soil moisture and consistency than construction companies (Zupanc et al., 2016). A high value of bulk density and poor hydraulic conditions expressed as stagnant water at the soil surface indicate that meliorative measures need to be taken to accelerate soil aggregation and thus improve soil structure. This can best be achieved with a suitable plant cover (e.g. *Medicago sativa* L.), where the roots of the plants can help to structure and loosen the compacted layers (Schomburg et al., 2019). It is important to establish plant cover as soon as possible, and we recommend that protective plants for reclamation remain for at least three years.

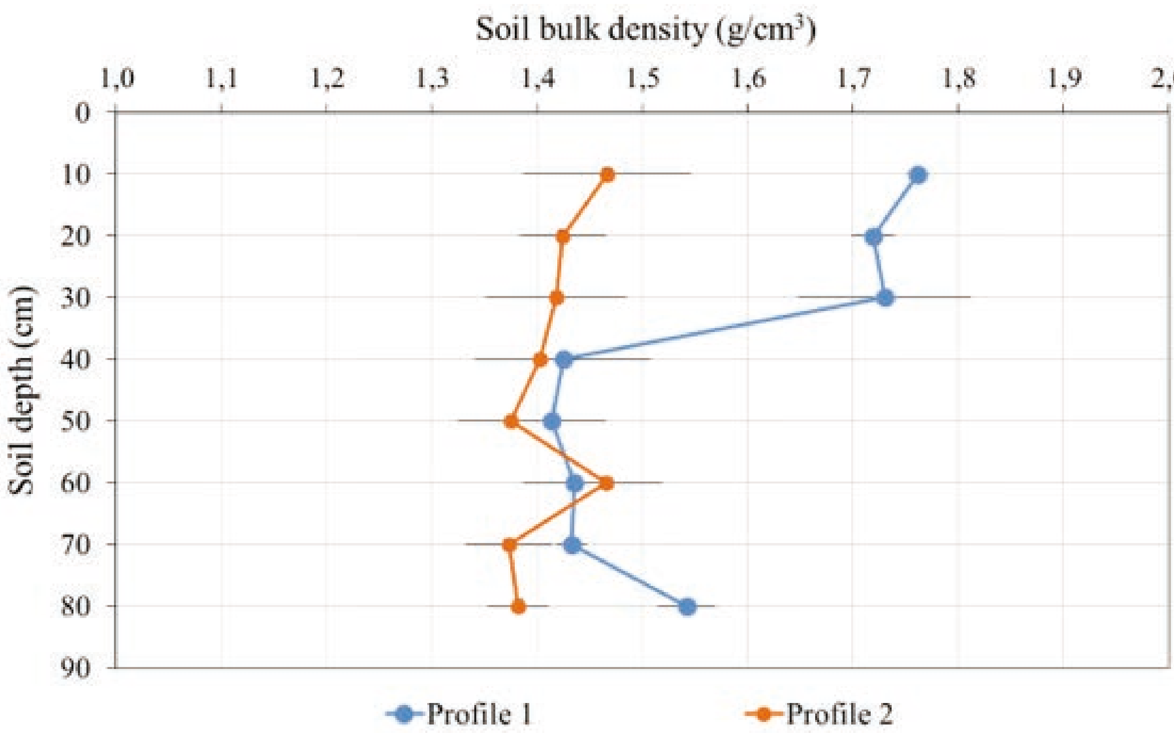

Figure 3: Average soil bulk density (g cm^{-3}) for soil Profile 1 and soil Profile 2
Slika 3: Povprečna volumska gostota tal (g cm^{-3}) v talnem profilu 1 in v talnem profilu 2

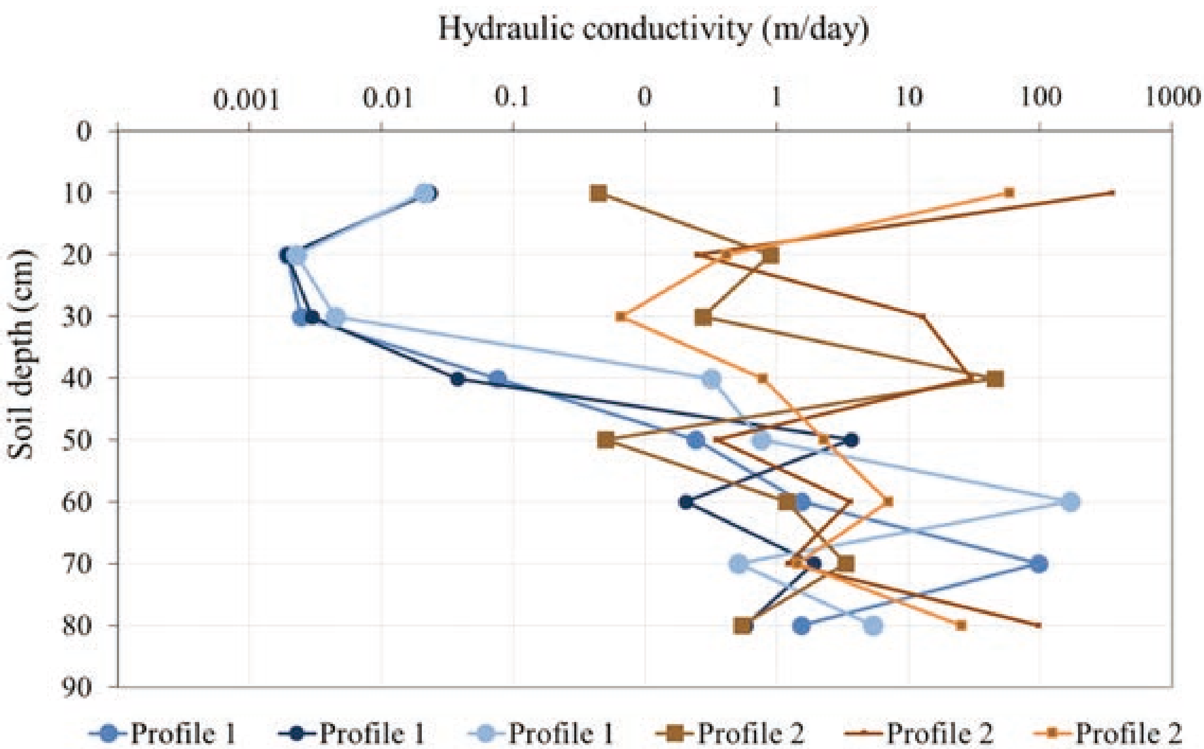

Figure 4: Saturated hydraulic conductivity (m day^{-1}) for soil Profile 1 and soil Profile 2 (three replicates)
Slika 4: Hidravlična prevodnost nasičenih tal (m dan^{-1}) v talnem profilih 1 in 2 (tri ponovitve)

4 CONCLUSIONS

The results of our study show that the temporary occupation of agricultural land by gravel deposits can have negative effects on soil functions. While chemical properties were not affected and were generally not the limiting factor for agricultural use, the bulk density and hydraulic conductivity of the soil showed serious consequences of mechanical stress. Hydraulic conductivity was reduced in the area where the topsoil was not removed prior to deposition (Profile 1) due to compaction in the upper 30 cm. The restored soils (Profile 2) and the lower soil layers of the both permanently occupied sites (profiles 1 and 2) had hydraulic conductivity typical of soils in alluvial plains. Removal of the topsoil prior to the start of construction was an appropriate measure.

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