Estimation of Soil Physico-chemical Properties by On-the-go Measurement of Soil Electrical Conductivity

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Summary

For modern crop management practices, like precision farming, is crucial information about detailed spatial distribution of soil properties. A study was conducted to evaluate the on-the-go measurement of soil electrical conductivity for mapping of agronomical relevant soil properties. The experimental work was carried out on the eight fields of Rostenice a.s. farm enterprise, located in the South Moravia region of Czech Republic. The measurement of apparent electrical conductivity of soil was done by using CMD-1 and CMD-6L instruments (GF Instruments, Czech Republic) in 2013 (117 ha) and 2016 (359 ha). Soil properties were obtained by soil sampling in irregular grid with the density of 1 sample per 3 ha. Soil samples were taken from the depth of 30 cm and analyzed for soil texture (percentage of clay, silt and sand particles), content of available nutrients (P, K, Mg, Ca) and soil organic matter (SOM) content.

The results of correlation analysis showed differences in main sensitivity of EMI to the soil properties across observed fields. Most frequent correlation was found in the percentage of clay particles smaller than 0.002 mm (r = 0.598). The correlation between EMI and nutrients content in soil and pH value was significant only for few fields. These results were obtained for individual fields, the aggregated evaluation showed lower relationships to EC. These outcomes showed, that rather than predictor of soil properties could be on-the-go measurement of soil EC used for identification of main zones within the fields at high spatial level.

Key words

digital soil mapping, precision agriculture, soil properties, electromagnetic induction

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Introduction

Measurements of apparent soil electrical conductivity (EC) are used for the assessment of soil heterogeneity since the late 1970s (Doolittle and Brevik, 2014). In the beginning, it was applied for identification of soil salinity, later became a method for mapping of soil variability in site specific crop management (Corwin and Lesch, 2005a).

According to Godwin and Miller (2003), the measurement of soil electrical conductivity is a cost-effective method complementing traditional soil survey, which provides rapid and non-invasive information on soil texture variability and available soil moisture. The most important factors acting on EC include the content of soluble salts in soil solution, relative moisture, soil water content and bulk density (Corwin and Lesch, 2005a). The influence of these factors can be found in most of the studies cited here, but their significance is different with regard to specific site conditions. In agricultural areas where soil salinization is not a significant factor, EC measurements are mainly influenced by the soil moisture and soil texture (Godwin and Miller, 2003). Finding the dominant soil characteristics on each plot is necessary for correct interpretation of EC maps (Corwin and Lesch, 2003; Brevik *et al.*, 2006). In addition, the knowledge of the most important factors influencing the spatial variability of crop yield or production quality is required for utilization of EC in site specific crop management (Corwin and Lesch, 2005b).

The advantage of the EC measurement is the vertical penetration of the electromagnetic or electric signal within the soil, and thus obtaining information of the soil profile. The result of the EC measurement is also not affected by the vegetation cover or crop residues (Brevik *et al.*, 2003), which makes it possible to carried out measurement on bare soil or under vegetation cover.

The aim of this study was to evaluate the relationship between selected soil physico-chemical properties and soil EC measured by electromagnetic induction (on-the-go methode).

Material and methods

The experimental was carried out on the selected fields located in the South Moravia region of Czech Republic (49° 05' N, 16° 50' E). Observed fields are listed in Table 1 and total examined area was 476 ha. Predominant soil type within the fields was identified from online available soil maps of the Czech Republic (Research Institute for Soil and Water Conservation, 2017) as Chernozem, Cambisol, haplic Luvisol and occasionally also Calcic Leptosols.

Soil sampling

Soil properties were obtained by soil sampling in irregular grid with the density of 1 sample per 3 ha. For the field 5601/4 the higher sampling density of 2 samples per ha was used for comparison of various sampling designs (not included in this study). Soil samples were taken from the depth of 30 cm by using Duoprob60 automatic sampler (Nietfeld, Germany) (Figure 1). The position of each sampling point was localized with Trimble Pathfinder ProXH DGPS reaching submeter accuracy. Each sample is composed from five sampling cores taken in the perimeter of 15-20 m. Soil samples were analyzed in laboratory according to the Czech valid methodology (Zbíral, 2002): for soil pH value (pH_{CaCl2}), content of available nutrients (P, K, Mg, Ca) by Mehlich 3 method (Zbiral and Nemec, 2000), and soil organic matter content (SOM) by modified Tjurin method. Also, percentage of clay (soil particles < 0.002 mm), silt (0.002 – 0.05) and sand (>0.25 mm) were estimated by sedimentation method (Zbíral, 2002).

Mapping of soil electrical conductivity

The measurement of apparent electrical conductivity of soil was done by using CMD-1 instrument (GF Instruments, Czech Republic) in 2013 (117 ha) and 2016 (334 ha) in the period without crop cover of soil (after harvest in summer or before sowing in autumn and spring). This device measures the electrical conductivity by the principle of electromagnetic induction (EMI) with 0.98 m dipole center distance and effective depth of measurement of 1.5 m (vertical mode) or 0.75 m (horizontal). The instrument was mounted on the plastic sledge in horizontal mode and drawn by car in 20 - 25 m track-lines. For this study, only the layer corresponding by the depth with CMD-1 was analysed (0.8 m in horizontal, 1.6 m in vertical mode). Measured values were recorded in 1 – 2 sec intervals together with geolocation by Trimble CFX 750 DGPS with submeter accuracy and later processed by ESRI ArcGIS software. As the output dataset, raster layer with spatial resolution of 5 m per pixel was created by using spatial interpolation (ordinary kriging). The parametrization of semivariograms was carried out for each field separately as well as the choice of semivariogram model. Results of semivariogram parameters, such as range, model type and prediction error (root mean square error - RMSE), are written for each field in Table 1.

Figure 1. Measurement of soil EC by CMD-6L device (left) and soil sampling with Duoprob 60 device

Results and discussion

The general information about observed fields and overview of EC measurement are shown in Table 1. Besides the basic information about the recorded EC values, also year/month of the measurement, used instruments and statistical characteristics of EC for individual fields are reported. Different ranges of EC values between the fields may also correspond to the date of measurement (spring, summer or autumn period) and actual soil moisture levels. Recent studies have shown that results of repeated measurements under different moisture vary, but the spatial distribution within the field does not change significantly (Serrano *et al.*, 2013; Lukas *et al.*, 2009).

The variability of the EC measured values, evaluated by the coefficient of variability (CV), ranged from 13.67 to 34.41 %. Resulted maps of EC values are depicted in Figure 2. Values of CV and basic statistical data of soil sampling results are given in Table 2. Generally, the lowest variability was observed at soil pH, on the contrary, the highest of Mg content in soil. Between each plot, the

Table 1. Summary of EC measurement on observed fields and basic statistical characteristics, incl. variogram parameters (range, variogram model and prediction error - RMSE)

Field	2301/15	2401/10	2401/12	2401/9a	2401/9b	3411	5301/4	5601/4
Area (ha)	65.82	70.79	46.05	96.08	62.87	34.49	62.34	37.79
Elev. (m a.s.l.)	217 - 256	211 - 278	214 - 262	207 - 260	199 - 241	262 - 304	202 - 226	236 - 268
EC Year/Month	2016/04	2013/10	2013/10	2016/09	2016/04	2016/04	2016/04	2016/09
EC Inst.	CMD6L	CMD1	CMD1	CMD1	CMD6L	CMD6L	CMD6L	CMD1
EC Avg. (mS.m-1)	49.65	75.32	53.17	68.45	25.28	45.02	32.24	46.36
EC Min.(mS.m-1)	26.01	40.35	27.74	32.12	10.56	21.88	19.06	15.99
EC Max. (mS.m-1)	117.62	131.74	97.00	130.58	94.50	107.56	60.13	111.69
EC CV (%)	30.14	18.82	21.69	13.67	19.99	30.19	15.38	34.41
Range (m)	456	687	151	308	320	143	480	138
Model type	sph	exp	sph	exp	sph	exp	sph	exp
RMSE (mS.m-1)	2.86	5.39	3.28	5.01	0.06	0.05	2.45	5.91
EC Pt.	7911	1896	2596	1305	4029	8141	3615	6439

Elev. – elevation; Inst. – measurement instrument used in the study; CV – coefficient of variability; Pt – number of records per field; sph/exp – spherical/exponential variogram model

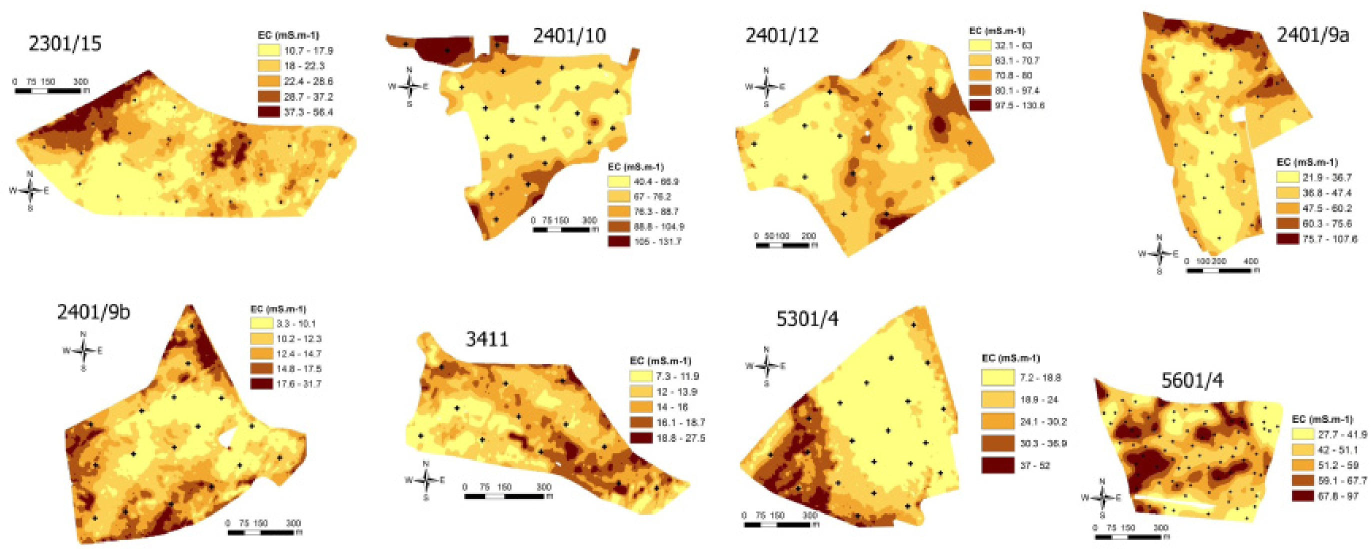

Figure 2. Maps of soil EC after spatial interpolation. Black crosses represent soil sampling points

CV varies significantly depending on soil characteristics. Values of coefficient of variability varied among fields based on the soil characteristics.

The results from soil sampling were compared with the measured EC values by correlation analysis (Table 3). For soil texture classes, medium level of correlation was found to the content of clay particles (positive, significant for five fields), partly also for the content of silt (significant for two fields) and sand (one field), both negative. The content of clay particles is among the most important factors influencing the electrical conductivity of soil (Corwin and Lesch, 2005a). Soil texture is the main factor affecting water availability for plants, so the knowledge of soil texture variability is crucial for precision farming (Godwin and Miller, 2003). Domsch and Giebel (2004) describe the possibility of estimation clay percentage in soil according to the regression analysis and classified soil texture based on the EC. Lower EC values are typical for light soils, higher values for heavy soil (Schmidhalter *et al.*, 2002).

An important factor influencing the electrical conductivity values is also the content of organic matter (Tarr *et al.*, 2005; Morari *et al.*, 2009). However, the significant correlation was found only for plots 5601/4 (r = 0.589) and 2401/12 (r = 0.356). Both fields also proved highest CV of SOM (27.95 % and 29.10 %).

From agrochemical properties, the positive correlation was found for content of K (3 of 8 plots) and Mg (in 2 plots). There was not identified statistically significant correlation with EC for soil pH or content of P. Heiniger et al. (2003) comment that differences in soil texture affect EC values more than small differences in nutrient content. Their study has shown that strong relationship to nutrient content in soil can only be expected in the cases when the nutrient content is associated with one of the four soil characteristics that influence the electrical conductivity of the soil – soil moisture, texture, cation exchange capacity and salt content in soil solution.

Table 2. Basic statistical characteristics of soil sampling results

Soil	Stat	2301/15	2401/10	2401/12	2401/9a	2401/9b	3411	5301/4	5601/4
n		21	23	21	15	17	37	12	78
pH	Avg.	7.24	6.95	7.34	7.31	7.04	7.36	7.38	7.28
	Min.	6.95	5.96	7.14	6.68	5.83	6.32	7.14	6.98
	Max.	7.62	7.40	7.49	7.47	7.49	7.72	7.53	7.48
	CV (%)	3.15	4.43	1.91	2.71	5.55	4.68	1.85	2.17
P (mg.kg-1)	Avg.	32	44	54	37	31	43	51	35
	Min.	20	29	20	25	20	20	30	20
	Max.	47	63	138	49	56	128	118	71
	CV (%)	24.31	24.52	40.80	20.23	32.51	50.79	40.25	37.98
K (mg.kg-1)	Avg.	217	301	239	254	192	254	177	224
	Min.	169	176	107	197	123	164	110	136
	Max.	249	431	416	368	292	466	240	481
	CV (%)	11.56	24.26	25.56	17.63	28.58	22.98	19.92	37.73
Ca (mg.kg-1)	Avg.	292	424	308	422	266	278	247	289
	Min.	242	229	177	249	188	139	214	148
	Max.	418	866	911	704	370	501	300	523
	CV (%)	17.12	37.05	38.13	27.68	17.13	25.80	9.59	30.26
Mg (mg.kg-1)	Avg.	10508	8062	11321	6691	7420	7259	7431	6817
	Min.	6470	4390	3190	4400	5750	2020	6250	4400
	Max.	21300	19600	40200	9140	9340	35400	9040	8930
	CV (%)	39.02	40.10	83.60	18.96	14.22	69.71	10.57	21.00
SOM (%)	Avg.	1.57	2.00	1.93	1.38	1.34	1.63	1.47	1.58
	Min.	1.13	1.41	0.33	0.88	0.69	1.18	0.95	0.52
	Max.	2.59	2.51	3.40	1.86	1.97	2.22	1.97	2.19
	CV (%)	25.32	15.75	29.10	20.00	24.92	14.78	20.45	27.95
Clay (%)	Avg.	22.46	22.42	25.78	21.05	30.53	22.50	32.76	30.67
	Min.	9.14	14.80	17.40	14.40	23.30	11.10	25.20	12.00
	Max.	27.90	29.70	36.10	24.60	42.60	32.50	47.10	44.90
	CV (%)	24.93	18.49	14.42	16.23	14.98	26.16	17.38	19.52
Silt (%)	Avg.	46.05	46.02	36.55	45.20	50.69	35.12	47.04	38.65
	Min.	29.70	36.90	25.70	38.00	30.40	25.00	33.20	22.10
	Max.	55.30	50.10	45.80	52.40	59.30	49.00	54.50	49.60
	CV (%)	16.38	8.54	14.73	8.84	15.26	17.79	13.16	18.06
Sand (%)	Avg.	32.90	21.22	32.79	24.28	26.81	39.10	30.51	38.93
	Min.	26.40	11.90	19.20	16.90	16.40	24.80	18.20	24.50
	Max.	50.50	32.90	51.10	35.40	48.90	57.60	52.70	61.70
	CV (%)	20.28	22.29	24.48	14.58	43.29	20.17	34.82	23.75

Table 3. Pearson correlation coefficients between soil sampling results and soil electrical conductivity calculated for individual fields and also for aggregated datasets of all fields. Bolded are values with statistical significance at the level of 95% probability

EC	2301/15	2401/10	2401/12	2401/9a	2401/9b	3411	5301/4	5601/4	All fields
pH	0.237	-0.243	-0.208	0.188	0.135	-0.189	-0.245	0.202	-0.110
P	0.228	0.134	-0.092	-0.111	0.331	-0.282	0.270	0.296	-0.120
K	0.028	**0.691**	**0.295**	-0.099	0.319	0.166	**0.605**	0.261	0.002
Mg	0.205	**0.562**	-0.032	-0.155	0.326	**0.633**	-0.309	0.213	0.008
Ca	-0.213	0.113	**-0.260**	0.060	0.460	0.313	-0.483	-0.069	-0.060
SOM	-0.166	0.144	**0.356**	0.021	0.353	0.076	-0.293	**0.589**	0.064
Clay	0.334	**0.473**	**0.545**	0.348	**0.598**	**0.542**	0.107	**0.568**	**0.265**
Silt	**-0.523**	0.196	-0.094	0.184	0.150	0.011	0.340	**-0.517**	**0.194**
Sand	0.159	-0.370	**-0.343**	-0.291	-0.381	-0.264	-0.439	-0.254	**-0.336**

With regard to the different EC measurement dates, the assessment of the relationship with soil properties should be done individually for each plot separately. The correlation between all soil samples and EC was significant only for clay content (r = 0.265), silt (r = 0.194) and sand (r = -0.336). The scatterplot in Figure 3 shows the comparison of clay content with EC for individual plots with clearly separable clusters of individual fields.

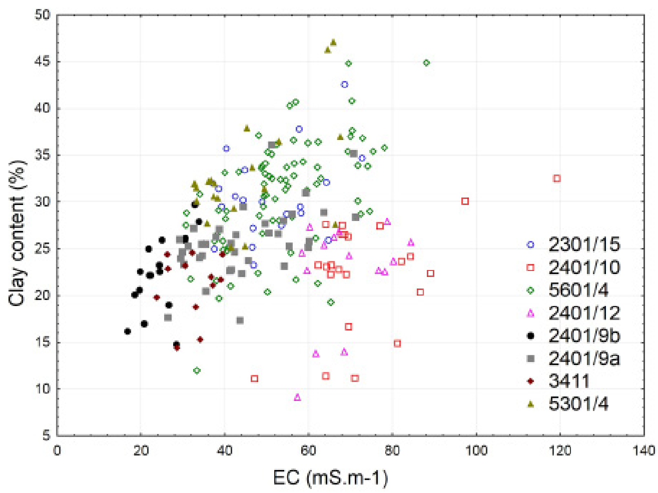

Figure 3. Scatterplot of EC and clay content categorized for individual fields

Although it is possible to build a robust model for prediction of soil properties, as shown by Heil and Schmidhalter (2012) in predicting soil texture from EC combined with elevation and terrain aspects, most studies expect the greatest potential of spatial EC measurement in precision agriculture for delineation of management zones and directed soil sampling (Corwin and Plant, 2005; Doolittle and Brevik, 2014; Peralta and Costa, 2013; Moral *et al.*, 2010). Directed soil sampling based on EC mapping leads to a significant reduction in the number of samples compared to sampling in a regular network (Lesch, 2005). At the same time, the data of EC can be used as ancillary data to subsequently refine soil mapping from low density sampling by spatial interpolation techniques (Kerry and Oliver, 2003).

Conclusions

The study examined the relationship between soil electrical conductivity (EC) and soil physico-chemical properties obtained by soil sampling over eight fields with acreage of 476 ha. On-the-go measurement of soil EC is a method for relatively easy mapping of spatial variability of soil conditions that is often used in precision agriculture as a alternative to traditional mapping of soil by soil sampling.

The results of soil sampling showed different spatial variability of the observed soil properties across the fields. Correlation analysis proved main sensitivity of EC measurement to the soil texture categories (clay, silt and sand) and content of SOM, all at the medium level of correlation. The relationship between EC and available nutrients content in soil (P, K, Mg, Ca) or pH value was not significant, except of K content at three and Mg content at two observed fields. These results were obtained for individual fields, the evaluation of aggregated field results into one dataset showed lower relationships to EC values.

Although only medium level of correlation EC to soil texture parameters was obtained, on-the-go measurement of EC could be used for an identification of main soil differences within the fields at high spatial level and for field stratification (zoning) in precision agriculture. Recent studies showed that these zones can be used for directed soil sampling or to delineate the management zones for site specific crop management.

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