APPLICATION OF DIFUSE SPECTRAL REFLECTANCE DATA FOR ASSESSEMENTS OF SOIL PROPERTIES

Cezary Kaźmierowski[1], Jan Piekarczyk[1], Jerzy Cierniewski[1], Krzysztof Kuśnierek[1], Sławomir Królewicz[1], Henryk Terelak[2], Tomasz Stuczyński[2] and Barbara Maliszewska-Kordybach[2]

1) Department of Soil Science and Remote Sensing of Soils, A. Mickiewicz University in Poznań, Dzięgielowa 27, 61-680 Poznań; *2)* Institute of Soil Science and Plant Cultivation – State Research Institute, Czartoryskich 8, 24-100 Puławy, Poland

*Corresponding author (email: cezark@amu.edu.pl; tel: +48 618296233; fax: +48 618296230)

Introduction

Contemporary environmental studies, including soil testing, is becoming more and more quantitative and thus requires implementation of numerous expensive and time-consuming tests. Financial and time limitations induce the development of new methods for indirect determination of various soil properties. Visible and near infrared (VNIR) diffuse reflectance spectroscopy (DRS) has proven to be a rapid and effective method of providing reliable data for soil monitoring, digital soil mapping, environmental modeling, and precision agriculture. Comprehensive lists of published investigations on DRS of soil properties have been presented recently. The presented study wase performed to investigate the possibility of application of DRS measurements in monitoring of arable soils chemistry.

Materials and Methods

During the program “Monitoring of Chemistry of Arable Soils”, in 2005, 212 soil samples from the surface layer (0 - 20 cm) were acquired from throughout the area of arable lands in Poland, covering approximately 140000 km^2. In these samples the following characistics were determined: textural composition (8 fractions); contents of organic carbon (Corg) and organic matter (OM), total nitrogen (N-Kjeldahl), carbonates; plants available forms of phosphorus (P_2O_5), potassium (K_2O), magnesium (MgO)and sulfur ($S\text{-}SO_4$); polycyclic aromatic hydrocarbons (PAHs); “total” forms of S, P, Na, K, Ca, Mg, Fe, Al., Mn, Cu, Ni, Cr, Zn, Cd, Co, Pb, Ba, Be, La, Li, Sr. exchangeable forms of Ca, Mg, K, Na, hydrolytic and exchangeable acidity (Hh, Hw), cation exchange capacity (CEC), sum of bases (TEB), degree of base saturation (BS) and C:N, ratio were calculated. Electrical conductivity (EC), soil salinity, radioactivit and pH (in water and KCL) were also mesured. All analysis were conducted in laboratories of the Institute of Soil Science and Plant Cultivation in Puławy.

Reflectance *r* of soil samples was measured in five replications at the wavelength range from 350 nm to 2500 nm, at 1-nm intervals, using a FieldSpec®Pro spectroradiometer (Analytical Spectral Devices, Inc., Boulder, CO, USA) with the attached Source Probe Mug-Lite®. DSR data were generalized into 10-nm intervals and transformed into root of *r*, 1/*r*, absorbance, first and second derivative of *r*, Kubelka Munk units and its derivative and continuum removal values. Correlation between reflectance and soil properties were calculated for the total dataset and for the clusters obtained by unsupervised Ward hierarchical algorithm based on Euclidian distance (StatistiXL - Nedlands, Australia).

Results

Spectral curvers of 212 soil samples and clusterin results are presented in figure 1.Coefficient of determination between DSR and soil properties obtained on total dataset were lower then values for clustered data (Tab. 1). Only total forms of Ca and Sr can be estimated from spectral data without clustering. After clustering of entire dataset the strongest relationships were observed between reflectance data and soil total concentration of Zn, Ni, Cu, Ba, Be, Li, Co, Cr, Mn, Fe, Al, K, Mg, S, exchangable cations (TEB and CEC), radioactivity and contents of Corg, N-kjel., $CaCO_3$, clay and sand fraction,

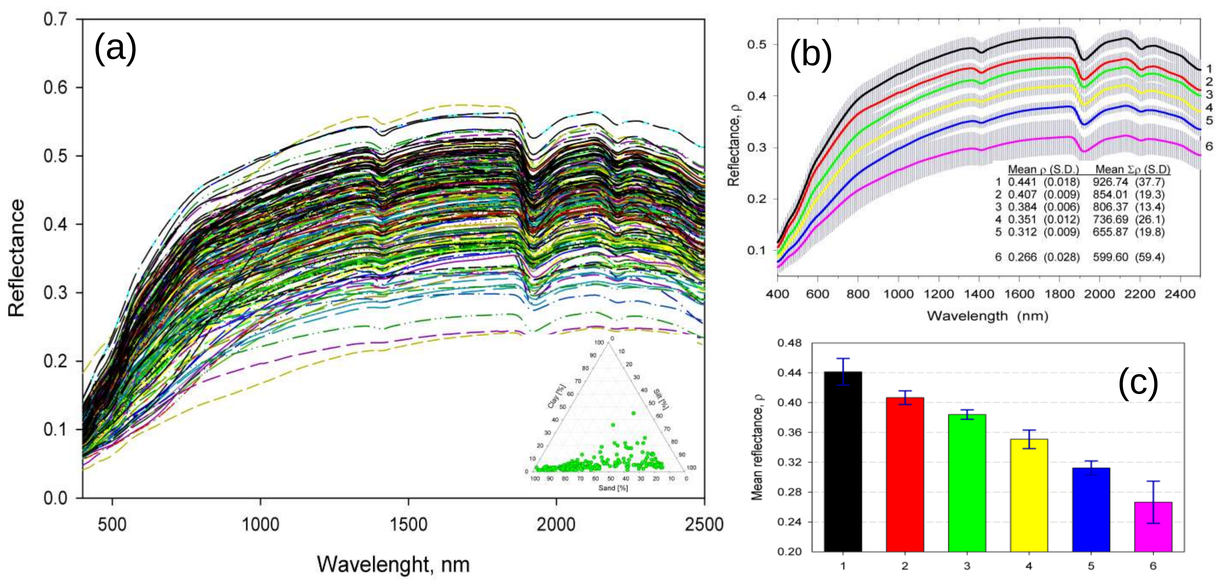

Fig. 1. Spectra of 212 soil samples of arable fileds in Poland (a), mean spectra and its standard deviation for six clusters obatined by Ward algorithm (b) and the diferences of mean clusters spectra (c).

Table 1. Mean and maximum coefficient of determination between DSR transformation and soil properties on the total dataset and clusters

	Forms*	Units	Mean R^2 on total data	Maximum R^2 on total data	Mean R^2 in culusters 1	2	3	4	5	6	Average clusters means R^2	Average clusters max R^2	Prediction posibility using DSR **
OM	ORG.	%	**0.048**	0.193	0.155	0.066	0.250	0.113	**0.083**	**0.080**	0.155	0.464	–
C:N		–	0.017	0.069	0.012	0.054	0.054	0.036	0.046	**0.166**	0.012	0.245	–
P	TC	%	0.030	0.147	0.091	0.076	0.106	0.069	0.078	0.203	0.091	0.383	–
$P\text{-}P_2O_5$	P.A.	mg P_2O_5 $100g^{-1}$	0.015	0.054	0.021	0.021	0.025	0.033	0.050	0.020	0.021	0.283	–
$S\text{-}SO_4$	P.A.	mg SO_4 $100g^{-1}$	0.008	0.052	0.064	0.033	0.048	**0.046**	0.007	0.112	0.064	0.229	–
$K\text{-}K_2O$	P.A.	mg K_2O $100g^{-1}$	0.030	0.184	0.039	0.023	0.086	0.124	0.106	**0.098**	0.039	0.363	–
Salinity		mg KCl $100g^{-1}$	0.034	0.155	0.043	0.086	0.052	0.070	0.119	0.101	0.043	0.383	–
EC		mS m^{-1}	0.034	0.156	0.043	0.083	0.053	0.071	0.119	0.102	0.043	0.384	–
pH H2O		–	0.029	0.156	**0.097**	0.070	0.053	0.051	0.060	0.187	0.097	0.401	–
pH KCL		–	**0.030**	0.144	0.087	0.064	0.044	0.038	0.076	0.177	0.087	0.393	–
Hh	EXCH.	mmol(+) kg^{-1}	0.033	0.171	0.095	0.040	0.036	0.035	0.118	0.177	0.095	0.387	–
K	EXCH.	mmol(+) kg^{-1}	0.047	0.266	0.090	0.050	0.114	0.113	0.113	**0.108**	0.090	0.415	–
Cd	T.C.	mg kg^{-1}	0.034	0.072	0.031	0.029	0.085	0.070	0.038	0.106	0.031	0.418	–
Pb	T.C.	mg kg^{-1}	0.152	0.178	0.015	**0.039**	0.044	0.163	0.059	0.332	0.015	0.352	–
PAHs-13	T.C.	µg $100g^{-1}$	0.075	0.122	0.064	0.025	0.048	0.059	0.031	0.135	0.064	0.308	–
PAHs-9	T.C.	µg $100g^{-1}$	0.080	0.128	0.065	0.026	0.048	0.057	0.030	0.133	0.065	0.308	–
Na	EXCH.	mmol(+) kg -1	0.086	0.265	0.134	0.148	0.244	0.057	0.183	0.088	0.134	0.487	– / (SCDS)
BS		%	0.073	0.303	0.098	0.112	**0.129**	0.138	0.161	0.110	0.098	0.488	– / (SCDS)
La	T.C.	mg kg^{-1}	0.179	0.359	0.054	0.095	**0.182**	0.146	0.084	**0.117**	0.054	0.479	– / (SCDS)
Na	T.C.	mg kg^{-1}	0.039	0.531	0.197	0.163	**0.166**	0.045	0.048	0.079	0.197	0.480	– / (SCDS)
Sand		%	0.287	0.491	0.098	0.088	**0.225**	**0.156**	0.130	**0.166**	0.098	0.544	+, SCDS
Silt		%	0.305	0.411	0.064	0.037	0.252	**0.142**	0.091	**0.169**	0.064	0.478	+, SCDS
Clay		%	0.173	0.620	0.202	0.342	0.213	0.260	**0.243**	0.191	0.202	**0.748**	+, SCDS
C	ORG.	%	**0.055**	0.228	0.155	0.032	0.263	0.113	0.106	**0.069**	0.155	0.493	+, SCDS
N - Kjel.		%	0.066	0.291	0.172	0.116	0.204	0.157	0.124	0.117	0.172	0.544	+, SCDS
$CaCO_3$		%	0.139	0.966	0.734	0.780	0.645	1.000	0.360	0.518	0.734	**0.991**	+, SCDS
Hw	EXCH.	mmol(+) kg^{-1}	0.031	0.256	0.122	**0.242**	0.125	0.044	0.141	0.189	0.122	**0.647**	+, SCDS
Al.	EXCH.	mmol(+) kg^{-1}	0.026	0.272	0.136	**0.235**	0.114	**0.049**	0.138	0.202	0.136	**0.663**	+, SCDS
Ca	EXCH.	mmol(+) kg^{-1}	0.106	0.418	0.241	0.246	**0.210**	0.153	**0.290**	0.125	0.241	**0.636**	+, SCDS
Mg	EXCH.	mmol(+) kg^{-1}	0.125	0.515	0.174	0.300	**0.191**	0.214	0.181	0.158	0.174	**0.657**	+, SCDS
TEB	EXCH.	mmol(+) kg^{-1}	0.112	0.450	0.239	0.251	**0.225**	0.164	**0.286**	0.134	0.239	**0.655**	+, SCDS
CEC	EXCH.	mmol(+) kg^{-1}	0.117	0.467	0.250	0.274	**0.237**	0.187	**0.280**	0.127	0.250	**0.667**	+, SCDS
Mg-MgO	P.A.	mg MgO $100g^{-1}$	0.096	0.378	0.095	0.244	**0.139**	0.063	0.213	0.204	0.095	0.545	+, SCDS
S	T.C.	%	0.048	0.228	0.199	0.063	**0.156**	0.092	0.122	**0.148**	0.199	0.521	+, SCDS
Al.	T.C.	%	0.159	0.561	0.218	0.221	**0.185**	0.167	**0.197**	0.140	0.218	**0.674**	+, SCDS
Fe	T.C.	%	0.169	0.559	0.237	0.262	**0.278**	0.196	**0.128**	0.175	0.237	**0.694**	+, SCDS
Zn	T.C.	mg kg^{-1}	0.033	0.073	0.097	0.128	**0.170**	0.087	0.037	0.108	0.097	0.510	+, SCDS
Mn	T.C.	mg kg^{-1}	0.099	0.337	0.116	0.142	0.104	0.184	0.112	0.229	0.116	0.523	+, SCDS
Cu	T.C.	mg kg^{-1}	0.021	0.090	0.035	0.199	0.185	0.097	0.061	0.177	0.035	0.561	+, SCDS
Ba	T.C.	mg kg^{-1}	0.103	0.443	0.128	**0.216**	**0.180**	0.203	0.125	0.193	0.128	0.588	+, SCDS
Be	T.C.	mg kg^{-1}	0.167	0.572	0.187	**0.268**	**0.269**	0.231	0.163	0.133	0.187	**0.668**	+, SCDS
V	T.C.	mg kg^{-1}	0.156	0.556	0.176	0.260	**0.236**	0.225	0.151	**0.158**	0.176	**0.679**	+, SCDS
Co	T.C.	mg kg^{-1}	0.135	0.469	0.182	0.148	**0.236**	0.132	0.168	0.296	0.182	**0.707**	+, SCDS
K	T.C.	mg kg^{-1}	0.137	0.643	0.214	0.241	**0.235**	0.226	**0.211**	0.150	0.214	**0.707**	+, SCDS
Li	T.C.	mg kg^{-1}	0.144	0.587	0.205	0.241	0.234	0.156	0.094	**0.136**	0.205	**0.710**	+, SCDS
Cr	T.C.	mg kg^{-1}	0.177	0.607	0.238	0.225	**0.284**	0.212	**0.160**	**0.160**	0.238	**0.725**	+, SCDS
Mg	T.C.	mg kg^{-1}	0.116	0.477	0.217	0.247	0.245	0.222	**0.190**	0.097	0.217	**0.732**	+, SCDS
Ni	T.C.	mg kg^{-1}	0.153	0.569	0.233	0.169	0.228	0.245	0.159	0.172	0.233	**0.761**	+, SCDS
Radioactivity		Bq kg^{-1}	0.161	0.421	0.153	0.139	**0.225**	0.119	0.059	**0.106**	0.153	0.537	+, SCDS
Ca	T.C.	mg kg^{-1}	0.053	**0.945**	0.190	0.210	**0.208**	0.093	**0.198**	0.103	0.190	0.652	+, TDS
Sr	T.C.	mg kg^{-1}	0.054	**0.844**	0.195	0.116	**0.178**	0.113	**0.132**	0.169	0.195	0.651	+, TDS

Transformation codes: Raw | 1dLog(1/R | 1dR | 2dR | KM | 1dKM | CR | SI

*Forms of expresion: T.C. - total concentration, P.A. - plant available form, EXCH - exchenchable cations, ORG - organic,
**SCDS - spectraly clustered dataset, TDS - total dataset

Soil reflectance data can not be used to predict soil reaction; C:N ratio; P_2O_5, K_2O and $S\text{-}SO_4$, Hh and BS; salinity and EC; “total” forms P, Cd, Pb, La and Na exchengeble K and PAHs. The most useful mathematical transformation of spectral data for modeling soil properties were second derivative of raw data, first derivatives of absorbance and Kubelka-Munk unit and continuum removal. However, non of these transformation can be concerned as “universal”. Therefore, the more effective method of soil properties assessment is clustering of a spectral soil library into groups according to spectral characteristics [7] and development of regression models (e.g. partial least squares methods) and various transformations of spectral data.

Conclusion

The results of analisys confirm the relationship between DSR data and various soil chemicakl properties, what make possible use thise techniques for lowerig cost and sawing time in soil monitoring.

The unsupervised clustering of spectral dataset into spectrally similar subsets has a potential to increase the usfulness of DRS data for the estimation of soil chemical properties. Besides unsupervised clustering, for these purposes various mathematical transformation of row data should be implemented. Beacuse, no one of available transformation is advantageous and in particular groups of soils (clusters) specific soil properties should be determined on the basis of different transftormation of spectral data.