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Class separability, correlation to biomass, parsimony and homogeneity of classes as criteria to decide on the goodness-of-classification when comparing Hungarian soil classification to World Reference Base inside a slightly saline plot

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Abstract

As a means of assisting the selection of promising soil classification systems, a set of criteria were presented and tested. Inside the studied slightly saline plot World Reference Base (WRB) and Hungarian soil classification (HU) were compared at all four levels in terms of class separability, correlation to biomass, parsimony and homogeneity of classes. WRB surpassed HU in terms of the very important homogeneity of classes only, but HU performed better in terms of class separability, correlation to biomass and parsimony of classes. With many possible classification units WRB categorized the soil into a large number of classes, but 67% and 78% of them were single-profile classes at levels 3 and 4, respectively inside the ca 0.9 km^2 area.

Keywords: NDVI, elevation, boxplot, scattergram

Introduction

Soil classification has not lost its relevance for modern soil research and practice, because soil classes provide a summary of many soil features (KUBIËNA, 1953). But not like in other disciplines, in soil science there are many classification systems coexisting (KRASILNIKOV et al., 2010) influenced by tradition, legal actions and other reasons.

The most widespread classification systems, USDA Soil Taxonomy and the World Reference Base for Soil Resources (WRB) (ROSSITER et al., 2017; ESFANDIARPOUR et al., 2018; SALEHI, 2018) were compared according to parent material (SOROKIN et al., 2021), classification levels, physical and chemical properties, and other features by many researchers. SHRADER et al. (1960) WEBSTER et al. (1977), ALLGOOD & GRAY (1978), OGUNKULE & BECKETT (1988), BUOL et al.

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(2011) studied the utility of soil classification systems for predicting selected properties and productivity, and our work follows this tradition.

We used Normalized Difference Vegetation Index (NDVI) [the ratio between the near-infrared and red reflectance difference and the sum of the same two parameters] as a universally applied remote sensing indicator/proxy of aboveground biomass (MCBRATNEY et al., 2003; TEAL et al., 2006; PETTORELLI, 2013).

We tested two soil classification systems in the present study. The Hungarian soil classification system, (HU) is a genetic and hierarchical classification system that was developed in the 1960s (SZABOLCS, 1966) and was updated later (JASSÓ et al., 1989) for mapping soils at a detailed scale and it is currently used on maps at scales of 1:10,000 to 1:1,000,000. HU has four levels, such as main type, type, subtype, variety, but it does not have a taxonomic key.

The World Reference Base for Soil Resources (WRB, 2015) does not have a declared hierarchy, but has several hierarchical levels. Its use is promoted by FAO as an "international classification" and it is also suggested reference inside the European Union (TÓTH et al., 2008). Nevertheless, its use is more common at less detailed scales, such as 1:1,000,000, and it is now being introduced for mapping of smaller areas (SCHULER et al., 2006). Its use is facilitated by a key which is based on diagnostic horizons and other features.

Our paper shows how classifications can be compared with the use of four practical criteria, such as class separability, class homogeneity, correlation with environmental parameters, and parsimony of classes, ranked in their order of importance. Such comparisons can help to select optimal classification to be used in an area. The work was motivated by the recent dispute on a renewed Hungarian soil classification that was suggested by MICHÉLI et al. (2018) and the subsequent debate articles of BIDLÓ (2019), MAKÓ (2019) and TÓTH (2019a). In his debate article, TÓTH (2019b) wrote *"My specific suggestion for authors is to map appropriate sample areas based on current Hungarian soil classification and the suggested approach, using both classifications. With the map, predict the most important soil ecosystem services, and then quantify the benefits of the suggested approach by comparing these with the services determined by an independent method."* This current paper shows a possible method to do what was suggested in 2019.

This report extends the depth of analysis of the TÓTH et al. (2022) publication for the Hungarian readership by providing more details of the WRB and Hungarian classifications, which are of great importance for the area. Data presented in *Figures 5, 7, 11–13* show overlap with the mentioned paper.

Materials and Methods

The study arable plot used for growing cereals (*Figure 1*) is located on the outskirts of the village of Dunavecse, on the former floodplain of the Danube River. The soils are slightly saline and have a sandy-loamy texture, with increasing average particle size along the depth of the profile. The water table is shallow and saline. Local depressions, formerly densely vegetated, are characterized by a higher fraction of silt, organic matter and salt content and a lower concentration of carbonates.

Elevation dominates most soil properties. With increasing elevation, the mean salt concentration, pH, sodicity, clay content and organic carbon content decreases, as well as $CaCO_3$ content increases in the thickness of 0 to 100 cm. The climate is semi-humid with annual temperature of ca 10.5°C.

A 4 cm resolution digital elevation model was obtained with UAV surveys using ground control points of known coordinates. NDVI values were calculated with NASA Landsat data. Annual maximum values between 2010 and 2019 were averaged for the 85 profiles, while NDVI ranges showed the difference between maximum and minimum values for the years considered.

The selected plot of 0.9 km^2 is rectangular (corner coordinates: (46° 55' 16 " N 19° 01' 37" E, 46° 55' 17" N 19° 02' 12" E, 46° 55' 55" N 19° 01' 41" E, 46° 55' 49" N 19° 02' 12" E). Within the plot 85 tubular profiles of 1 m depth were taken (*Figure 1*) which were described according to SZABOLCS (1966). There were also four digged profiles that were described, sampled and analysed. Parameters used for classification were obtained by analysing one-third of the samples, while others were estimated using measured morphological and instrumental (X-ray fluorescence spectroscopy analysis, EC and soil moisture) data, including EC, pH, Na, SOC, $CaCO_3$ content, hygroscopicity (*Table 1,* columns 9–14) with multivariate regression equations; after which profiles were classified according to WRB and HU independently in multiple iterations.

The WRB classification was performed at four levels (*Table 1*, column 5). Reference soil groups (RSG) were determined and all possible qualifiers were added. The number of applicable principal ("princ" below) and supplementary ("suppl" below) qualifiers ranged from 1 to 4, and 1 to 5, respectively. The number of all qualifiers ranged from 2 to 6. Despite its non-hierarchical structure, soil classification was performed at levels 1, 2, 3 and 4. As our main objective was soil productivity assessment, qualifiers were added according to the fixed order of nomenclature of the WRB principles. Optional qualifiers were added according to the following approach:

- WRB1 level RSG
- WRB2 level RSG+1princ
- WRB3 level RSG+2princ or RSG+1princ+1suppl
- WRB4 level RSG+3princ or RSG+2princ+1suppl or RSG+1princ+2suppl

The application of qualifiers according to the above principle is in harmony with the principles of WRB name generation (WRB, 2015, p. 14–15, 3d–5.#) used for soil mapping. Qualifiers that cannot be directly associated with yield (supplementary texture qualifiers) were ignored.

All HU levels were used for classification (*Table 1*, column 6) and then the soil evaluation index proposed by IZSÓ (1986) was determined.

Evidently the classes (*Table 1*) reflect the rules of both classification systems and where there was for example alluvial/hydromorphic feature noticed and expressed in HU it often was not expressed in WRB due to the strict limits of WRB regarding strength of the feature, depth of occurrence and thickness of relevant layer.

Table 1

Classification of the soil profiles applying Hungarian Soil Classification (HU) and World Reference Base for Soil Resources (WRB) at four levels and important average values of profiles as ten-year-average NDVI values, range of NDVI values during the ten years (R_NDVI), 0–0.3 m $pH_{2.5}$, $Na_{2.5}$, $CaCO_3$ %, Soil organic carbon % (SOC), hygroscopicity (%), ECe (µS cm^{-1}) . Classification first level is indicated by CAPITAL, second level by *Italic*, third level by underscoring and fourth level by superscript. If not more than three levels are indicated, fourth level is same as third level for WRB. The digits following class names indicate the codes that identify the classes of Figures 4–10. Thousands show first level, hundreds second level, tens third level and ones fourth level of classification, but several combined features result in more than four digits in HU at the fourth level.

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
A1	175294	648629	95.64	Alcalic *Haplic* CALCISOL 4100	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.72	0.26	8.50	4.82	20	1.39	1.63	1386
A2	175294	648729	95.00	Endoprotosalic *Amphicalcic* KASTANOZEM 6110	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.70	0.29	8.40	4.43	6	1.46	1.78	2073
B1	175344	648579	95.61	Protosodic *Amphigleyic* PHAEOZEM 5100	Solonetz-like in deeper horizons MEADOW with shallow humic horizon depth, calcareous from surface 304110	0.70	0.27	8.20	0.01	16	1.51	1.70	1401
B2	175344	648679	95.46	Protosodic *Cambic* CALCISOL 4230	Solonetz-like in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 204210	0.73	0.29	8.48	1.11	23	1.29	1.46	1566

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
B3	175344	648779	95.10	Endoprotosalic *Haplic* CHERNOZEM 7130	Salty in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 303210	0.71	0.34	8.33	1.48	11	1.47	1.69	1780
B4	175344	648879	95.67	*Chernic* PHAEOZEM 5200	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.77	0.18	8.16	0.46	16	1.30	1.66	976
B5	175344	648979	95.94	*Amphicalcic* CHERNOZEM 7200	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.76	0.22	8.06	0.01	9	1.51	1.71	1151
B6	175344	649079	95.43	Katoprotosalic *Amphigleyic* CHERNOZEM 7260	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.71	0.35	8.23	1.16	15	1.47	1.57	970
B7	175344	649179	95.18	Endoprotosalic *Epicalcic* CHERNOZEM 7370	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.69	0.30	8.24	1.58	18	1.66	1.80	1297
C1	175444	648579	95.83	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.75	0.21	8.03	0.19	14	1.56	1.81	1100
C2	175444	648679	95.72	Endogleyic *Amphicalcic* CHERNOZEM 7230	Calcareous *meadow* CHERNOZEM with medium humic horizon depth, moderately saline 201250	0.75	0.20	8.27	0.01	15	1.50	1.74	1163

Table 1 continued

Profile identification code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ ($mmol\ l^{-1}$)	$CaCO_3$ %	SOC%	hy_1%	EC_e $\mu S\ cm^{-1}$
C3	175444	648779	95.23	Endogleyic *Cambic* CALCISOL Endoprotosalic 4220	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.73	0.31	8.48	2.20	22	1.39	1.49	1936
C4	175444	648879	95.28	Endofluvic *Endocalcic* CHERNOZEM Cambic 7410	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.76	0.19	8.22	0.50	11	1.36	1.44	882
C5	175444	648979	96.24	Cambic *Endocalcic* KASTANOZEM 6220	Typical *calcareous* CHERNOZEM with medium humic horizon depth, calcareous from surface 191210	0.77	0.19	8.01	0.01	10	1.45	1.64	880
C6	175444	649079	95.07	Endogleyic *Amphicalcic* CHERNOZEM Endosalic 7232	Solonetz-like in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 204210	0.65	0.25	8.19	0.78	10	1.47	1.83	1289
C7	175444	649179	95.42	Alcalic *Haplic* CALCISOL Endoprotosalic 4101	Calcareous *humous* ALLUVIAL with medium humic horizon depth, in the middle is a layer of sand 391202	0.66	0.28	8.50	1.60	22	1.28	1.40	1760
D1	175544	648579	95.45	*Epicalcic* CHERNOZEM 7300	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.76	0.19	8.21	0.92	10	1.52	1.72	1142
D2	175544	648679	95.89	Cambic *Endocalcic* CHERNOZEM 7430	Typical *calcareous* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 191202	0.76	0.18	8.07	0.01	11	1.53	1.71	1074

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
D3	175544	648779	95.33	Endoprotosalic *Epicalcic* CHERNOZEM 7370	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.72	0.23	8.47	4.68	13	1.47	1.65	1732
D4	175544	648879	95.26	*Amphicalcic* CHERNOZEM 7200	Typical *calcareous* CHERNOZEM with medium humic horizon depth, calcareous from surface 191210	0.75	0.25	8.33	1.09	5	1.29	1.66	983
D5	175544	648979	96.04	Cambic *Endocalcic* CHERNOZEM 7430	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.75	0.22	8.20	0.01	13	1.47	1.61	1016
D6	175544	649079	94.68	*Katocalcic* CHERNOZEM 7500	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.59	0.36	8.43	6.41	3	1.63	1.82	1801
D7	175544	649179	95.36	Amphiprotosalic *Endogleyic* REGOSOL Calcaric 1000	Salty in deeper horizons *meadow* CHERNOZEM with shallow humic horizon depth, calcareous from surface 203110	0.71	0.26	8.28	0.63	23	1.21	1.43	1765
E1	175644	648579	95.22	Amphigleyic *Chernic* PHAEOZEM Calcaric 5250	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.75	0.18	7.93	0.01	10	1.73	2.10	855
E2	175644	648679	95.68	Endofluvic *Amphicalcic* CHERNOZEM Endoprotosalic 7221	Salty in deeper horizons *meadow* CHERNOZEM with shallow humic horizon depth, calcareous from surface 203110	0.75	0.18	8.43	1.57	25	1.25	1.46	1273

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
E3	175644	648779	95.51	Cambic *Endocalcic* CHERNOZEM 7430	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.75	0.19	8.36	4.23	16	1.57	1.64	1384
E4	175644	648879	95.34	Endoprotosalic *Haplic* CHERNOZEM 7130	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.75	0.18	8.25	1.84	16	1.28	1.61	1618
E5	175644	648979	95.44	*Haplic* CHERNOZEM 7100	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.72	0.25	8.41	4.55	17	1.41	1.80	1450
E6	175644	649079	94.69	Katoprotosalic *Haplic* CHERNOZEM 7120	Calcareous *alluvial* MEADOW with medium humic horizon depth, in the middle is a layer of sand 311202	0.66	0.31	8.32	4.49	13	1.49	1.86	1674
E7	175644	649179	95.29	Pantocalcaric *Chernic* PHAEOZEM 5210	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.73	0.21	8.28	1.19	14	1.41	1.60	1637
F1	175744	648579	95.14	*Haplic* CHERNOZEM 7100	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.75	0.19	8.14	1.92	12	1.61	1.84	1516
F2	175744	648679	95.59	Endogleyic *Endocalcic* CHERNOZEM 7420	Calcareous *meadow* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 201202	0.75	0.17	7.99	0.01	17	1.53	1.74	1361

Table 1 continued

Profile identification code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
F3	175744	648779	95.62	Endogleyic *Epicalcic* CHERNOZEM Endoprotosalic 7352	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.75	0.19	8.33	1.60	22	1.36	1.64	1588
F4	175744	648879	95.62	Endoprotosalic *Haplic* CHERNOZEM 7130	Salty in deeper horizons *meadow* CHERNOZEM with shallow humic horizon depth, calcareous from surface 203110	0.76	0.18	8.11	1.62	14	1.49	1.70	1584
F5	175744	648979	95.20	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Solonetz-like in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 204210	0.69	0.34	8.41	2.35	8	1.49	1.57	1703
F6	175744	649079	94.84	Katofluvic *Amphicalcic* CHERNOZEM Endoprotosalic 7210	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.71	0.38	7.98	2.82	8	1.65	1.87	1363
F7	175744	649179	95.14	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Solonetz-like in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 204210	0.74	0.19	8.14	2.46	5	1.45	1.74	1493
F8	175743	649254	94.80	Endocalcic *Chernic* GLEYSOL Endoprotosalic 3010	Salty in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 303210	0.67	0.30	8.02	1.34	4	1.88	1.96	1924

Table 1 continued

Profile identification code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
G1	175844	648579	94.99	Endogleyic *Amphicalcic* KASTANOZEM Fluvic 6101	Calcareous *alluvial* MEADOW with shallow humic horizon depth 311100	0.73	0.23	8.60	4.14	24	1.44	1.70	2237
G2	175844	648679	95.69	Katoprotosalic *Haplic* CHERNOZEM 7120	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.75	0.20	8.28	0.01	18	1.33	1.67	1179
G3	175844	648779	95.56	Endoprotosalic *Haplic* CHERNOZEM 7130	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.76	0.17	8.15	0.01	16	1.57	1.75	1279
G4	175844	648879	95.72	Pantocalcaric *Chernic* PHAEOZEM Cambic 5211	Typical *calcareous* CHERNOZEM with medium humic horizon depth, calcareous from surface 191210	0.76	0.19	8.17	0.01	14	1.69	1.65	1506
G5	175844	648979	94.85	Pachic *Endocalcic* CHERNOZEM 7440	Typical *calcareous* CHERNOZEM with medium humic horizon depth, calcareous from surface 191210	0.72	0.24	8.00	0.01	10	1.57	2.01	1206
G6	175844	649079	94.93	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.72	0.29	8.30	1.49	5	1.45	1.77	1570
G7	175844	649179	95.34	*Amphicalcic* CHERNOZEM 7200	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.76	0.14	8.02	0.01	9	1.41	1.66	1197

Table 1 continued

Profile identification code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
G8	175844	649279	94.84	Endogleyic *Amphicalcic* CHERNOZEM 7230	Salty in deeper horizons MEADOW with shallow humic horizon depth, calcareous from surface 303110	0.65	0.27	8.26	4.19	4	1.71	1.94	1776
H1	175944	648579	94.91	Amphicalcic *Chernic* GLEYSOL Endoprotosalic 3001	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.70	0.30	8.02	7.08	26	1.41	1.97	1760
H2	175944	648679	95.66	Katofluvic *Chernic* PHAEOZEM Pantocalcaric 5220	Calcareous *terrace* CHERNOZEM with shallow humic horizon depth, on the top is a layer of sand 211101	0.73	0.24	8.52	2.50	20	1.45	1.52	1678
H3	175944	648779	95.43	*Amphicalcic* CHERNOZEM 7200	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 331200	0.75	0.17	8.27	0.01	16	1.49	1.52	1175
H4	175944	648879	95.70	Amphigleyic *Epicalcic* KASTANOZEM 6240	Calcareous *meadow* CHERNOZEM with medium humic horizon depth, on the top is a layer of sand 201201	0.76	0.16	8.10	0.75	11	1.57	1.81	1199
H5	175944	648979	95.05	Pachic *Epicalcic* CHERNOZEM 7360	Typical *calcareous* CHERNOZEM with medium humic horizon depth, calcareous from surface 191210	0.74	0.19	8.02	0.01	10	1.69	1.80	1460
H6	175944	649079	95.00	Endofluvic *Amphicalcic* CHERNOZEM 7220	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.73	0.27	7.95	2.11	6	1.69	1.87	1194

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
H7	175944	649179	95.75	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.77	0.15	7.98	0.01	8	1.53	1.81	1087
H8	175944	649279	95.35	Endogleyic *Amphicalcic* CHERNOZEM Endoprotosalic 7231	Solonetz-like in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 304210	0.69	0.30	8.07	2.51	6	1.61	1.75	1636
I1	176044	648579	94.87	Endogleyic *Epicalcic* CHERNOZEM Alcalic 7351	Solonetz-like in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 304210	0.70	0.31	8.54	3.19	7	1.69	1.82	1762
I2	176044	648679	95.46	Katofluvic *Endogleyic* CHERNOZEM 7620	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 331200	0.71	0.36	8.22	0.18	12	1.37	1.77	916
I3	176044	648779	95.46	Endogleyic *Epicalcic* CHERNOZEM Endoprotosalic 7352	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.76	0.18	8.08	0.01	11	1.41	1.68	1128
I4	176044	648879	95.79	Amphigleyic *Epicalcic* CHERNOZEM 7340	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.76	0.15	8.10	1.60	15	1.53	1.72	1524
I5	176044	648979	94.98	Pachic *Haplic* CHERNOZEM 7110	Typical *calcareous* CHERNOZEM with medium humic horizon depth, calcareous from surface 191200	0.73	0.27	8.02	3.75	8	1.80	1.91	1453

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
I6	176044	649079	95.14	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Calcareous *terrace* CHERNOZEM with medium humic horizon depth 211200	0.73	0.29	8.16	4.51	8	1.65	1.83	1329
I7	176044	649179	95.80	*Amphicalcic* CHERNOZEM 7200	Calcareous *terrace* CHERNOZEM with medium humic horizon depth 211200	0.75	0.22	8.43	0.01	13	1.37	1.47	1471
I8	176044	649279	95.33	Endogleyic *Epicalcic* CHERNOZEM Endoprotosalic 7352	Solonetz-like in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 304210	0.70	0.38	8.11	0.60	8	1.49	1.78	1176
J1	176144	648579	94.89	Katogleyic *Epicalcic* CHERNOZEM Katoprotosalic 7320	Solonetz-like in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 304210	0.72	0.26	8.30	1.93	7	1.80	1.92	1982
J2	176144	648679	95.40	Endoprotosalic *Amphicalcic* CHERNOZEM 7250	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.73	0.22	8.16	0.58	18	1.49	1.55	1097
J3	176144	648779	95.51	Cambic *Epicalcic* CHERNOZEM 7310	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 201200	0.75	0.18	8.20	0.47	10	1.41	1.76	1095
J4	176144	648879	95.99	*Amphicalcic* CHERNOZEM 7200	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.74	0.22	8.00	0.01	14	1.41	1.75	1303

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
J5	176144	648979	95.05	Amphicalcic *Chernic* GLEYSOL Endoprotosalic 3001	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.70	0.32	8.09	0.01	9	1.65	1.79	1692
J6	176144	649079	95.22	Pantocalcaric *Chernic* PHAEOZEM Endoprotosalic 5212	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.72	0.31	8.27	1.43	13	1.69	1.70	1280
J7	176144	649179	95.28	Pantocalcaric Katofluvic CAMBISOL 2100	Calcareous *humous*ALLUVIAL with medium humic horizon depth 391200	0.73	0.27	8.51	6.29	31	1.33	1.67	1489
J8	176144	649279	95.35	Amphifluvic *Chernic* PHAEOZEM Pantocalcaric 5230	Solonetz-like in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 204210	0.72	0.35	8.49	3.26	18	1.49	1.57	1752
J9	176144	649379	95.18	Alcalic *Pantocalcaric* PHAEOZEM Endosalic 5310	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.72	0.27	8.59	6.09	16	1.53	1.36	2477
K1	176244	648579	95.21	Cambic *Endogleyic* CHERNOZEM Endoprotosalic 7610	Salty in deeper horizons MEADOW with medium humic horizon depth, calcareous from surface 303210	0.71	0.26	7.90	0.03	13	1.57	1.93	985

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
K2	176244	648679	95.50	Endogleyic *Epicalcic* CHERNOZEM 7350	Calcareous *terrace* CHERNOZEM with medium humic horizon depth, in the middle is a layer of sand 211202	0.72	0.23	8.47	4.52	27	1.53	1.59	1653
K3	176244	648779	95.64	Amphicalcic *Chernic* GLEYSOL 3000	Calcareous *meadow* CHERNOZEM with medium humic horizon depth, at the bottom is a layer of sand 201203	0.76	0.19	8.29	0.99	15	1.57	1.68	1272
K4	176244	648879	95.86	Katofluvic *Epicalcic* CHERNOZEM Endoprotosalic 7320	Salty in deeper horizons *meadow* CHERNOZEM with medium humic horizon depth, calcareous from surface 203210	0.76	0.17	8.37	2.24	10	1.61	1.71	1191
K5	176244	648979	95.20	Katogleyic *Epicalcic* CHERNOZEM Katoprotosalic 7330	Salty or solonetz-like in deeper horizons *chernozem* MEADOW with medium humic horizon depth, calcareous from surface 333210	0.73	0.29	8.31	0.91	9	1.40	1.75	1532
K6	176244	649079	95.23	Pantocalcaric *Chernic* PHAEOZEM 5210	Calcareous *terrace* CHERNOZEM with medium humic horizon depth 211200	0.75	0.21	8.34	3.49	15	1.33	1.62	1354
K7	176244	649179	95.45	Endogleyic *Endocalcic* KASTANOZEM Endofluvic 6230	Calcareous *terrace* CHERNOZEM with medium humic horizon depth 211200	0.76	0.18	8.16	0.01	6	1.57	1.95	1049
K8	176244	649279	95.58	Katofluvic *Cambic* CALCISOL Endoprotosalic 4210	Calcareous *humous* ALLUVIAL with medium humic horizon depth, in the middle is a layer of sand 391202	0.72	0.20	8.27	1.01	20	1.37	1.72	1211

Table 1 continued

Profile identi-fication code	Northing (m)	Easting (m)	Elevation above sea level (m)	WRB classification and code at four levels	HU classification and code at four levels	10-year Mean NDVI Value	R_NDVI	$pH_{2.5}$	$Na_{2.5}$ (mmol l^{-1})	$CaCO_3$ %	SOC%	hy_1%	EC_e µS cm^{-1}
K9	176244	649379	94.99	Endogleyic *Amphicalcic* KASTANOZEM 6100	Calcareous MEADOW with medium humic horizon depth 301200	0.67	0.24	8.37	4.65	11	1.61	1.87	1236
L1	176344	648579	95.60	Alcalic *Amphicalcic* CHERNOZEM 7240	Calcareous *meadow* CHERNOZEM with medium humic horizon depth 331200	0.75	0.17	8.55	2.79	10	1.68	1.65	2044
L2	176344	648679	95.31	Endofluvic *Chernic* PHAEOZEM Cambic 5240	Calcareous *terrace* CHERNOZEM with medium humic horizon depth 211200	0.67	0.23	8.28	2.11	10	1.53	1.73	1233
L3	176344	648779	95.66	Katofluvic *Chernic* PHAEOZEM Pantocalcaric 5220	Calcareous *terrace* CHERNOZEM with shallow humic horizon depth 211100	0.74	0.19	8.30	1.71	19	1.21	1.70	1001
L4	176344	648879	95.60	*Pantocalcaric* PHAEOZEM 5300	Calcareous *meadow* CHERNOZEM with shallow humic horizon depth 201100	0.67	0.21	8.49	2.97	28	1.30	1.44	1557
Y1	176194	649429	95.50	Endoprotosalic *Pantocalcaric* CAMBISOL 2200	Calcareous *humous* ALLUVIAL with medium humic horizon depth, in the middle is a layer of sand 391202	0.71	0.26	8.34	2.06	19	1.49	1.60	1085

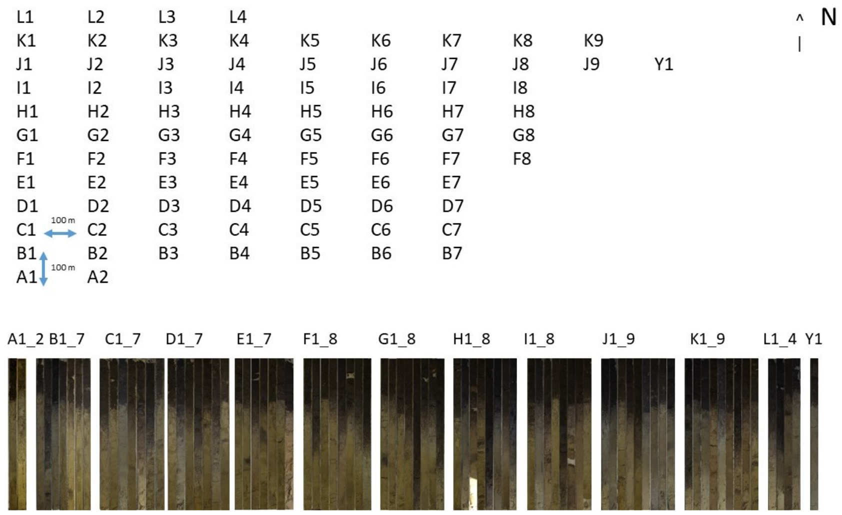

Figure 1
Layout of profiles inside the plot. Graph is not to scale. Standard distance of profiles in rows and columns was 100 m, except for A1, A2, F8 and Y1, see Table 1 for coordinates (sunfleck of H3 and missing sample in a few profiles, F6, I6 etc are artefacts due to difficult sampling/photography)

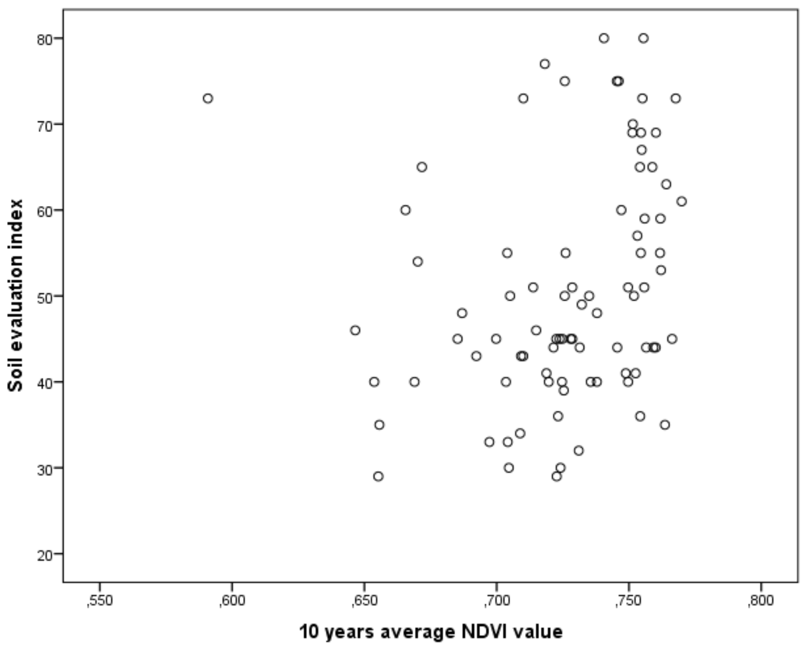

Figure 2
Scattergram of soil evaluation index and mean NDVI values

The class separability was assessed by the number of classes that showed significant differences in NDVI values pairwise, using ANOVA. The larger the ratio of significantly different class pairs, the better is the classification.

Class homogeneity was analysed for mean NDVI and, as a reference, for elevation, at the four classification levels by the value of "1-RV", where RV is the pooled within-class variance/total variance. The higher this values, the more precise is the classification.

Parsimony of classes was determined by the number of distinguished classes, with special consideration of single-profile classes. Greater number of classes, especially single-profile classes might cause difficulties for mapping (VAN HUYSSTEEN et al., 2013).

Correlation of classes to environmental parameters was tested by calculating Pearson correlation between mean NDVI and elevation values of distinguished classes at all four levels. Stronger correlation means easier use for predicting productivity.

A series of boxplots shows the NDVI and elevation values of distinguished classes. Width of boxes indicates number of cases in the class.

Results and Discussion

As *Figure 1* and *Table 1* show there was great lateral and depth variation of soil morphology as well as quantitative soil properties, but the spatial distribution of properties will be described in another publication in detail. With increasing depth, SOC% and clayiness decreased, but salinity related properties and $CaCO_3$% increased. The variation of $CaCO_3$ was much less in the full one-meter profile than in the 0–30 layer, but clayiness was more heterogeneous in the full profile length.

Although the soil evaluation index did not highly correlate with mean NDVI, it still indicated a significant correlation of $r = 0.231^*$ (*Table 2, Figure 2*). This finding has corroborated the findings of TÓTH et al. (2009) who found moderate performance of this index for yield evaluation. The stronger negative correlations with the range of NDVI and salinity indicate the profound base and suitability of the approach.

Table 2
Correlation coefficient of the major variables with soil evaluation index (n = 85)

		Soil evaluation index
10 years average NDVI value	Pearson Correlation	0.231^*
	Sig. (2-tailed)	0.033
10 years NDVI range	Pearson Correlation	-0.255^*
	Sig. (2-tailed)	0.019
Elevation above sea level (m)	Pearson Correlation	0.140
	Sig. (2-tailed)	0.201
ECe (0–30 cm) $\mu S\ cm^{-1}$	Pearson Correlation	-0.334^{**}
	Sig. (2-tailed)	0.002
ECe (0–100 cm) $\mu S\ cm^{-1}$	Pearson Correlation	-0.588^{**}
	Sig. (2-tailed)	0.000

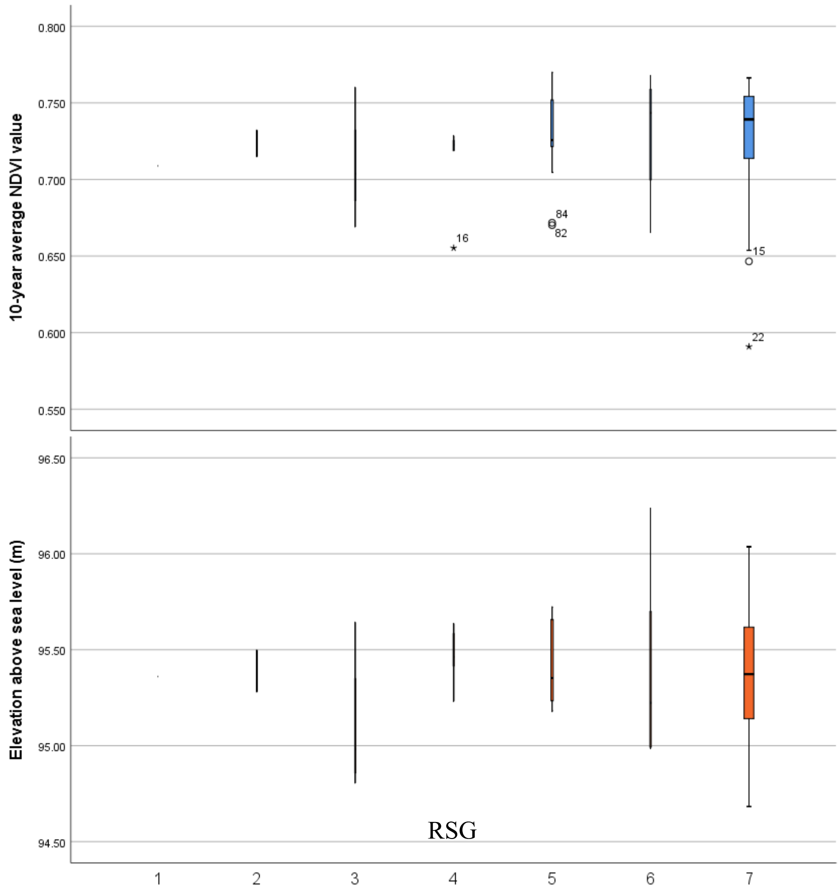

Figure 3
Mean values of NDVI (top) and elevation (bottom) at level 1 of WRB (Reference soil groups). See profile, classification and code list in Table 1

Evaluation of the two classification systems in terms of NDVI and elevation

The highest NDVI values can be attributed to the Chernozem, Kastanozem, and Phaeozem reference groups, but these three reference groups do not differ significantly (*Figure 3*). The NDVI values of the Calcisol and Regosol RSGs were the lowest, however, the latter had only one profile, so the difference could not be interpreted statistically. According to the elevation, the Gleysols are in the lowest and the Kastanozem and Chernozem are separated at the highest position, but the other reference soil groups are not clearly differentiated. The profiles classified according to the RSG therefore do not represent homogeneous and not clearly distinct groups according to either NDVI or elevation. The distribution of NDVI values and the elevation of the RSGs was broadly similar.

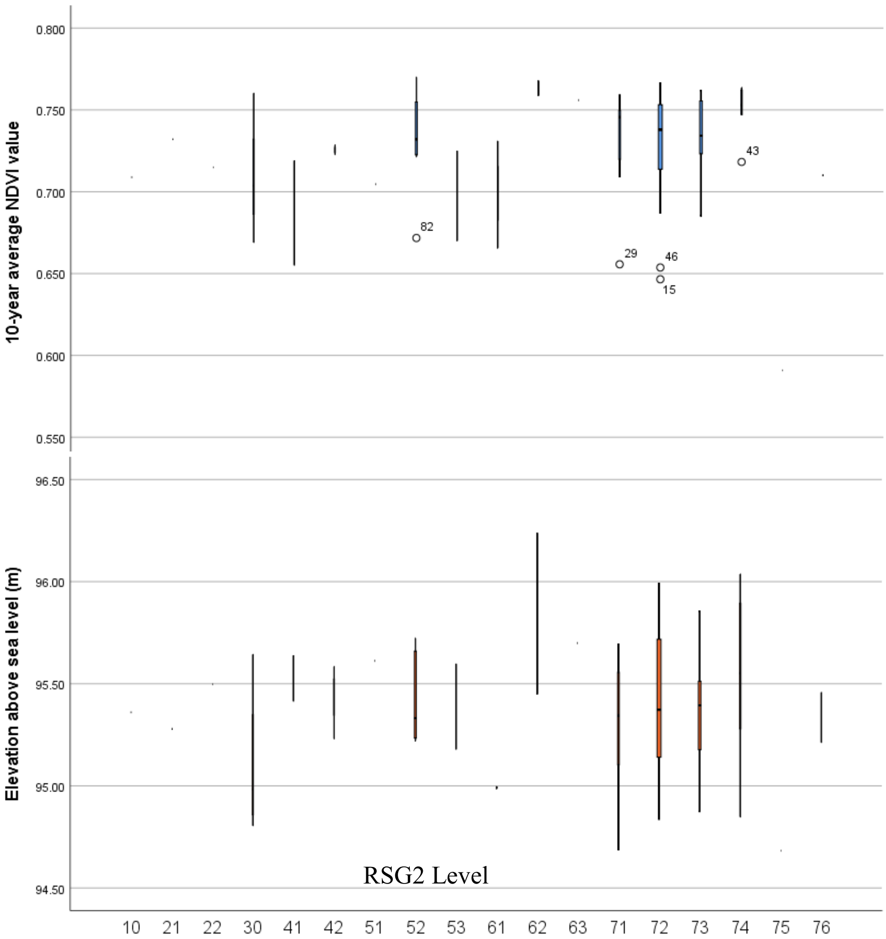

Figure 4
Mean values of NDVI (top) and elevation (bottom) at level 2 of WRB. See profile, classification and code list in Table 1

The highest mean NDVI value was shown by Endocalcic, Amphicalcic and Pantocalcaric grade Chernozems, Kastanozems and Phaeozems, but same classes showed also low NDVI values for some profiles (*Figure 4*). This is a good indication that the homogeneity of classes obtained by a second-level classification of a reference group and a qualifier is low and significantly dispersed according to NDVI. In some cases, the second classification level is well differentiated within the RSG based on NDVI, such as between Amphicalcic and Endocalcic Kastanozems and Chernic and Pantocalcaric Phaeozems. Based on the qualifiers, there is no such distinction in the value of NDVI or elevation inside Chernozems.

The profiles at highest elevations have been classified as Endocalic and Amphicalcic at the second level, and Haplic and Chernic at the lowest elevations, but these properties cannot really be related to their topographic position. The distribution of NDVI values by second level classes is only broadly similar to the distribution of elevation.

In classes containing higher number of profiles, the lowest NDVI values were showed by classes with Alcalic, Gleyic and Protosalic qualifiers based on the second qualifier added at the third level of the classification, almost independently of RSG and first qualifier, which are associated with poorer productivity (*Figure 5*). Third-level qualifiers (Cambic, Endoprotosalic, Endofluvic) do not clearly indicate favourable soil conditions. The homogeneity of the classes is low according to the elevation, and the standard deviation of the elevation values is large even within the third classification level. The added qualifiers of the profiles in lowest elevation at the third level are varied (Endogleyic, Amphigleyic, Endoprotosalic, Katoprotosalic, Katofluvic), but partly refer to the low topographic position; this cannot be stated for the profiles at highest elevation (Cambic, Katofluvic, Amphicalcic). At this level, the distribution of classes by NDVI and elevation showed no similarity. The statistical evaluation of the differences is complicated by the fact that the number of different classes increases remarkable with the level of classification, so the number of single-profile classes increased as well.

In many cases, there were no additional added classifiers at the fourth level, so they are identical with the third level classification (see *Table 1* for details). For the profiles showing highest NDVI values, Cambic is added as a fourth-level qualifier, which cannot be causally related to the higher NDVI value, while the profiles with the lowest NDVI value were classified as Endosalic, Endoprotosalic, or Katoprotosalic at the fourth level (*Figure 6*). Here, low NDVI is associated with salt accumulation in the profile. These profiles are simultaneously located in the lowest topographic position, so the distribution of NDVI and elevation is similar in this relationship, but this is not typical for the other qualifiers added at the fourth level. The heterogeneity of the individual classes and the standard deviation of the values in terms of NDVI and elevation are also typically highest where the fourth level was identical with the third classification level, i.e., no further qualifier could be given.

The NDVI values and elevation values of Chernozem and Meadow main soil types appear to be well separated (significantly different) at the first classification level (*Figure 7*). The NDVI and elevation values for Alluvial soils fall between the two previous groups and are not significantly different. In general, higher elevation values are associated with higher productivity values, presumably because at higher elevations productivity is not inhibited by damaging surplus water. The thickness of the boxplots also clearly shows the relative number of soil profiles belonging to each main soil type, the sample contains mostly Chernozem profiles and few Alluvial soil profiles.

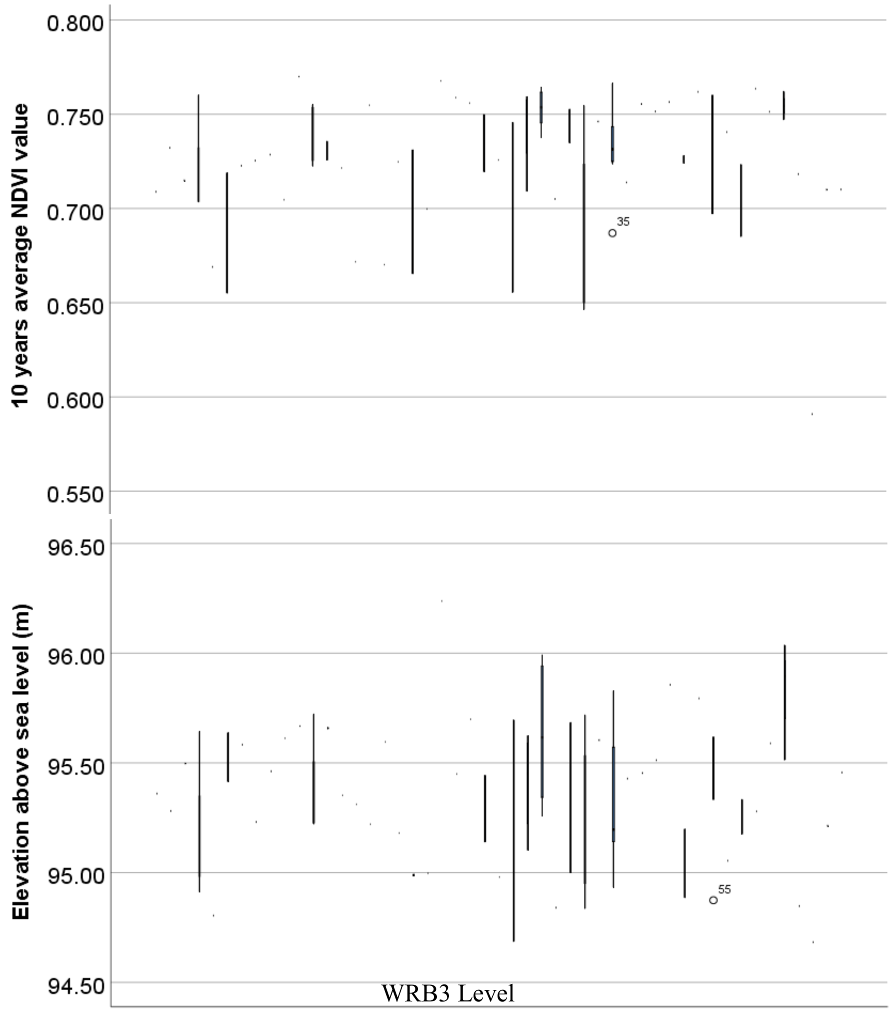

Figure 5
Mean values of NDVI (top) and elevation (bottom) at level 3 of WRB[*]

[*]*Codes and names of the classes shown in the graphs from left to right are the following 100-Amphiprotosalic Endogleyic Regosol, 210-Pantocalcaric Katofluvic Cambisol, 220-Pantocalcaric Cambisol (Endoprotosalic), 300-Amphicalcic Chernic Gleysol, 301-Endocalcic Chernic Gleysol, 410-Haplic Calcisol (Alcalic), 421-Cambic Calcisol (Katofluvic), 422-Cambic Calcisol (Endogleyic), 423-Cambic Calcisol (Protosodic), 510-Amphigleyic Phaezoem (Protosodic), 520-Chernic Phaeozem, 521-Pantocalcaric Chernic Phaeozem, 522-Katofluvic Chernic Phaeozem, 523-Amphifluvic Chernic Phaeozem, 524-Endofluvic Chernic Phaeozem, 525-Amphigleyic Chernic Phaeozem, 530-Pantocalcaric Phaeozem, 531-Pantocalcaric Phaeozem (Alcalic), 610-Endogleyic Amphicalcic Kastanozem, 611-Amphicalcic Kastanozem (Endoprotosalic), 622-Endocalcic Kastanozem (Cambic), 623-Endogleyic Endocalcic*

At the second level of classification (soil types), the basic Chernozem soil type (190) and its transition to Meadow and Alluvial soils (200; 210) are clearly distinguished (*Figure 8*). No significant differences in productivity or elevation are found between them, but the trend for both parameters is 190 > 200 > 210. For types 200 and 210, some NDVI values are very low (many outliers), suggesting effect of other soil problem (e.g. erosion). The elevation values for soil types 190, 200 and 210 showed the widest range. It is interesting that for the type 200 (meadow Chernozem), the lowest elevation is associated with the lowest (outlier) NDVI value. Within the main type of Meadow soils, three types can be distinguished, the basic type of Meadow soil (300) and the transitions towards Chernozem soils (330) and Alluvial soils (310). There is no significant difference between the NDVI values for these classes, but as expected the order is 330 > 310 > 300; where the order of productivity presumably decreases with the adverse effect of surplus water. The difference between the elevation values of each type is more significant, the alluvial Meadow soil (310) shows significantly smaller value, while the Chernozem Meadow soils (330) lie slightly higher than the Meadow soils (300). Overall, NDVI values by soil type generally reflect the productivity-inhibiting adverse effect of surplus water.

The third level shows the distribution of the two parameters according to the soil subtypes (*Figure 9*). Subtype for which we do not see boxplot diagrams also appear here (301), as it only has a single soil profile. Compared to the previous ones, the subtypes provide much additional information, since they also display the salinity effect. In the case of Meadow Chernozem soils, productivity visibly decreases in the direction of salt-affected subtypes (201 > 203 > 204) and the elevation decreases similarly. A similar observation can be made for the subtypes of Chernozem Meadow soils (330), the subtype salty in deeper horizons (333) lies at a lower elevation and is less productive than the subtype free from salt effects (331).

We don't really get any extra information from the level 4 boxplot diagrams, as there are a lot of soil variety with a single soil profile here (*Figure 10*). These soil varieties do not have a boxplot diagram, so the differences in NDVI and elevation between the varieties are not very easily comparable. Wherever this is possible (e.g. 203110 - 203210 or 211200 - 211202), the differences are not very clear either.

Kastanozem, 624-Amphigleyic Epicalcic Kastanozem, 710-Haplic Chernozem, 711-Haplic Chernozem (Pachic), 712-Haplic Chernozem (Katoprotosalic), 713-Haplic Chernozem (Endoprotosalic), 720-Amphicalcic Chernozem, 721-Katofluvic Amphicalcic Chernozem, 722-Endofluvic Amphicalcic Chernozem, 723-Endogleyic Amphicalcic Chernozem, 724-Amphicalcic Chernozem (Alcalic), 725-Amphicalcic Chernozem (Endoprotosalic), 726-Amphigleyic Chernozem (Katoprotosalic), 730-Epicalcic Chernozem, 731-Epicalcic Chernozem (Cambic), 732-Katofluvic Epicalcic Chernozem, 733-Katogleyic Epicalcic Chernozem, 734-Amphigleyic Epicalcic Chernozem, 735-Endogleyic Epicalcic Chernozem, 736-Epicalcic Chernozem (Pachic), 737-Epicalcic Chernozem (Endoprotosalic), 741-Endofluvic Endocalcic Chernozem, 742-Endogleyic Endocalcic Chernozem, 743-Endocalcic Chernozem (Cambic), 744-Endocalcic Chernozem (Pachic), 750-Katocalcic Chernozem, 761-Endogleyic Chernozem (Cambic), 762-Katofluvic Endogleyic Chernozem

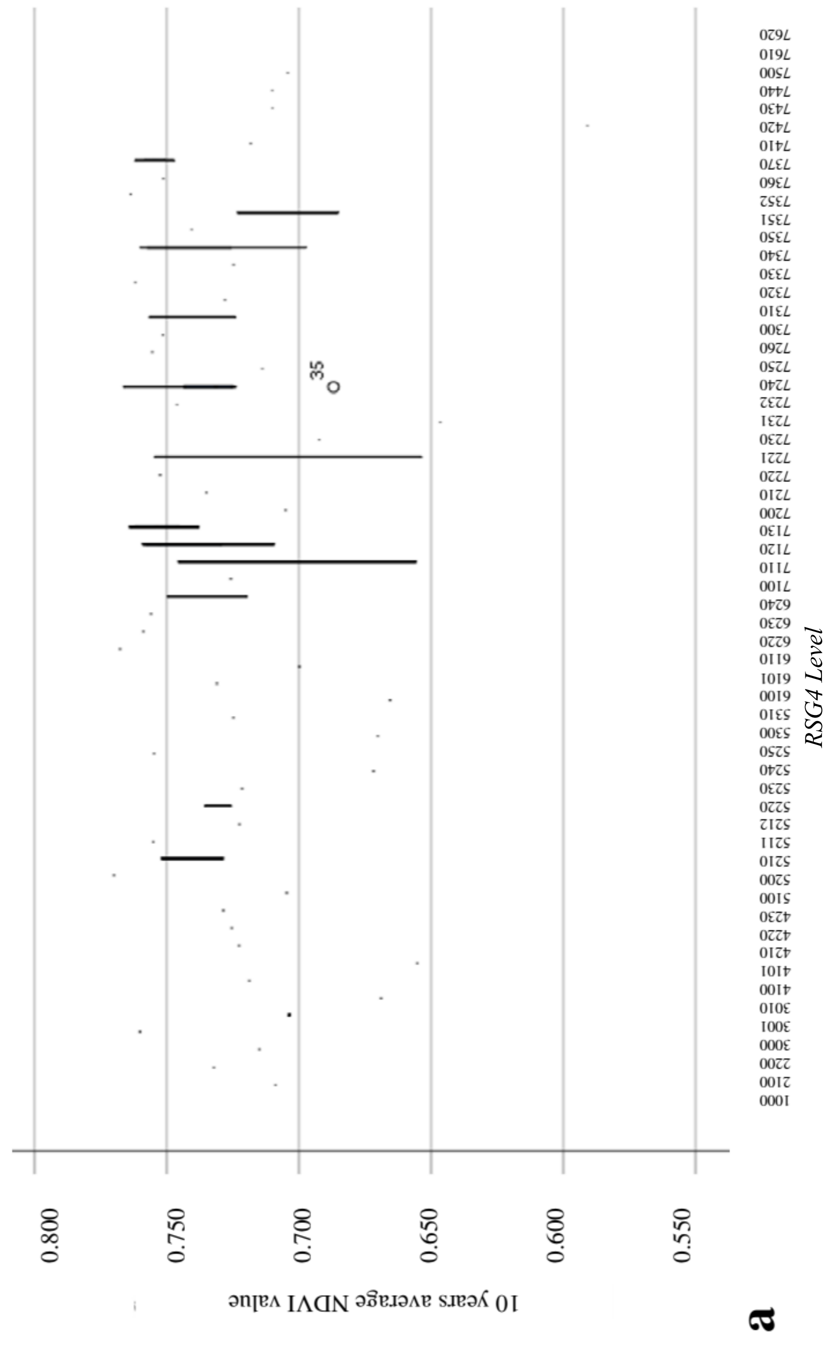

Figure 6
Mean values of NDVI (a) and elevation (b) at level 4 of WRB. See profile, classification and code list in Table 1

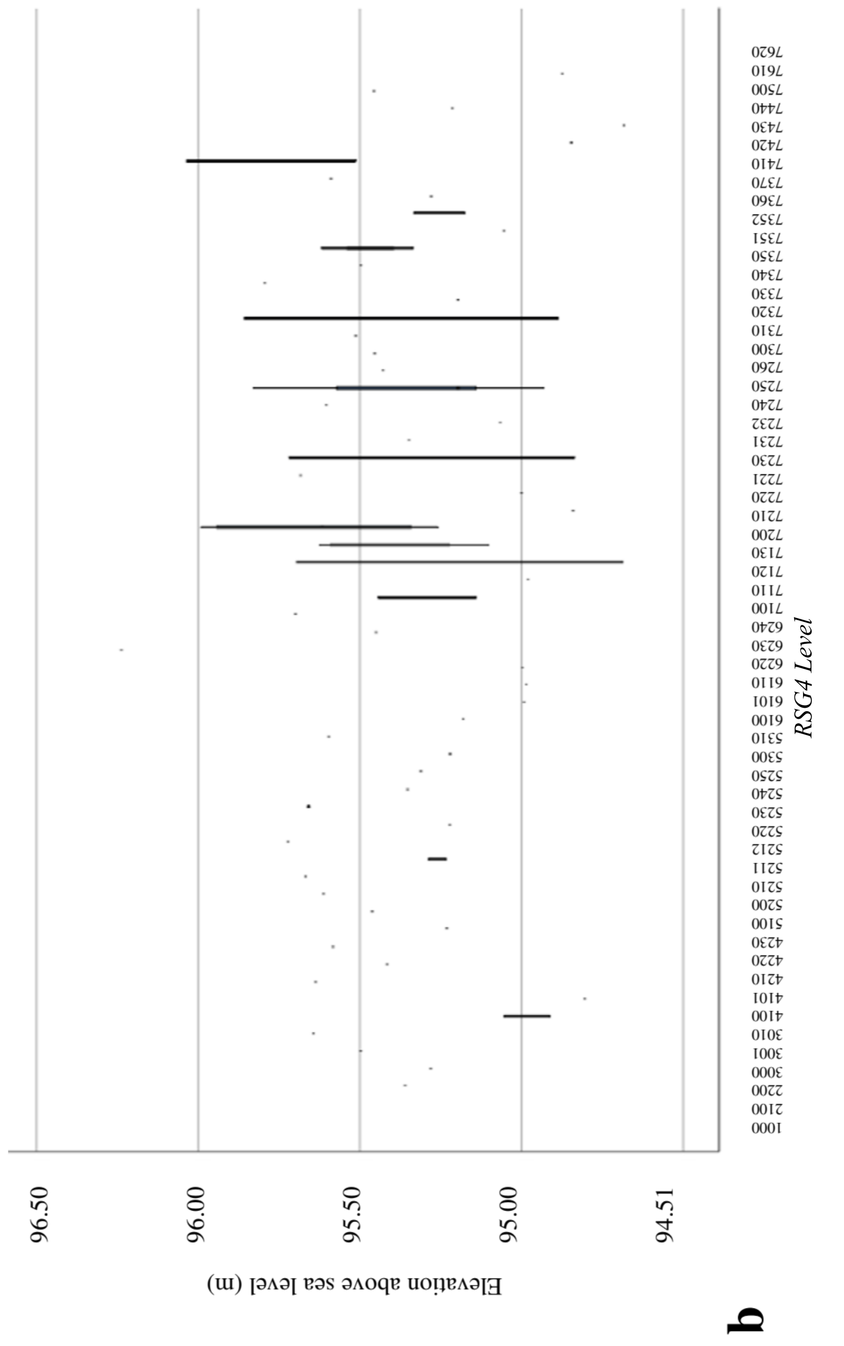

Figure 6 continued

Comparative evaluation of the classification systems

Compared to the ideal case of complete separability (ARNOLD, 2001), only a fraction of the classes was separated (*Figure 11*). At levels 1, 3 and 4, HU demonstrated better differentiation, but differences were not great.

As shown by *Figure 12* the homogeneity of the classes, calculated according to BECKETT & BURROUGH (1971), was greater for WRB, the best at the more detailed levels of 3 and 4. This is explained by the flexibility provided by the large number of principal and supplementary qualifiers. The 1-RV of the WRB was about 2 times higher than the corresponding value of HU (*Figure 12*).

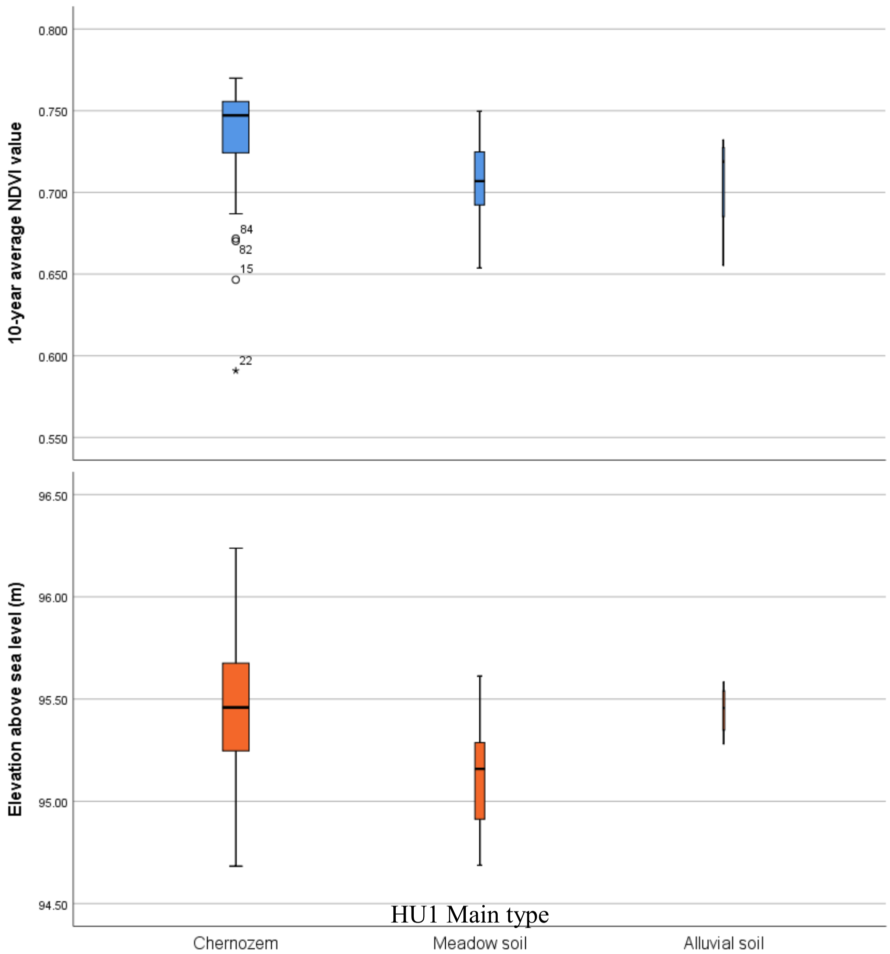

Figure 7
Mean NDVI (top) and elevation (bottom) of Chernozem (n = 59), Meadow (n = 22) and Alluvial soils (n = 4) at the main type level (HU1) of the Hungarian Classification System

WRB1 was separated into two, the WRB3 and the WRB4 to four times as many classes as HU (*Table 3*). The number of HU4 classes significantly increased compared to HU3, and the number of WRB4 classes was twofold of HU4. Statistical evaluation was challenging due to the large number of single-profile classes. HU had 0, 0, 8 and 54% and WRB had 14, 33, 67 and 78% such classes at levels 1, 2, 3 and 4, respectively. At level 4 both systems had a large number of single-profile classes. HU had lower number of single-profile classes, while the WRB was less manageable with higher number. On the other hand *Figure 3* shows that the number of classes with more than one profile showed much less difference.

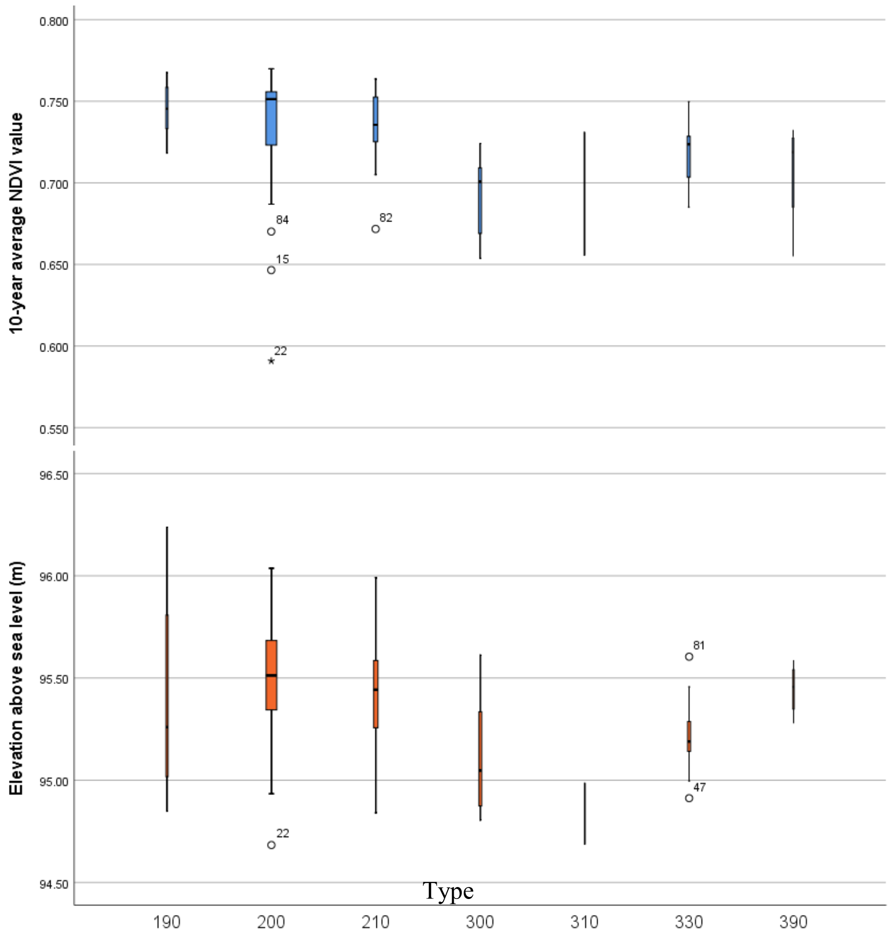

Figure 8
Mean NDVI (top) and elevation (bottom) of the classes of the Hungarian Classification System at level two. See profile, classification and code list in Table 1

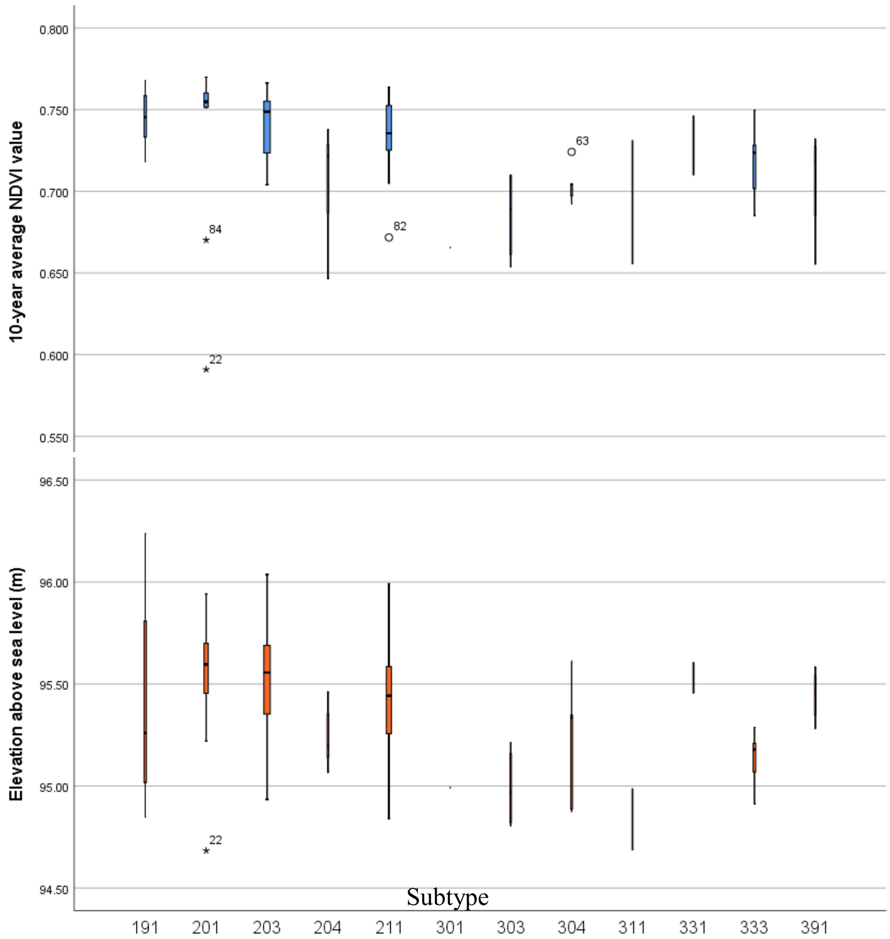

Figure 9
Mean NDVI (top) and elevation (bottom) of the classes of the Hungarian Classification System at level three. See profile, classification and code list in Table 1

Table 3
Pearson correlation coefficient between ten-year average NDVI values and mean elevation of the distinguished classes at four levels. Number of classes is indicated in brackets

Level	WRB classification	HU classification
1	0.388 (7)	0.561 (3)
2	0.763** (18)	0.763* (7)
3	0.574** (49)	0.821** (12)
4	0.562** (59)	0.707** (26)

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Correlation of NDVI values with elevation is shown in *Table 3*. In case of detailed levels HU3 ($r = 0.821^{**}$) and WRB3 ($r = 0.574^{**}$) were found to be suitable for productivity and yield estimation. At level 4, HU also performed better ($r = 0.707^{**}$) than WRB ($r = 0.562^{**}$).

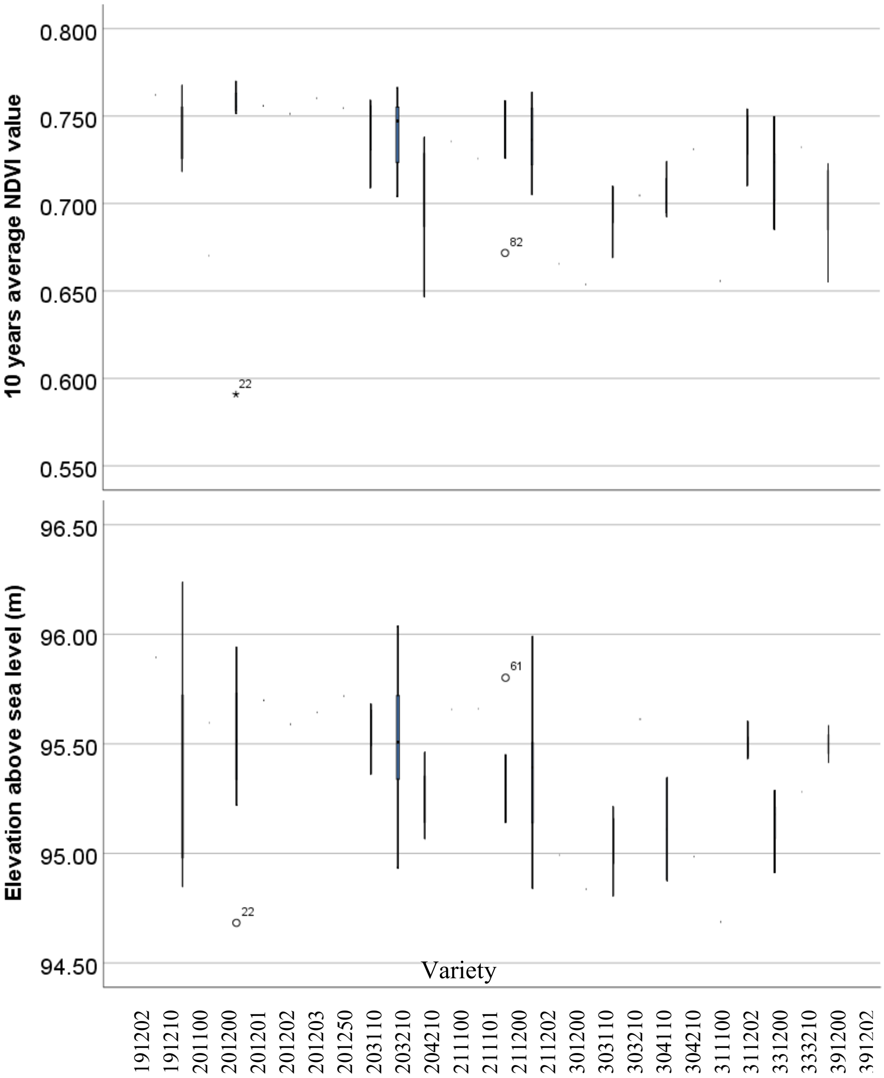

Figure 10
Mean NDVI (top) and elevation (bottom) of the classes of the Hungarian Classification System at level four. See profile, classification and code list in Table 1

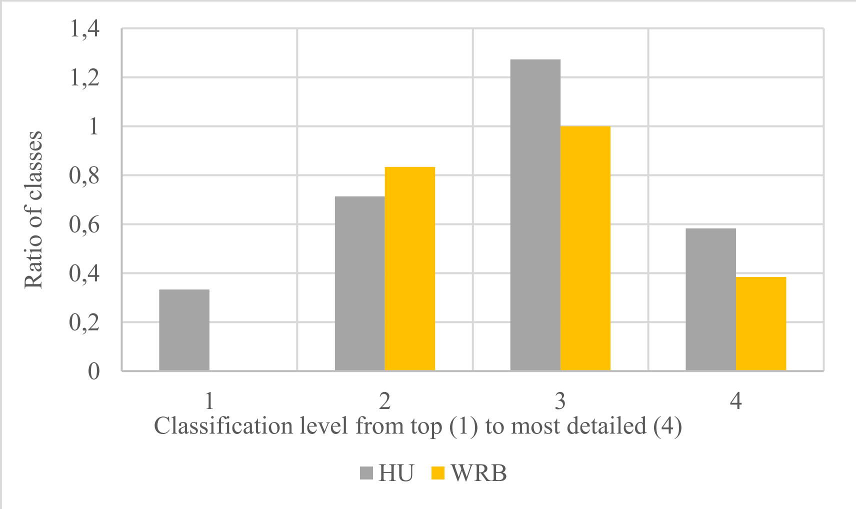

Figure 11
The ratio of significantly different classes compared to the total number of classes at the four levels of Hungarian Classification and World Reference Base

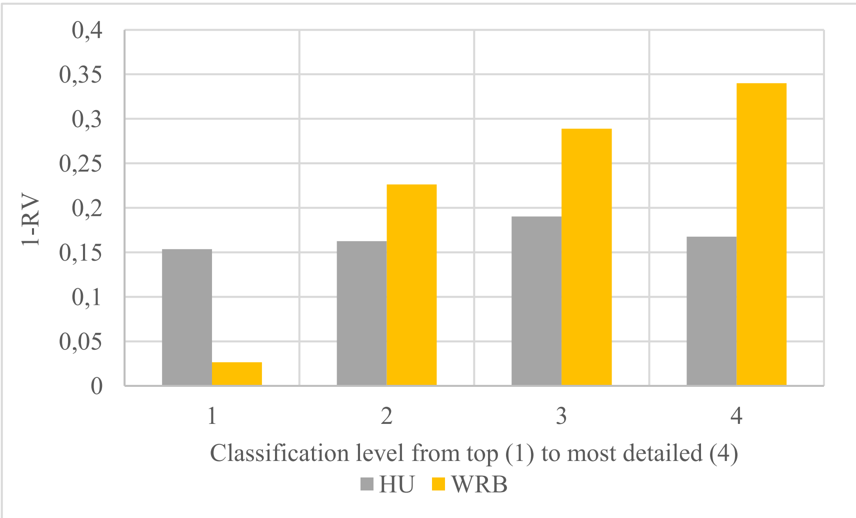

Figure 12
1-RV values (the fraction of within-class variance/total variance) calculated with NDVI for the four levels of Hungarian Classification and World Reference Base

Consistent with the results of SCHULER et al. (2006), the WRB had a greater number of classes (*Table 3, Figure 13*). However, due to the greater number of environmental factors covered, any global classification system is likely to have a greater number of classes than local systems. In HU, the environmental factors are closely related to the specific morphological, sedimentological and climatic conditions of the Pannonian basin, which are reflected in the specific soil development characteristics. These particularities have determined the intensity of soil-forming factors and processes, which is reflected in the local organic matter and $CaCO_3$ accumulation, water balance and leaching. Such pedogenic processes indicate an increase of the thickness of the profile during the Quaternary, when loess deposition and thus the widespread presence of $CaCO_3$ (STEFANOVITS, 1963), together with the alluvial character of the landscape and the ubiquitous shallow water table, significantly influenced the physical and chemical properties of the soils in the area (ARANY, 1956).

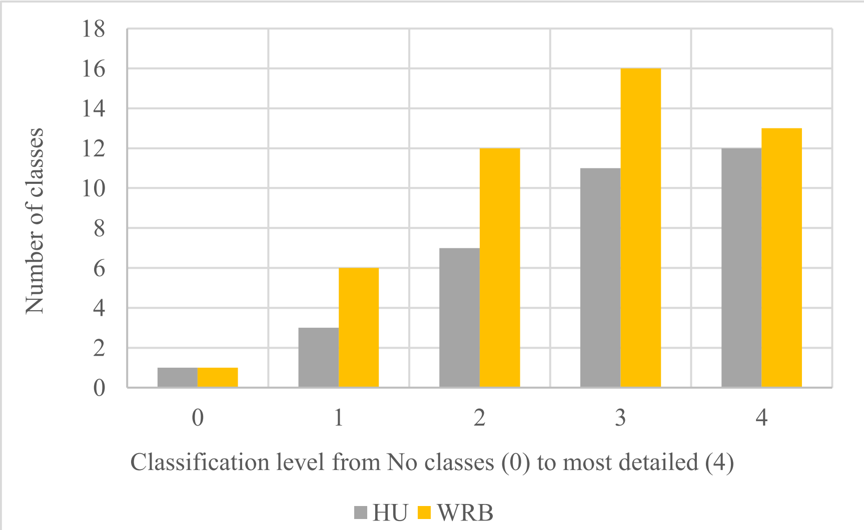

Figure 13
Number of classes with more than one profile at the four levels of Hungarian Classification and World Reference Base

Our results show that none of the classification systems performed excessively poorly or outstandingly when only levels 3 and 4 are considered. An advantage and at the same time a disadvantage of WRB is that it considers many aspects using a large number of physical and chemical parameters (KRASILNIKOV et al., 2009). The good performance of HU may be due to extensive experience with alluvial, floodplain and saline soils. This knowledge was integrated from earlier Hungarian classification systems (TREITZ, 1924, DE SIGMOND, 1927, 1938) into the current soil classification. More details of technical evaluation are provided in TÓTH et al. (2022).

Because transitioning to a new system involves significant changes in all databases, including GIS datasets, which may lead to disputes (BIDLÓ, 2019; MAKÓ, 2019; TÓTH, 2019a, b), such transitions should ideally be preceded by a thorough discussion highlighting the advantages and disadvantages of both the old and new systems in terms of land use management and mapping.

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