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PEDOTRANSFER FUNCTIONS FOR BULK DENSITY ESTIMATION OF FOREST SOILS

PEDOTRANSFER FUNKCIJE ZA PROCJENU GUSTOĆE ŠUMSKIH TALA

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ABSTRACT: The data of 45 soil profiles from a 16 × 16 km grid across Slovenia was analysed to develop a local pedotransfer function (PTF) for bulk density (ρb) estimation. In total, 106 soil horizons were considered. Concentration of organic carbon (OC) was found to be well correlated (r = -0.861, p < 0.001) with ρb. Two separate line segments were fitted to the data, which was partitioned into two intervals, based on OC content (below 36.0 g/kg and above 36.0 g/kg). Nearly 80 % of the variability in ρb is explained with segmented regression. The local PTF was compared with published PTFs and four validations indices (MPE, SDPE, RMSPE and R^2) confirmed the highest prediction quality of the local PTF. The differences of carbon stock (C_{pool}) estimation, based on usage of different PTFs could be higher than 160 t OC per hectare. Prediction of carbon stocks could be substantially improved by calibration of the models coefficients with data stratified according to each unique soil type.

Key words: pedotransfer function PTF, organic carbon OC, segmented regression, forest soil, carbon stock C_{pool}

INTRODUCTION – Uvod

Since forest soil sampling and analyses of chemical and physical properties of forest soils are time consuming and labor intensive, the development of alternative methods is indispensable. By using pedotransfer functions (PTFs), soil scientists are able to get information on crucial soil properties, which are otherwise difficult (expensive or time consuming) to obtain. PTFs can be defined as statistical models for predicting soil physical (bulk density, soil hydraulic properties, etc.) and chemical (e.g. cation exchange capacity) properties from other more available and routinely measured properties.

The first PTF (for wilting coefficient) was developed by Briggs and McLane 1907 (Landa and Nimmo, 2003), while PTFs for estimation of soil bulk density (ρ_b) were introduced in the 1970s' (e.g. Jeffrey, 1970). At first, bulk density was correlated only with soil organic matter (SOM) (Adams, 1973; Federer, 1993; Rawls and Brakensiek, 1985, Honeysett and Ratkowski, 1989), but later the information on soil texture was added to some PTFs (Leonavičiute, 2000; Kaur et al., 2002). Simple univariate models were supplemented with multiple regressions and different equations were developed separately for the organic and the mineral soil layers (e.g. Harrison in Bocock, 1981), or even for different genetic soil horizons (e.g. Leonavičiute, 2000). Recently, various techniques of tree regressions were incorporated in PTFs development (e.g. Martin et al., 2009).

Soil bulk density (ρ_b) is defined as the mass of a unit volume of dry soil (105 °C), which includes both solids and pores and, thus, bulk density reflects the total soil porosity (FAO, 2006). Usually, it is expressed in g/cm^3 or kg/dm^3. Soil bulk density is necessary for the assessment of soil carbon and nutrient pools (Tamminen and Starr, 1994) and for other mass-to-volume conver-

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sions. It is also needed when estimating soil water retention characteristics and is a required input parameter in models of water, sediment and nutrient transport (Bouconneau et al., 1998). Additionally, soil bulk density is an indicator of soil compaction, porosity and site productivity (Tamminen and Starr, 1994; Salifu et al., 1999).

Several studies have investigated variation in forest soils properties at very detailed spatial scales (Phillips and Marion, 2005; Scharenbroch and Bockheim 2007) and revealed that soil variability can be high even on short distances and in small areas. Especially recent studies evaluating existing PTFs (e.g. De Vos et al., 2005; Martin et al., 2009) warn against usage of PTFs without first testing their accuracy, and stress the importance of local calibrations of coefficients in the models.

The aim of our study was to develop a local PTF for the estimation of soil bulk density of (forest) mineral soils in Slovenia. Based on literature, we hypothesized that (1) the bulk density ρ_b correlated strongly with soil organic carbon concentration (OC) and (2) that our local PTF perform better than published PTFs.

2 METHODS – Materijali i metode

2.1 Data sources and laboratory work – *Izvori podataka i laboratorijski rad*

The information on soil bulk densities as well as physical and chemical properties of soil horizons was taken from the soil database of the Slovenian Forestry Institute (SFI). Only the data on soil profiles opened in year 2006 on the 16 × 16 km network across Slovenia were finally selected; in total, 45 soil profiles with 109 soil horizons (Figure 1). Summary information about soil profiles is presented in Table 1.

Figure 1 Locations of soil profiles (n = 45) across Slovenia from which the data for development of a local PTF for bulk density (ρ_b) estimation was derived.

Slika 1. Položaj profila tla (n=45) u Sloveniji na osnovi kojih su dobivene lokalne pedotransfer funkcije (PTF) za procjenu gustoće tla.

To describe locations of the soil profiles and evaluate morphological and physical properties of the soil horizons, FAO methodology was followed (FAO, 2006). In each soil horizon, separate soil samples were taken for bulk density estimation and for chemical and physical soil analysis. Samples for bulk density estimation (ISO 11272) of a fine earth fraction (< 2mm) were obtained in five replicates by using metal O-rings with volume of 5 cm^3. In the laboratory, soil samples were air dried (105 °C) and weighed. Variability of bulk density estimation using metal O-rings based on 5 replicates is presented in Figure 2., where almost 80% of values have a CV less than 10%. Soil samples for chemical and physical soil analysis were also air dried and passed through a 2 mm sieve. The fine earth fraction (< 2mm) was retained (UN/ECE ICP-Forests 2006, http://www.icp-forests.org/pdf/FINAL_soil.pdf) for further chemical and physical analyses. The following methods were used:

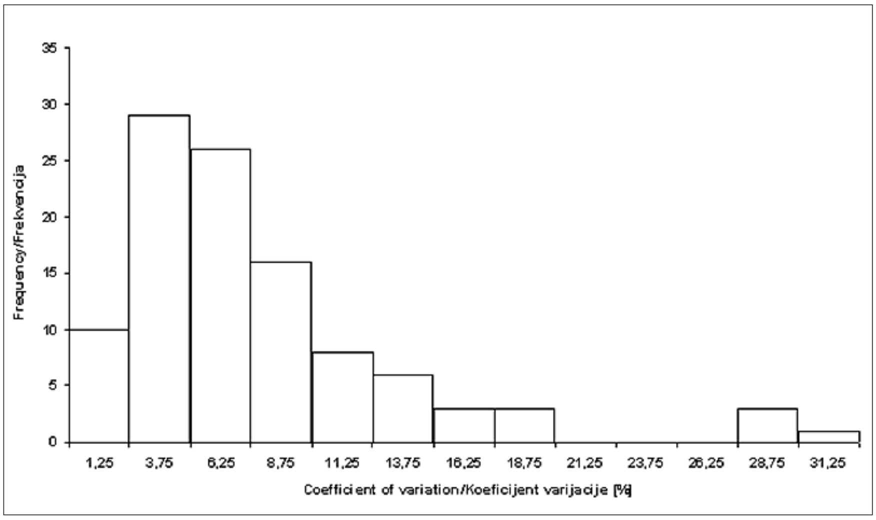

Figure 2 Frequency distribution for coefficient of variation (CV) for bulk density measurements, obtained using 5 cm^3 metal O-rings.

Slika 2. Distribucija frekvencija za koeficijent varijacije (CV) gustoća tala, izmjerenih korištenjem metalnih O-prstenova zapremine 5 cm^3

pH was determined in calcium chloride following ISO 10390 on automatic pH-meter Metrohm Titrino, C and N content using dry combustion using ISO 10694 and/or 13878 on Leco CNS-2000, carbonates following ISO 10693 with Scheibler calcium-meter (Eijkelkamp) and soil texture following ISO 11277 with sedimentary method and pipette according to Köhn.

Table 1 Summary information of soil profiles included in the study, grouped according to World Reference Base soil reference groups (SRG)

Tablica 1. Zbirni podaci o profilima tla uključenim u studiju, grupiranima prema WRB referentnim grupama tala (SRG)

SRG *Referentna grupa tala prema WRB*	N	**Soil depth, cm** *Dubina tla, cm*		**Elevation, m** *Nadmorska visina, m*	
		mean	SD	min	max
Acrisol	2	135	21.2	110	557
Cambisol	23	77	24.0	262	1318
Fluvisol	1	120		188	188
Histosol	2	73	23.3	1227	1497
Leptosol	1	33		720	720
Luvisol	9	83	30.6	316	910
Phaeozem	6	57	20.6	532	1208
Planosol	1	100		383	383

2.2 Statistical analyses and model comparison

Statističke analize i usporedba modela

In total, 109 soil samples were included in the statistical analyses. Three influential points (soil samples) according to Cook's distance were excluded from further analysis. The simple and multiple regression models were used to predict ρ_b from different explanatory variables. According to PTFs, developed by Hoekstra and Poelman (1982), van Wallenburg (1988) and Reinds et al. (2001), regression models with segmented relationships were also tested. Only variables that show statistical significance at the 0.05 level were included in the models. Models were compared using partial F-test.

From the literature, four different published PTFs were selected (Jeffrey, 1970; Harrison et al., 1981; Tamminen, 1994; Kaur et al., 2002) using following equations:

Jeffrey: $\rho_b = 1.482 - 0.679 \cdot \log_{10}(LOI)$

Harrison: $\rho_b = 1.729 - 0.769 \cdot \log_{10}(LOI)$

Tamminen: $\rho_b = 1.565 - 0.229 \cdot \sqrt{LOI}$

Kaur: $\rho_b = 0.313 - 0.191 \cdot OC + 0.02102 \cdot Clay - 0.000476 \cdot Clay^2 - 0.00432 \cdot Silt$

where ρ_b is soil bulk density (g/cm^3), *OC* is OC concentration by dry combustion method, *LOI* is organic matter content (g/kg) by Loss-On-Ignition method, *Clay* is percentage of a clay fraction (0-2 μ) and *Silt* is percentage of silt fraction (2-63 μ) . For conversion of the data on OC obtained by dry combustion method and Loss-On-Ignition method, the equation according to Craft et al. (1991) was used:

$$OC = 0.40 \cdot LOI + 0.0025 \cdot LOI^2 \rightarrow LOI = 20 \cdot \sqrt{OC + 16} - 80$$

The local PTF was compared with published PTFs using four validation indices: mean predicted error (MPE), standard deviation of the prediction error (SDPE), root mean square prediction error (RMSPE) and coefficient of determination (R^2). These indices are defined as:

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\rho_{bp,i} - \rho_{b,i}\right)$$

$$SDPE = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\left(\rho_{bp,i} - \rho_{b,i}\right) - MPE\right)^2}$$

$$RMSPE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\rho_{bp,i} - \rho_{b,i}\right)^2}$$

$$R^2 = \frac{\left[\mathrm{cov}(\rho_{bp,i}, \rho_{b,i})\right]^2}{\mathrm{var}(\rho_{bp,i}) \cdot \mathrm{var}(\rho_{b,i})}$$

Where $\rho_{b,i}$ is measured bulk density of i^{th} soil sample, $\rho_{bp,i}$ is predicted bulk density of i^{th} soil sample, *n* is the number of soil samples, *cov* is the covariance and *var* is the variance.

2.3 Carbon stock calculation (C_{pool})

Izračun zalihe ugljika (C_{pool})

Carbon stock per given area, hectare in our case, was calculated using following equation:

$$C_{pool} = \sum_{i=1}^{k}\left(OC_i \cdot d_i \cdot \rho_{b,i} \cdot ston_i \cdot 100\right)$$

Where OC_i is organic carbon concentration of i^{th} soil horizon, d_i is thickness of i^{th} soil horizon (in m), $\rho_{b,i}$ is bulk density of i^{th} soil horizon (in g/cm^3), $ston_i$ is a correction factor for stoniness in i^{th} horizon and *n* is the number of soil horizons for a given soil profile.

Statistical analyses were carried out using the R 2.9.3 software environment (R Development Core Team, 2009). Package ''segmented'' was used to fit regression models with segmented relationships (Muggeo, 2008).

3 RESULTS AND DISCUSSION – Rezultati i rasprava

3.1 Development of local PTF for predicting soil bulk density of mineral part of soil

Razvoj lokalnih pedotransfer funkcija za predviđanje gustoće mineralnog sloja tla

Soil bulk density and concentration of organic carbon were strongly correlated ($r = -0.86$, $p < 0.001$). Other chemical soil properties, except the concentration of total nitrogen (N), were less correlated with bulk density (Figure 3). The correlation between bulk density and base saturation (BS) and the correlation between bulk density and clay content were not statistically significant ($p > 0.05$).

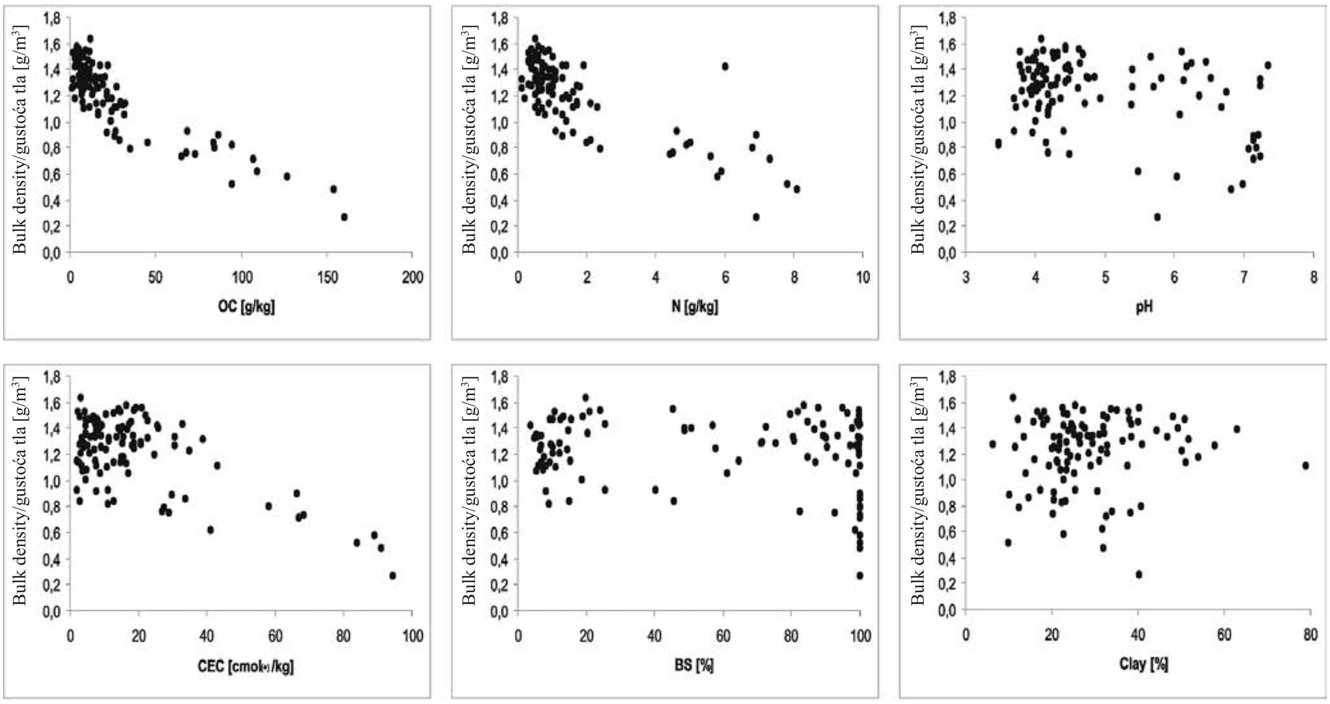

Figure 3 Relationship between bulk density (ρb) and concentration of organic carbon (OC), concentration of total nitrogen (N), cation exchange capacity (CEC), base saturation (BS) and clay content (Clay) for 106 soil samples.

Slika 3. Odnos gustoće tla i koncentracije organskog ugljika (OC), ukupnog dušika (N), pH, kapaciteta za izmjenu kationa (KIK), sume baza (BS) i sadržaja gline (glina) za 106 uzoraka.

More than 73 % of the total variability of bulk density was explained by OC (model SFI 1, Table 2). Adding other chemical properties as explanatory variables in the multiple regression models (models SFI 2, SFI 3,

Table 2 Regression relationship between soil properties as predictors and bulk density as response for 106 soil horizons (OC – organic carbon, BS – base saturation, CEC – cation exchange capacity, CLAY - clay content.

Tablica 2. Regresijski odnos karakteristika tla kao prediktora i gustoće tla kao odziva za 106 horizonata tla (OC – organski ugljik, BS – suma baza, KIK - kapacitet za izmjenu kationa, glina – sadržaj gline).

Model	Response variable *Varijabla odziva*	Intercept	OC	pH*	BS*	CEC* *KIK*	CLAY* *glina*	SE	Adj. R^2
SFI 1	ρ_b	1.3983	-0.0734					0.1403	0.7384
SFI 2	ρ_b	1.4509	-0.0720	-0.0115				0.1404	0.7379
SFI 3	ρ_b	1.3752	-0.0749		0.0004			0.1399	0.7398
SFI 4	ρ_b	1.3902	-0.0788			-0.0011		0.1402	0.7385
SFI 5	ρ_b	1.3438	-0.0734				0.0019	0.1390	0.7431
SFI 6	ρ_b for OC < 3.6 %	1.4842	-0.1424					0.1257	0.7958
	ρ_b for OC ≥ 3.6 %	1.1253	-0.0452						

* denotes not statistically significant variable in the model

* *označava nesignifikantnost varijable u modelu*

SFI 4 and SFI 5 in Table 2) did not significantly improve the prediction of SFI 1 (partial F-test, $p > 0.05$). Unexpectedly, soil texture, especially clay content, was not statistically significant variable in the models; contrary to many studies revealing that clay content is related with soil bulk density (Kaur, 2002; Leonavičiute, 2000).

The segmented regression method (SFI 6) improved prediction of ρ_b (partial F-test, $p < 0.001$). The independent variable OC was partitioned into two intervals and a separate line segment was fitted to each interval. The boundary between two segments (breakpoint) was 36.0 g/kg OC (Figure 4). Nearly 80 % of the total variability in ρ_b was explained by using segmented regression.

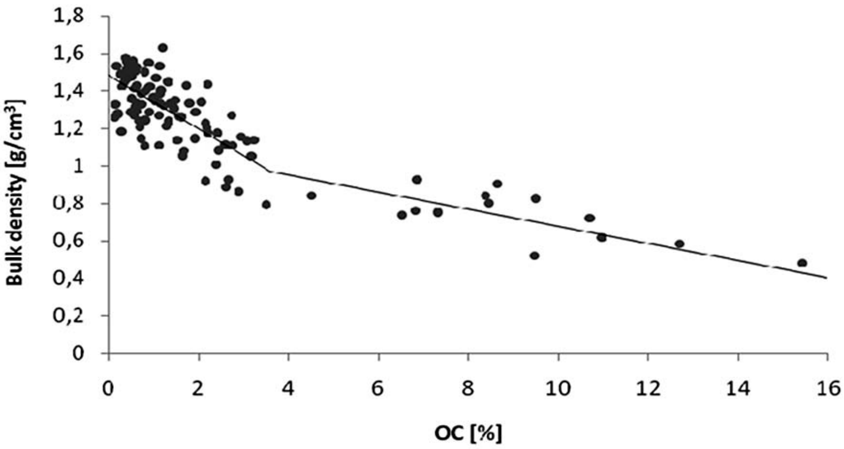

Figure 4 Segmented regression relationship between soil bulk density (ρ_b) and organic carbon content (OC) in the mineral soil [g/kg]

Slika 4. Segmentirana regresija odnosa gustoće tla (ρ_b) i sadržaj organskog ugljika (OC) u mineralnom sloju tla [g/kg]

3.2 Validation of local and published PTFs for mineral part of soil

Validacija lokalnih i objavljenih pedotransfer funkcija za mineralni sloj tla

For the validation of local and published PTFs, bulk density was calculated using four published PTFs and predicted values were compared with local PTF (SFI 6). The prediction quality of all five PTFs is presented in Figure 5. All four validation indices confirmed the highest prediction power of our local PTF (Figure 5) by

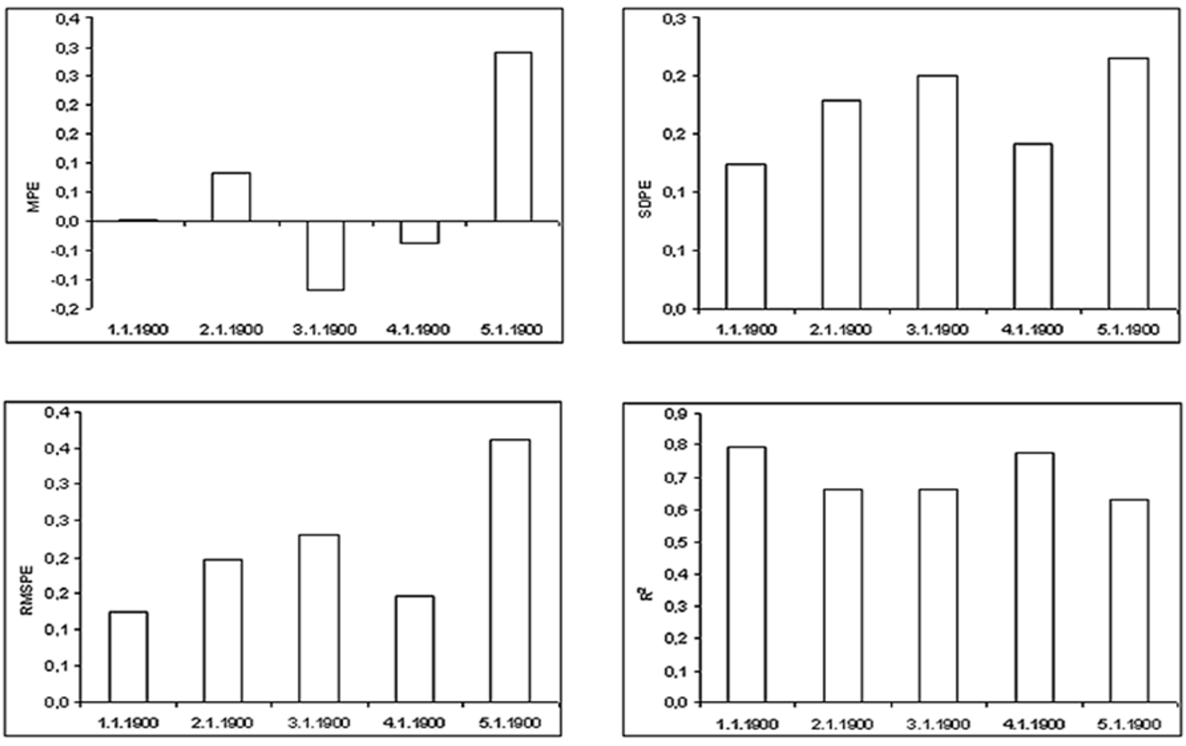

Figure 5 Evaluation indices for published PTFs and local PTF (SFI 6)

Slika 5. Indeksi evaluacije za objavljene i lokalni PTF (SFI 6) having the lowest value of bias of the regression model (MPE), the lowest random variation of the predictions after correction for the global bias (SDPE), the lowest overall error of the predictions (RMSPE) and the highest coefficient of determination (R^2).

In the case of high bulk density, local SFI 6 PTF seems slightly less accurate (Figure 6). Probably, that could be explained because of not including information on clay content, which is normally the highest just for the soil horizons with high bulk densities (Urbančič et al., 2005). For other PTFs the systematic error in predictions is evident from the scatterplots of Figure 6.

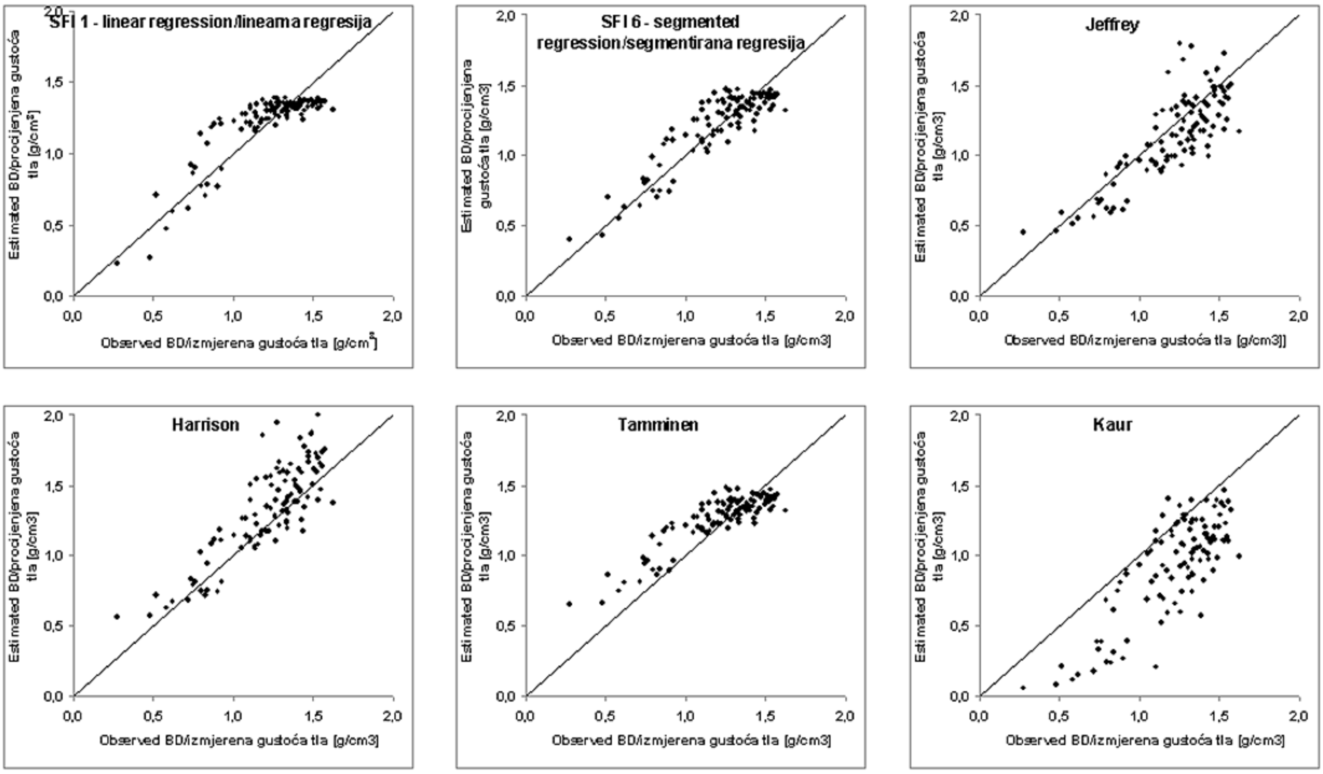

Figure 6 Performance of two local PTFs and published PTFs for the total dataset: estimated versus observed bulk densities with references to the 1:1 line.

Slika 6. Kvaliteta predviđanja dvije lokalne i objavljenih pedotransfer funkcija za ukupni zbir podataka: procijenjene u odnosu na izmjerene gustoće s linijama izjednačenja.

3.3 Carbon stock calculation using different PTFs

Izračun zalihe ugljika korištenjem različitih pedotransfer funkcija

Carbon stock (C_{pool}) per hectare was calculated for different soil profiles, based on the usage of different PTFs (Table 4). Four different soil profiles were randomly selected from our soil database of the 16 × 16 km grid: Zajama, Lubnik, Besnica and Merljaki (Table 3). In the calculation of C_{pool}, the stone content in soil horizons was considered, while the root portion was not. We assumed no surface rock outcrops.

Soil profile "Zajama" was excavated in the Pokljuka plateau and is classified as Leptosol, soil profile "Lubnik" was dug near Škofja Loka and is classified as Cambisol, profile "Besnica" was excavated near Ljubljana and is classified also as Cambisol, whereas soil profile "Merljaki" is classified as Acrisol and was excavated near Nova Gorica. Morphological, physical and chemical properties are presented in detail in Table 3.

The calculation of the C_{pool}, based on the PTF of Kaur et al. (2002) gives highly underestimated values for all four soil profiles. The differences between calculated C_{pool} using PTF SFI 6 and measured C_{pool} are not unambiguous, i.e. for soil profile "Lubnik" and "Besnica" the carbon stock is underestimated, while for soil profile ''Zajama'' carbon stock is overestimated. The calculations of C_{pool} revealed that differences of calculated carbon stock per hectare could be quite large and are strongly dependent upon the PTFs algorithm. However, the lowest difference of the C_{pool} based on measured and calculated bulk density was found for profile ''Merljaki''. Both chemical and physical properties of this profile are close to average soil properties, included in this study, i.e. lower OC concentration and high bulk density (Figure 3). Consequently, the

Table 3 Morphological, physical and chemical properties of four soil profiles for evaluating C_{pool} estimations.
Tablica 3. Morfološka, fizikalna i kemijska svojstva četiri profila tla za ocjenu kvalitete predviđanja zalihe ugljika

Profile *Profil*	Horizon *Horizont*	Horizon boundary *Granica horizonta* Upper *Gornja*	Lower *Donja*	Physical soil properties *Fizikalna svojstva tla* Clay *Glina*	Silt *Prah*	Sand *Pijesak*	Stoniness *Kamenitost*	ρ_b	Chemical soil properties *Kemijska svojstva tla* OC	N	pH	CEC - *KIK*	BS
	-	Cm	Cm	%	%	%	%	g/cm³	%	%	-	cmol/kg	%
Zajama	**AC**	0	13	9.9	48.2	42.0	15	0.520	9.47	0.78	6.99	83.89	100
	CA	13	33	20.2	57.0	22.8	40	0.737	6.52	0.56	7.24	68.28	100
Lubnik	**AC**	0	15	32.5	51.9	15.6	15	0.719	10.70	0.73	7.13	66.72	100
	BC	15	45	40.7	43.1	16.1	40	0.801	8.47	0.68	7.18	58.05	100
Besnica	**A**	0	3	20.4	27.7	51.9	5	0.842	8.38	0.5	3.47	12.62	45.7
	Bv	3	29	12.2	40.3	47.5	8	1.468	1.06	0.06	3.89	5.39	15.7
	BC	29	49	18.1	36.1	45.8	30	1.529	0.45	0.03	4.01	4.16	10.8
	CB	49	82	18.9	34.0	47.2	65	1.474	0.49	0.03	4.00	4.43	12.5
Merljaki	**A**	0	10	25.4	40.8	33.8	5	0.928	6.86	0.46	3.69	10.95	40.3
	E	10	47	21.5	50.6	27.9	10	1.239	0.67	0.06	3.81	7.18	6.6
	BE	47	85	26.5	43.2	30.3	13	1.339	0.63	0.05	3.84	5.95	5.6
	BC	85	122	32.9	46.5	20.6	13	1.206	0.69	0.05	3.95	5.65	12.3

Table 4 Estimated carbon stock (C_{pool}) till depth of parent material for four different soil profiles based on measured and calculated bulk densities.
Tablica 4. Zaliha ugljika do dubine matičnog supstrata za četiri profila tla, procijenjena na osnovi izmjerenih i izračunatih gustoća tla.

Profile *Profil*	Measured bulk density *Izmjerena gustoća tla*	Carbon stock C_{pool} in t/ha *Zaliha ugljika C_{pool} u t/ha* Bulk density calculated using PTF *Gustoća tla izračunata pomoću PTF* SFI 6	Jeffrey	Harrison	Tamminen	Kaur
Zajama	112.1	138.0	115.0	139.3	166.3	52.7
Lubnik	220.2	200.7	169.3	206.2	247.6	59.8
Besnica	75.3	68.6	62.4	73.7	72.0	52.1
Merljaki	135.9	137.7	126.0	148.9	145.6	101.4

model is nicely predicting the ρ_b of the profile ''Merljaki'', whereas differences for other soil types are larger; i.e. even higher than 25 t of OC per hectare (profile ''Zajama''). Using non local PTFs drawn from literature may resulted in high differences between measured and calculated C_{pool} up to 160 t of OC per hectare (profile ''Lubnik'', PTF Kaur).

4. CONCLUSIONS – Zaključci

Using national data from a 16 × 16 km plot network, we developed a pedotransfer function for bulk density of mineral forest soils of Slovenia. Most of the variability in soil bulk density can be explained by concentration of organic carbon. Adding other chemical (pH, N, CEC, BS) and physical soil properties (soil texture) in the regression equation did not significantly improve the prediction quality. The prediction quality of all five PTFs (Jeffrey, Harrison, Tamminen, Kaur and local SFI 6) were tested using four validation indices (MPE, SDPE, RMSPE, R^2), the result being that local PTF SFI 6 gives the most accurate prediction of soil bulk density.

The PTFs were also used for prediction of carbon stocks in forest soils. Unexpectedly, using the local PTF SFI 6 could still lead to possible inaccuracies of the C_{pool} calculation higher than 25 t of OC per hectare. We assume that the main reason for that is a high pedodiversity of Slovenian forest soils, requiring additional soil ρ_b sampling, especially for the main forest soil types.

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SAŽETAK: S obzirom na vremensku zahtjevnost i veliku količinu rada potrebnog za uzorkovanja i analize kemijskih i fizikalnih svojstava šumskih tala, razvoj alternativnih metoda je vrlo važan. Korištenjem pedotransfer funkcija (PTF), znanstvenici koji se bave proučavanjem tala mogu dobiti informaciju o najvažnijim svojstvima tala koja je inače teško (skupo ili vremenski zahtjevno) dobiti. PTF se mogu definirati kao statistički modeli za predviđanje fizikalnih (gustoća, hidraulička svojstva, itd.) i kemijskih (npr. kapacitet za izmjenu kationa) svojstava tla iz drugih, dostupnijih ili rutinski analiziranih svojstava.

Cilj ovog rada je bio razviti lokalnu PTF za procjenu gustoće mineralnog dijela šumskih tala Slovenije. Na osnovi literature, hipoteza je bila da (1) gustoća snažno korelira s konce4ntracijom organskog ugljika (OC) i (2) lokalna PTF daje bolčje vrijednosti od objavljenih pedotransfer funkcija.

Podaci 45 profila tla s bioindikacijske 16 x 16 km mreže u Sloveniji su analizirani s ciljem razvijanja lokalne pedotransfer funkcije za procjenu gustoće tla. Ukupno je obrađeno 106 profila tla.

Uzorci za procjenu gustoće tla uzeti su u pet ponavljanja korištenjem metalnih O-prstenova zapremine 5 cm^3. U laboratoriju su uzorci tla osušeni na 105 °C i izvagani za daljnje kemijske i fizikalne analize. Korištene su sljedeće analitičke metode: pH je određen u KCl prema ISO 10390 na automatskom ph-metru Metrohm Titrino, sadržaj C i N je određen prema ISO 10694 i/ili 13878 na elementarnom analizatoru Leco CNS-2000, karbonati prema ISO 10693 Scheiblerovim kalcimetrom a mehanički nsastav tla prema ISO 11277 sedimentnom metodom i pipetom prema Köhnu.

Jednostavna i multipla regresija korištene su za predviđanje ρb korištenjem različitih zavisnih varijabla, a testirani su također i regresijski modeli sa segmentnim odnosima.

Koncentracija organskog ugljika (OC) dobro korelira (r = -0.861, p < 0.001) s gustoćom tla. Dva odvojena segmenta linije izjednačenja uklopljeni su u podatke koji su razdijeljeni u dva intervala prema sadržaju OC (ispod i iznad 36,0 g/kg). Gotovo 80 % varijabiliteta gustoće tla objašnjeno je segmentnom regresijom (Slika 4.).

Lokalna pedotransfer funkcija uspoređena je s objavljenim funkcijama a četiri indeksa validacije (MPE, SDPE, RMSPE and R2) potvrdila su najveću kvalitetu predviđanja lokalne pedotransfer funkcije (Slika 5.).

Razlike u procjeni zalihe ugljika u tlu (Cpool) različitih pedotransfer funkcija bile su veće od 160 t/ha (Tablica 4.). Predviđanje zaliha ugljika moglo bi biti značajno unaprijeđeno kalibracijom koeficijenata u modelima pomoću podataka razvrstanih prema vrsti tla.

Ključne riječi: pedotransfer funkcija PTF, organski ugljik OC, segmentna regresija, šumsko tlo, zaliha ugljika C_{pool}