IDENTIFICATION OF SPATIAL VARIABILITY OF SOIL PHYSICO-CHEMICAL PROPERTIES FOR PRECISION FARMING

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Abstract: *Site-specific crop management practices, known as precision farming, requires information about detailed spatial distribution of soil physico-chemical properties related to the yield productivity. Traditional mapping of soil properties in form of soil sampling is inefficient for assessment of high level of spatial variability due to the high costs. For this reason, a study was conducted within the research projects NAZV QJ1610289 and TACR TH02030133 to evaluate the digital soil mapping techniques, including proximal sensing methods in the form of on-the-go measurement of soil electrical conductivity, for mapping of agronomical relevant soil properties.The experimental work was carried out on the selected fields of Rostenice a.s. farm enterprise, located in the South Moravia region of Czech Republic. Total area of 476 ha within eight fields was measured from 2013 to 2016 by using CMD-1 instrument (GF Instruments, Czech Republic) mounted on the plastic sledges. 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). 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), cation exchange capacity (CEC), soil organic matter content (SOM) and wilting point (WP). The results showed different level of spatial variability among the observed fields. The correlation analysis proved differences in main sensitivity of EMI to the soil properties, mainly 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 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..*

Keywords: SOIL HETEROGENEITY, DIGITAL SOIL MAPPING, SOIL PROPERTIES, ELECTROMAGNETIC INDUCTION.

1. Introduction

The Czech Republic has a specific land use defined by the highest average farm holding area in the European Union (over 130 ha per farm). The national statistical evaluation of agriculture sector (Ministry of Agriculture of the Czech Republic, 2015) showed that 50.3 % of agricultural land in Czech Republic is managed by farm enterprises with acreage 1000 ha. Also, there is known large average size of fields - statistical evaluation of the size of land parcels shows that 60 % of arable land is located within the fields with the area over 20 hectares. Higher diversity of the landscape relief and pedoclimatic conditions in combination with the size of land blocks occur in visible heterogeneity of land. This leads to an increased interest in the precision farming practices and technologies for site-specific crop management, where high quality of input geo-information about the land are required.

One of the method for digital soil mapping is measurement of apparent soil electrical conductivity (EC), which is 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).

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 (Godwin and Miller, 2003). According to the study of Corwin and Lesch (2005a), the most important factors influencing EC include the content of soluble salts in soil solution, relative moisture, soil water content and bulk density. The effect of these factors can be found in most of the studies cited here, but their significance varies with regard to specific site conditions. In agricultural areas where soil salinization is not a significant factor, EC measurements are the primary function of 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 by the soil, and thus obtaining information of the soil profile. The result of the EC measurement is also not affected by the vegetation cover of the soil 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 verify the use of on-the-go soil EC measurement by electromagnetic induction for mapping of within field spatial variability of selected physico-chemical properties of soil.

2. Material and Methods

The study was carried out on the selected fields of farm enterprise Rostenice a.s., located in the South Moravia region of Czech Republic (49° 05' N, 16° 50' E). Experimental fields are listed in Table 1, total area covered by this study was 476 ha of arable land. Predominant soil type within the fields was identified from available soil maps as Chernozem, Cambisol, haplic Luvisol and occasionally also Calcic Leptosols.

Fig. 1 *Soil sampling by automatic sampler Nietfeld Duprob 60.*

Soil sampling

Soil properties were obtained by soil sampling in irregular grid with the density of 1 sample per 3 ha. More dense sampling grid (2 samples per ha) was applied for field with ID 5601/4 (acreage 37.79 ha). Soil samples were taken from the depth of 30 cm by using Duoprob60 automatic sampler (Nietfeld, Germany) drawn by off-rad vehicle (Fig. 1). The position of each sampling point was localized with Trimble Pathfinder ProXH DGPS reaching submeter accuracy. Each sample is composed from 5 sampling cores taken in the perimeter of 15-20 m. Soil samples were analyzed in laboratory for soil pH value, content of available nutrients (P, K, Mg, Ca), and soil organic matter content (SOM). Also percentage of clay (soil particles < 0.002 mm), silt (0.002 – 0.05) and sand (>0.25 mm) were estimated.

Mapping of soil electrical conductivity

On-the-go measurement of soil EC was carried out by using CMD-1 instrument (GF Instruments, Czech Republic) in 2013 (117 ha) and 2016 (334 ha), both in the period without crop cover of soil. 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 off-road vehicle (Fig. 2) in 20 - 25 m track-lines. 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 measurement in 2016 was extended by six-dipole experimental instrument CMD-6L for simultaneous measurement in six soil depths in horizontal mode over next 268 ha. For this study, only the layer corresponding by the depth with CMD-1 was analyzed.

Fig. 2 *Measurement of soil EC by GF Instruments CMD devices.*

3. Results and Discussion

The basic information about observed fields and overview of experimental activities are written in Table 1. Besides the general information about the recorded EC values, also year of the measurement, used instruments and statistical characteristics of EC for individual fields are reported. Different ranges of EC values across the fields may, in addition to various soil conditions, also correspond to different measurement periods (spring / autumn) and thus also to different soil moisture levels during the measurement. However, 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).

Table 1: *Summary of EC measurement on experimental fields.*

Field ID	Area [ha]	EC Avg.	EC Min.	EC Max.	EC CV
2013 - GF Instruments CMD1					
2401/10	70.79	75.32	40.35	131.74	18.82
2401/12	46.05	53.17	27.74	97.00	21.69
2301/15	65.82	49.65	26.01	117.62	30.14
2016 - GF Instruments CMD1					
2401/9a	96.08	68.45	32.12	130.58	13.67
5601/4	37.79	46.36	15.99	111.69	34.41
2016 - GF Instruments CMD6L					
2401/9b	62.87	25.28	10.56	94.50	19.99
3411	34.49	45.02	21.88	107.56	30.19
5301/4	62.34	32.24	19.06	60.13	15.38

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 illustrated in Figure 3. Generally, the lowest variability was observed at soil pH, on the contrary, the highest of Mg content in soil. Between each plot, the CV varies significantly depending on soil characteristics. Values of coefficient of variability varied among fields based on the soil characteristics.

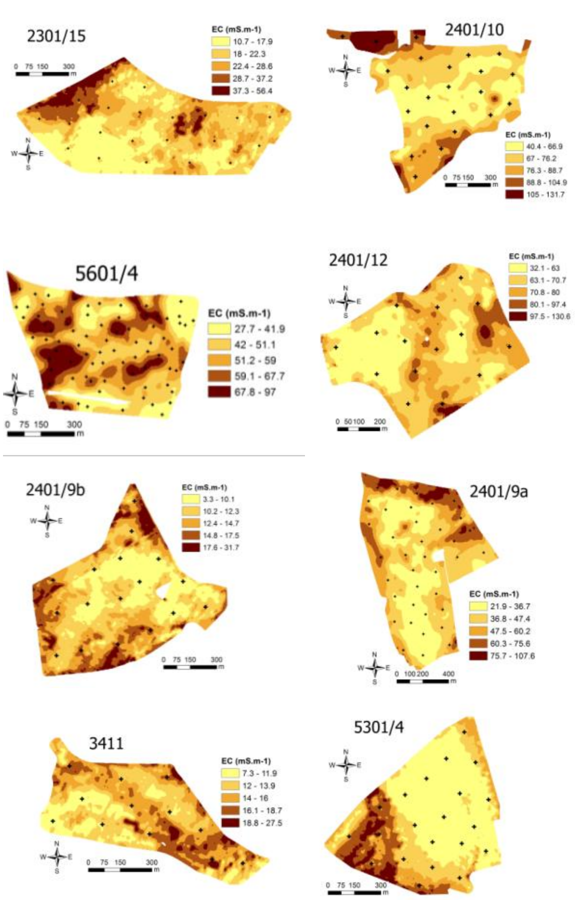

Fig. 3 *Maps of soil EC after classification. Black crosses represent soil sampling locations.*

The results of soil samples analysis were compared with the measured EC values by correlation analysis (Table 2). It was found an average level of correlation, mainly between the clay particles content (6 out of 8 plots), partly also for the content of silt and sand, 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, thus the knowledge of spatial distribution of soil texture 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.

An important factor influencing the electrical conductivity values is also the content of soil 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 %). There was found a positive correlation to soil EC between K content (3 of 8 plots) and Mg content (in 2 plots), but not in case of pH value and 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: *Pearson correlation coefficients among soil sampling results and soil electrical conductivity. Bolded values are statistical significant at the level of 95% probability.*

EC	pH	P	K	Mg	Ca	SOM	Clay
2301/15	0.237	0.228	0.028	0.205	-0.213	-0.166	0.334
2401/10	-0.243	0.134	**0.691**	**0.562**	0.113	0.144	**0.473**
2401/12	-0.208	-0.092	**0.295**	-0.032	**-0.260**	**0.356**	**0.545**
2401/9a	0.188	-0.111	-0.099	-0.155	0.060	0.021	0.348
2401/9b	0.135	0.331	0.319	0.326	0.460	0.353	**0.598**
3411	-0.189	-0.282	0.166	**0.633**	0.313	0.076	**0.542**
5301/4	-0.245	0.270	**0.605**	-0.309	-0.483	-0.293	0.107
5601/4	0.202	0.296	0.261	0.213	-0.069	**0.589**	**0.568**

Considering 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). 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 (or zone) 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).

4. Conclusions

The results of correlation analysis showed main sensitivity of EC measurement to the soil texture categories (content of clay particles) and content of SOM. Except of K content, the relationship between EC and nutrients content in soil and pH value was almost not significant. The main advantageous of EMI measurement is the delineation of main field zones at high spatial level, which reflect spatial differences in soil properties. Recent studies showed that these zones can be used for directed soil sampling or to estimate the management zones for site specific crop management.

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