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Development and implementation of data collection technologies for digital mapping of soil electric conductivity

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Abstract. One of the main preconditions for the introduction of soil protection measures and sustainable use of a soil is to strengthen the knowledge base about the specific habitats characteristics with high spatial resolution and adequate interventions to these properties. One of the most common sensors used to describe the level of soil variability are devices that measure the electric conductivity of the soil.

Platform for the electrical conductivity measuring has been developed and implemented into the standard combined machines for the tillage and seeding, using an existing work tools as part of the platform. Within the field work the series of measurements was conducted with this machine and platform and data of electrical conductivity were collected. On the same field as a reference method electrical conductivity was measured by an electromagnetic induction probe EM38 MK2. Compared data from the measuring platform and the EM38 MK2 probe showed a high correlation value. The experiments demonstrate the possibilities of technical solutions of soil conductivity measurement implementation on tillage and seeding machines where by a modification of selected tillage and seeding machines together with incorporation of sensors directly onto the work tools is possible to obtain measuring platform that enables data collection directly during operation of the machine on the field.

Key words: Soil electric conductivity, soil mapping, soil sensor.

INTRODUCTION

Precision agriculture technology has been introduced several years ago. Despite all the potential of this technology, there are still many problems that hinder their higher usage and adoption. Implementation of precision agriculture implies somewhat high level of expertise and technical skills of the users. Most farmers, however, sees this approach as too complex. As also shown in studies from the USA, Great Britain, Denmark and Germany, it is one of the reasons for the low diffusion of technology of precision agriculture compared to the assumptions (Reichardt et al., 2009). The same was concluded in 2005 by McBratney et al., who states that precision farming is still developing, but not as fast as expected 5 years ago. The development of appropriate decision support systems and systems for performing accurate decisions remains a major obstacle to the adoption of the technology. The main idea of precision agriculture is based on the belief that the variability of conditions for plant growth is one of the main contributions to the differences in yields and therefore also different inputs under different soil conditions could be a way to approach the situation. Number of growers already has, for example, yield data from several seasons. However, the effectiveness of the decision–making process can be guaranteed only when we receive high quality information on the spatial variability of soil, which limits yield in certain parts of the field. Lack of knowledge which information is significant and economically acceptable is the most limiting factor (Adamchuk, 2007). The high price for the sampling and laboratory analysis supports the deployment of sensors which will evaluate required soil properties; such as during towing of sensors over plot (Adamchuk et al., 2004; Viscarra Rossel et al., 2011). Variable sampling applications require significant amount of samples, but where there is a possibility the hand sampling should be replaced by an autonomous or semi–autonomous data collection. Regarding the measurement of field variability, sensors on agricultural machines can deliver the best accessible spatial and temporal information (Heege, 2013). Deployment of geophysical instruments or implementation of sensory equipment to commonly used machines will enable an overall reduction in costs of data collection, sampling network optimization, time savings and reduce demands on workers. Corwin & Lesch (2003) or Terrón et al. (2011) confirms that the conductivity measurement of soil becomes one of the most widely used techniques for field variability mapping for the needs of precision agriculture technologies and farmers can use the measurement for fast and accurate characterization of soil environment (Doerge, 2001). Measurement of the electrical conductivity of the soil is suitable for detection of many soil parameters and variables description (Fortes et al., 2015; Moral et al., 2010) or yields potential prediction (Johnson et al., 2003). Indirect measurement of soil properties thus have many promising applications, which should be further developed and improved.

The purpose of the measurements was to determine whether it is possible to install the soil electrical conductivity platform into commonly offered tillage and seeding machine for purpose of measurement and data collection between field operation, cultivation and seeding.

METHODS AND MATERIALS

The measurement and verification of the measurement electronics was done on the field, which manages agriculture company ZD Dolany (geographical coordinates: 50°22'48"N, 15°57'40"E). Field experiments were carried out during seeding of spring wheat. The soil is *Haplic Luvisol* (FAO, 2014). The highest part of the field is at the northern part an altitude of 325 m a.s.l. and further field is sloped to the lowest altitude 29 m a.s.l. Field acreage was 14.2 ha (see Fig. 1).

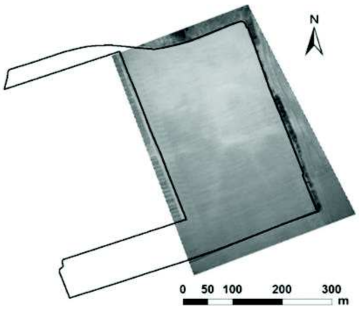

Figure 1. Aerial picture of the experimental plot, which was taken after sowing by unmanned aircraft.

Scheme of sampling patterns and moving trajectories illustrated Fig. 2.

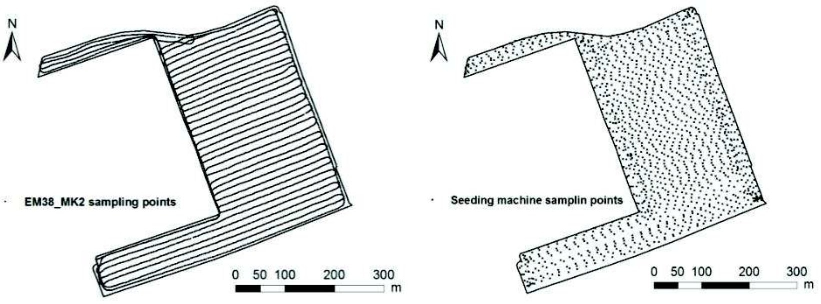

Figure 2. Sampling patterns and moving trajectories of EM38 MK2 device (left) and sampling points collected during seeding (right).

The most commonly used electrical and electromagnetic sensors for field–scale on–the–go measurements are electrical resistivity (ER) and electromagnetic induction (EMI) (Corwin & Lesch 2005). ER and EMI measure the electrical conductivity of the bulk soil, which is referred to as the apparent soil electrical conductivity (EC_a).

Measuring electronics, which use principles of electrical resistivity measurements, was installed on a modular seeding machine Farmet Falcon (Farmet a.s., Ceska Skalice, Czech Republic) with working width of 6 m. Electrical Resistivity method could be described as a galvanic contact method. As electrodes the discs tiller of first section were used. These discs were electrically isolated from the machine frame through rubber segments. Disc allowed contact with the soil during the work only. The speed during the measurement with EM38 MK2 probe was about 2.8 m s^{-1} and the speed of the seeding machine about 3.4 m s^{-1}. Speed sets corresponded to normal operating speed at which proper work of tools was ensure. That movement speed affects especially the density of sampling. Electrodes connection was done according to article of Milsom (2003), where the mentioned connections are known as Wenner array. Connecting corresponds to the diagram in Fig. 3, where the individual discs formed a pair of voltage (V) and current (I) electrodes. Distance between electrodes (a) was 0.25 m. Outputs from electrodes were stored onto measuring units together with the GPS position. Storage interval was 5 sec. Measuring device was developed on Department of Agriculture Machines and Department of Machine Utilization, CULS Prague.

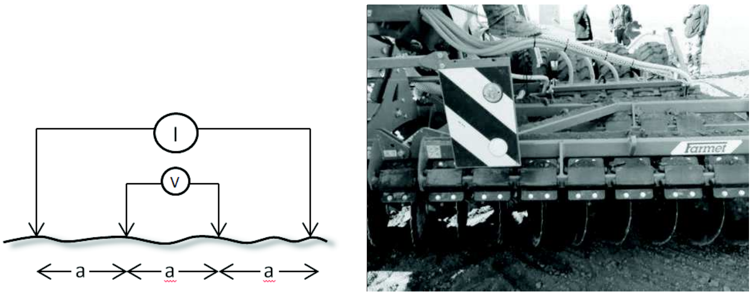

Figure 3. Connection of electrodes on the seeding machine Falcon and front disc section of seeding machine, which were used as electrodes.

To obtain a validation set of measurements of electrical conductivity from platform which was installed on seeder, the measurement using reference probe EM38 MK2 (Geonics Limited, Ontario, Canada) on the same date was carried out as well. Probe EM38 MK2 is a commercially sold product utilizing noncontact electromagnetic induction measurements. The validation data were measured in the vertical mode of probe in spacing of 12 m between parallel lines. Data were stored together with GPS position and storage interval was 1 sec.

Software ArcGIS 10.2 (ESRI, Red lands, USA), Statistica 12 (StatSoft, Inc., Tulsa, OK, USA) and tools GS+ for Windows (Gamma Design Software, LLC, Michigan, USA), Microsoft office (Microsoft Corporation, Redmond, USA) were used.

RESULTS AND DISCUSSION

Two sets of ER and EMI data were processed using statistical and geostatistical methods. In order to get accurate data and to eliminate measuring errors, several modifications on the initial EC_a values were performed before next processing. The majority of errors, when measuring EC_a with galvanic contact method by seeding machine Falcon, occurred when the machine started a new line. Thus, values especially on headlands were removed from the data set. These values were eliminated by trimming the marginal points recorded. Values larger or less than three times of the standard deviation from the mean value were also excluded from the initial data set. The time series were smoothened during the subsequent modification. A simple running average method was applied to smooth the time series of all measurements using following equation:

$$\hat{Y}_t = \frac{1}{3}(Y_{t-1} + Y_t + Y_{t+1}) \tag{1}$$

where: Y are original values at time t.

The descriptive statistics of EC_a data set is shown in Table 1. The range of values expressed as the maximum and minimum as well as variation coefficient illustrates the variability of the individual data sets. Asymmetry from the normal distribution is described as a coefficient of asymmetry. The normality condition is met, if the interval of inclination lies between -2 and 1 (Lopez–Granados, 2002). A normal distribution is demonstrated by low values of skew. On the other hand normality is not limiting condition for geostatistical evaluation.

As Kolář & Kužel (1998) reported, the soil belongs to the most variable environments. In order to implement variable application and interventions it is necessary to describe the variability of the field (Piers and Nowak, 1999). Standard deviation and the variance are useful measures for describing the spread of a set of measurements. Describe the variability around the mean and variance is related to the geostatistical parameters. Suitable indicator for the comparison of the variability level is the coefficient of variation (*CV*). *CV* expresses dispersion in the relative terms. It is useful for comparing the variation of different data sets of observations of the same property (Webster & Oliver 2007). Measures indicate a higher degree of variability in the data set obtained by seeding machine Falcon.

Table 1. Descriptive statistics of data set

Variable / Property	EC_a EM38 MK2 0–1 m	EC_a Falcon 6
Mean value (mS m^{-1})	34.2	31.9
Median	33.5	27.4
Standard deviation	9.5	20.7
Variance	90.3	428.5
CV (%)	27.8	53.7
Skew	0.17	0.51
Minimum	12.6	5.7
Maximum	56.8	83.4
N	5,294	1,088

In order to find out spatial relationships between tested values and calculation of variogram parameters the experimental variograms were built and substituted by model variograms in the next step. Model variograms were fitted for both files and parameters Nugget (C_0), Sill ($C_0 + C$) and Range (A_0) were calculated. The spatial relation itself is expressed as a portion of the nugget (C_0) in the sill value ($C_0 + C$). The spherical model of the variogram of EC_a values with nugget was chosen. Parameters of model variogram were taken off (Table 2). Based on the values of A_0 may be estimated mutual spatial dependence of the data.

Table 2. Parameters of model variogram for soil electric conductivity values

Variable / Property	EC_a EM38 MK2 0–1m	EC_a Falcon 6
Nugget C_0 ((mS m^{-1})^2)	2.7	108.7
Sill $C_0 + C$ ((mS m^{-1})^2)	46.8	275.2
Range A_0 (m)	98.8	69.7
R^2	0.99	0.91
RSS	29.7	2,445
$C_0/C_0 + C$ (%)	5.7	39.4
Model	Spherical	Spherical

The measurement errors as well as the variability character can influence the values of nugget (Lopez-Granados et al., 2002). Division of spatial relations into classes is described e.g. in Cambardella & Karlen (1999) and Lopez–Granados et al., (2002). Following criterion $C_0/C_0 + C < 25\%$ indicates a strong spatial relationship for the tested files of EC_a measured by EM38 MK2. The values of EC_a measured by Falcon showed medium strong spatial dependence ($C_0/C_0 + C$ from 25 to 75%). Medium spatial dependence of data could be caused by higher distances between measured points. *Ordinary Kriging* interpolation method was used for spatial interpolation of measured values. Part of the assessment process was also validation of the interpolation by *Cross–Validation* method. Estimated values which were collected after this process were correlated with measured values. The correlation coefficient *R* should be equal to 1 in an ideal case. Coefficients of correlation for the data sets are shown in Table 3. The lower value of the correlation coefficient was found for the values of conductivity which were measured by the seeding machine Falcon. There was impacted by lower levels of spatial dependence of data.

Table 3. Comparison of measured and predicted data

Variable / Property	EC_a EM38 MK2 0–1 m	EC_a Falcon 6
coefficient of correlation R	0.99	0.59

On the basis of regression and correlation analysis, the significance of variogram modelling for the subsequent interpolation was proved. Reliable conductivity maps are presented in Fig. 4. For the purpose of data set comparison, when the points do not have identical coordinates, both maps were resampled to the grid of 5 x 5 meters and data from both sets were paired. This steps enable comparison and assessment of values recorded from the sensors.

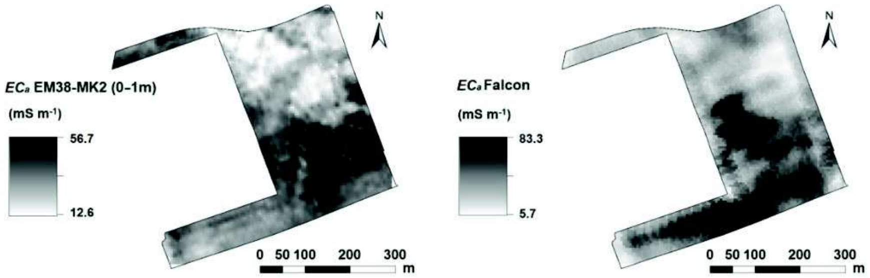

Figure 4. Maps of kriged estimates.

Presented resampling of data sets allowed a mutual comparison. Regression and correlation analysis was used for the comparison. The comparison and evaluation of these two data sets were carried out by means of regression and correlation analysis. Fig. 5 shows the results of this analysis. In the legend of the chart, it is also possible to read determination and correlation coefficient values (*$R^2 = 0.40$* and *$R = 0.63$* respectively), including significance test ($p < 0.05$).

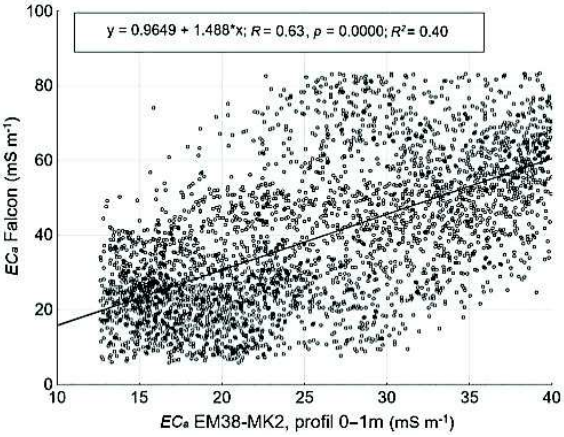

Figure 5. Relationship between data from sensor installed in the seeding machine Falcon and outputs from EM38 MK2.

In the case of implementation of individual approach on the field, its parts, creating application maps or zones there are usually three factors which must be considered: the information which will be used as the basis for the creation of a zones the information processing procedures (ie. classifications) and how many zones should be created (Fridgen et al., 2004). Proximal sensors provide important results to create a sampling plan (Corwin & Lesch 2010). As Steinberger et al. (2009) refer that modern farm machinery with installed sensors could collect a large amount of data during field operation. On the other hand, communication and compatibility is the main limiting factor.

The monitoring systems and sensors implemented to the tillage and seeding machines seems like very attractive option in relation with the use of the sensor technology. Telematics' monitoring systems in the combination of GPS navigation offers a number of very valuable information. The mere knowledge of the position will allow to monitor the agricultural technology usage (deployment location and work inspection). If the more information are added to the machine position (such as: fuel consumption, slipping or pulling force) the data which can indirectly give evidences about the variability of soil environment or the economic balance of the partial areas of land with few additional costs could be obtained. Development of machines and mobile technologies will continue and this technology offers a wide area for variable applications and service in farming (Xin et al., 2015).

CONCLUSION

The rapid development of sensor technology and data processing, which frequently contribute to the efficient and sustainable agricultural production, along with the development of the internet and telecommunications are nowadays the key innovative processes. The research activities are supported by the following research hypotheses: 1) The sensors used for soil properties measuring are based on a relatively simple measurement principles and the implementation in machines for tillage and seeding is real. 2) The introduction of machines which are able to collect the soil variability data during field work, can deliver an important tool for the development and advancement of the precision agriculture technologies. Currently, the data collection associated mainly with individual and independent activity that requires additional entrance on the field, acquisition costs of the measuring device and time for data collection. This solution is based on the idea that the machine and field operations will also become the source of data. Outputs from measuring platform and sensors, which was installed on the seeding machine showed a significant correlation with the data from sensor EM 38, which is placed on a standard. The data collection will be processed concurrently with the work of machines, at high density of measurement and the actual soil conditions.

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