Proximal soil sensing in the framework of iSOIL project

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Abstract

Soil environment represents highly variable system and lots of soil properties have a direct relationship with soil fertility or can influence quality of soil tillage and energy consumption during soil tillage.
Variable inputs and treatments require a detailed description of soil environment. Nowadays there are several soil sensors which are able to monitor continuously and to bring the detailed description of soil properties in comparison with conventional soil sampling.
In the framework of iSOIL project, several geophysical measuring devices (Soil electric conductivity (EC_a), gamma ray sensors, draft force measurement) were gathered and used together in one experimental field. The focuses of iSOIL project are: i) improving fast and reliable mapping of soil properties and ii) the relation between sensor outputs and soil properties.

Keywords: EC_a, Gamma ray sensor, Draft force, particle size distribution, pH, Organic carbon.

Introduction

An ideal soil sensor responds to the variability of a single soil attribute and is highly correlated to a corresponding conventional analytical measurement method. However, in reality, every sensor developed responds to more than one soil property and separation of their effects is difficult, or even non-feasible (Adamchuk & Viscarra Rossel, 2010).
Although the idea of precision farming is known quite a long time, its realization and particular elements of the precision farming system utilization is still behind. As McBratney et al. (2005) write: “precision Agriculture is advancing but not as fast as predicted 5 years ago”. The development of proper decision-support systems for implementing precision decisions remains a major stumbling block to adoption. The results of the exhibition interviews presented by Reichardt et al. (2009) show differences in the adoption of the various precision farming techniques with the majority of the interviewed farmers still using data collection practices rather than variable rate application techniques. The most widely disseminated forms of precision farming are data collection techniques such as GPS based area measurement and GPS based yield mapping. Less widely used techniques are variable rate application of chemicals and/or fertilizers such as site-specific N fertilising. Precision agriculture needs high-resolution maps of physical and chemical soil properties together with yield and crop biomass maps to enable operational decision support in crop management and to conjure variable rate application maps (Egmond et al., 2010).
A lot of spatial information or a combination of them can be used to derive the variability in a field. The physical and chemical properties of the soil, determined from manual soil sampling, are often used in fertilizer recommendations for crops. Normally a large number of samples, and hence big costs and lot of time, is needed to achieve statistical significance among samples in determining management zones (Franzen et al., 2002). Developing a management zone map is

essential for effective variable rate applications. Many economically sufficient methods of the soil variability evaluation based on very simple measurement principle are available and there is a real opportunity for the automation of these processes in a near future (Godwin & Miller, 2003).

Material and methods

The experimental agricultural field is located in the central part of the Czech Republic. It represents intensively exploited arable land with commonly planted crops such as canola, spring barley, winter wheat and corn. The landscape is gently waved with an altitude ranging from 440 to 460 m. The main soil unit is Dystric Cambisol developed on arenaceous mar (classification system World Reference Base). The area is in typical temperate zone climate with average annual temperature from 7 to 8.5 degrees Celsius and with 500 to 750 mm of annual precipitation.

<u>Instrumentation</u>

The field was sampled and geophysical measurements were done by the group of researches from the Czech University of Life Sciences (CULS), from the Helmholtz Centre for Environmental Research (UFZ) and from the Soil Company (TSC) in the spring and autumn of 2009.

Soil samples were taken up to the depth of 300 mm (soil pH, organic carbon content (SOC - %) and particle-size distribution (clay, sand and silt - %). 39 sampling points were localized.

Geophysical measurements were taken along transects. Five sampling research projects were undertaken. The first was conducted by The Soil Company (TSC) which collected gamma measurements - The Mole system (i.e. four variables 137Cs, 232Th, 238U, 40K, - $Bqkg^{-1}$). The second sampling project conducted by The Helmholtz Centre for Environmental Research (UFZ), was the measurement of electromagnetic induction EC_a (EM31 and EM38 - mSm^{-1}). The third sampling project was conducted by CULS. Electric conductivity EC_a and draft force were measured in this project. A galvanic contact resistivity method was used. The draft force (kN) measurement was carried out by means of a measuring frame with one shovel and also during ploughing by means of tractor with an electro hydraulically controlled hitch.

Results

For the data sets analysing, CANOCO 4.5 package (Ter Braak & Šmilauer, 2002) was used. Due to rather short gradients (0.339 SD units) in detrended correspondence analysis (DCA), the linear methods for studying data set variability were applied. Clay, sand and silt content, further organic matter content and pH were chosen as explanatory variables. As dependent variables the conductivity data (EM31 horizontal mode, EM31vertical mode, EM38 horizontal mode (spring measuring), EM38 horizontal mode (autumn measuring) and Galvanic contact resistivity sensor – profile 0-300 mm), gamma ray sensor, draft forces were used.

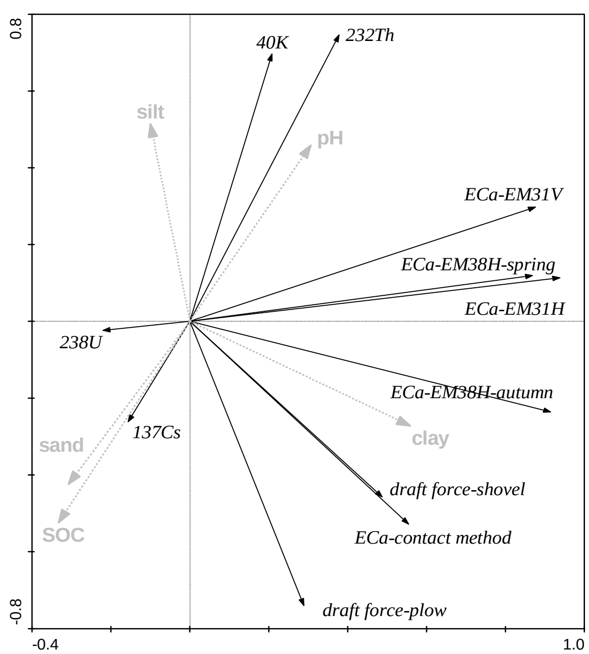
Principal component analysis (PCA) was used to assess the overall variation patterns in data set. Scaling was focused on inter-species distances and data were centred and standardized by species. For better interpretation, the explanatory variables values were passively projected onto an ordination scatter plot.

The relative importance of each explanatory variable for the variation in data set was evaluated using redundancy analysis (RDA). RDA with a single explanatory variable followed by a Monte Carlo permutation test with 999 permutations was used to quantify the effect of each variable. Tests of the first canonical axes were applied for single explanatory variable tested, and test of all canonical axes was applied for testing of all explanatory variables. Explanatory variables clay, silt and sand were mutually correlated and therefore the silt was removed from the analysis.

Table 1. The effects of explanatory variables on dependent variables.

Explanatory variables	Eigenvalue	F-ratio	p-value
all	0.422	4.556	0.001
clay	0.144	4.706	0.002
sand	0.130	4.196	0.004
SOC	0.110	3.451	0.003
pH	0.087	2.653	0.02

Eigenvalue - sum of all canonical eigenvalues; F-ratio for the test of significance of all (first) canonical axes; p-value - corresponding probability value obtained by the Monte Carlo permutation test (999 permutations)



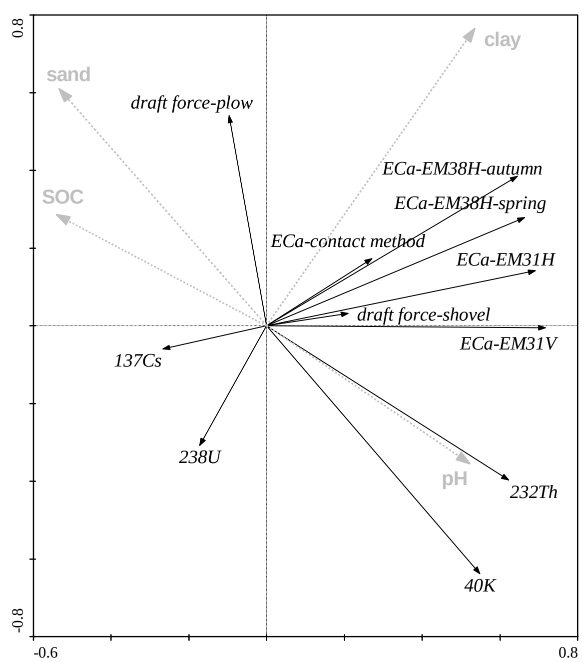


Figure 1. Ordination diagram of principal component analysis (PCA) with passively projected explanatory variables.

Figure 2. Ordination diagram of redundancy analysis (RDA).

In PCA, the first ordination axis explained 37.5 % of the total variation and could be associated to clay content. The second most important gradient in data variation (21.1 % of data variability) corresponds more to SOC, pH and silt and sand content.

According to RDA, effects of all variables were statistically significant. All variables explained together 42.2 % of the total variation (Table 1). Most variation was explained by particle-size distribution (clay content explained 14.4 % of variability, sand content 13.0 %), followed by SOC (11.0 %) and pH (8.7 %).

Conclusion

Clay: increasing clay content caused increase of conductivity, draft force values. ^{137}Cs and ^{238}U were negatively correlated with the increasing clay content.
Sand: Increasing sand content positively influenced tillage values (increase of draft force values) and ^{137}Cs, and negatively influenced were ^{232}Th and ^{40}K values.
SOC: With increasing SOC, draft force values were positively correlated. On the other hand ^{232}Th and ^{40}K values were correlated negatively.
pH: Increasing pH values were quite strongly positively correlated with increasing ^{232}Th and ^{40}K, while correlation with ^{137}Cs was negative. pH was also slightly correlated with conductivity values.

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