Key properties for delineating soil management zones

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Abstract

At present, it is possible to obtain rich data sets on soil variability. However, there is a need to select independent key properties to identify management zones. In a previous study focusing on loess soil, we identified the electrical conductivity measured with a soil sensor, topsoil pH and elevation as key properties. In this study the number of soil properties was enlarged and a sandy soil was targeted. Surprisingly, we identified the same variables as key properties. They were used to delineate management classes and an excellent multiple regression model could be constructed between yield and the key properties.

Keywords: EM38-MK2, gamma ray, LIDAR, ECa, pH, elevation, wheat yield

Introduction

Advances in sensing technology and data capture techniques are now able to provide a wealth of detailed data and information on soil, crops and associated environmental properties like topography. However, this information might duplicate to some extent. So the challenge is to select those properties which are essential for the faced application. Therefore it is best to delineate land management zones on the basis of stable properties which are readily obtainable. Vitharana et al. (2008) made a first effort to address this issue for the European loess belt. They concluded that out of 12 soil and topographic properties three could be considered as essential: pH, apparent electrical conductivity (ECa) and elevation. Our aim was to extend this study to another important European soil-landscape, the sand belt, to evaluate how generic their conclusion was. Additionally we extended our study to more soil properties.

Materials and methods

A 4.2 ha arable field (central co-ordinates: 3°37′22.43″ E and 51°07′00.03′ N) located in the sandy area of northern Belgium, which is part of the greater sand belt of northern Europe, was selected. Maize (mostly as animal feed), potatoes and wheat are the main crops of cultivation, which is a typical rotation for the area.
Five types of geo-referenced information were collected on this field:

1. Elevation data (DEM) obtained by an airborne LIDAR scan. On average, one observation per 4 m^2 was taken with an average horizontal and vertical error of 0.14 m and 0.20 m, respectively. Given the rather flat topography of the area, no other topographic indices were derived.
2. Soil samples were taken at 30 randomly chosen locations over two depth intervals: 0 -0.3 m (topsoil) and 0.6 – 0.9 m (subsoil). All samples were analyzed for their organic carbon content (OC in %), sand content and pH.
3. Detailed measurements of the soil apparent electrical conductivity (ECa) were taken with an electromagnetic induction sensor (EM38-MK2, Geonics Ltd) with two inter-coil distances (0.5 and 1 m). Both horizontal (ECa_H0.5 and ECa_H1.0) and vertical orientations (ECa_V0.5

and ECa_V1.0) were measured. The between-line distance of these sensor measurements was 2 m. All ECa data were standardized to a temperature of 25°C.

4. Using The Mole (The Soil Company) gamma ray detector system, the gamma rays (Bq kg^{-1}) emitted by the natural radionuclides ^{40}K, ^{238}U, ^{137}Cs and ^{232}Th present in the top 30 cm of the soil were measured at the same 30 locations where soil samples were taken. The details of the spectra processing methodology were described by van Egmond et al. (2010).
5. On 29/7/2006 the wheat yield of the field was harvested with a commercial combine (New Holland CX880) equipped with a DGPS and a yield monitor. Post-processing of the data included standardization to 15 % moisture content and the filtering of erroneous data (like e.g. due to the time delays in grain flow at the start or end of harvest lines).

Identification of key properties

The 30 values of the 15 variables were subjected to a principal component (PC) analysis (performed on the correlation matrix) which identified three components explaining 72.5 % of the total variability. After Varimax rotation, these three components were best represented by ECa_H0.5 (with a loading of 0.97 on PC 1), elevation (with a loading of 0.85 on PC 2) and top-soil pH (with a loading of 0.84 on PC 3) (Fig. 1). So these three variables are considered to be the key properties for the characterization of soil variability within this area. Surprisingly, these are the same variables as identified by Vitharana et al. (2008) for the loess area.

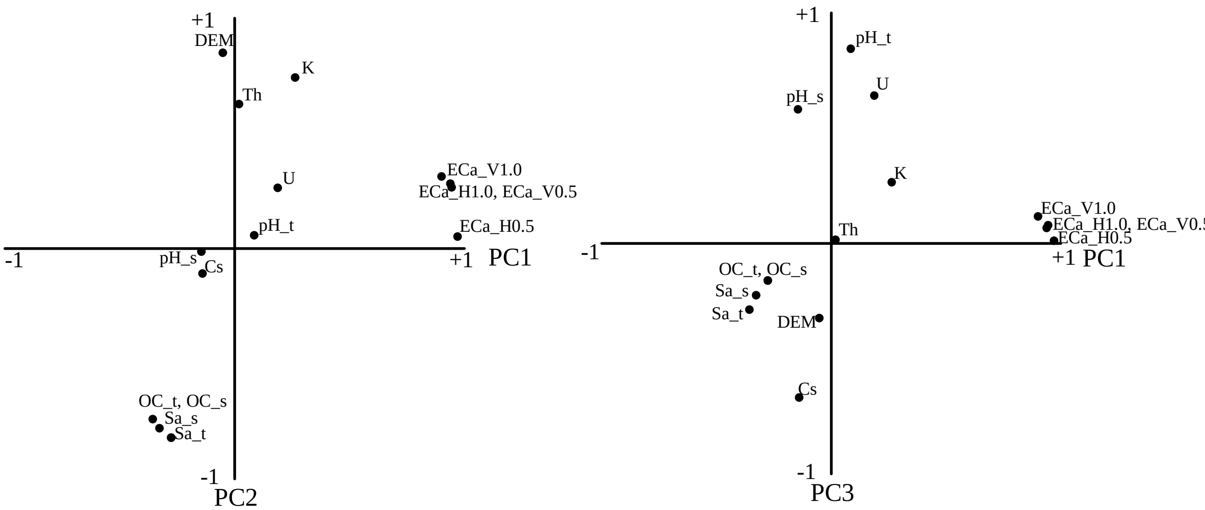

Figure 1. Loading plots of the first and second PC (left) and the first and third PC (right). Symbol definitions are given in the text.

Management zones

Each of the three key variables was interpolated with ordinary kriging to create a map (for this purpose, the topsoil of 70 additional locations was sampled and analyzed for pH resulting in 100 measured locations). As most determining variable, Fig. 2 (left) shows the map of ECa_H0.5. These three maps were subjected to a fuzzy *k*-means classification with extragrades (McBratney & de Gruijter, 1992; Minasny & McBratney, 2006). The optimal number of classes was 2 with a third class being the extragrade. The 2 classes formed two zones of about the same area (Figure 2, middle). The extragrade class formed two elongated zones along the border.

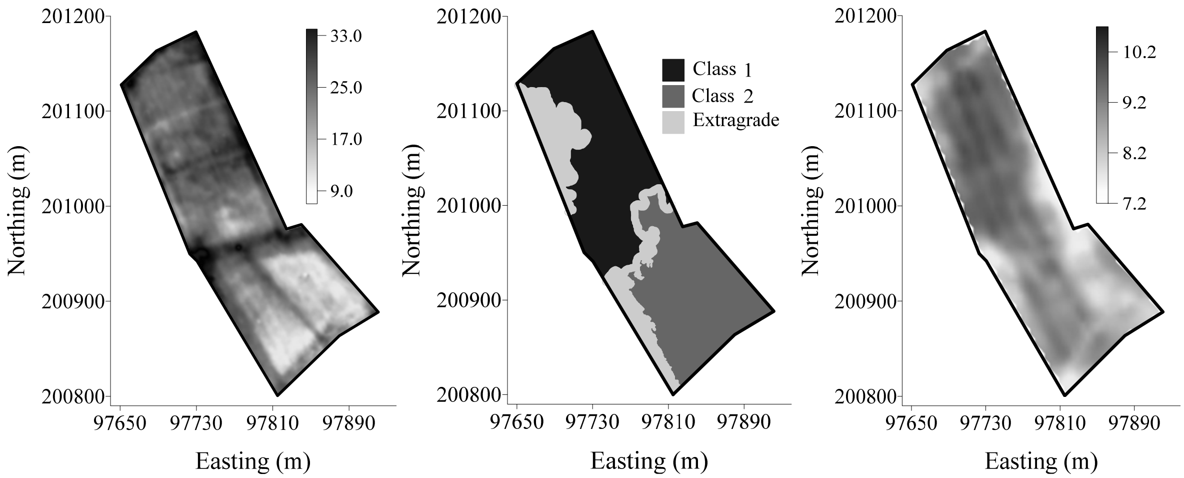

Figure 2. Maps of ECa_H0.5 (in mS m^{-1}) (left), the management classes obtained with a fuzzy *k*-means with extragrade classification (middle) and wheat yield (t ha^{-1}) (right).

Wheat yield

The two management classes reflected clear differences in wheat yield: class 1 produced on average (based on 3646 data) a yield of 9.9 t ha^{-1} (s = 0.54 t ha^{-1}), while class 2 produced on average 8.6 t ha^{-1} (s = 0.57 t ha^{-1}, based on 2353 data). The extragrade class showed an intermediate average yield of 8.8 t ha^{-1} (s = 0.71 t ha^{-1}, with 763 data). A stepwise multivariate regression between yield and the key properties resulted in the following model:

$$\text{Yield} = -0.324 + (0.175 \cdot \text{ECa\_H0.5}) + (1.009 \cdot \text{DEM}) - (0.00217 \cdot \text{ECa\_H0.5}^2),$$

with $R_{adj}^2 = 0.88$, $p < 0.001$.

The top-soil pH did not contribute significantly.

The relationship between yield and ECa_H0.5 was further analyzed through a boundary line analysis (Kitchen et al., 1999). We used the procedure described by Shatar & McBratney, (2004), in which the 10 % highest yield data are selected by splitting the cloud in bins. The idea is that only the highest yield data have ECa as a limiting factor, lower yields are due to other limiting factors (like insect pests) By concentrating on the highest yield data, the relationship between yield and ECa was modeled as a quadratic curve (Figure 3):

$$\text{Yield} = 6.537 + (0.232 \cdot \text{ECa\_H0.5}) - (0.00331 \cdot \text{ECa\_H0.5}^2),$$

with $R^2 = 0.97$.

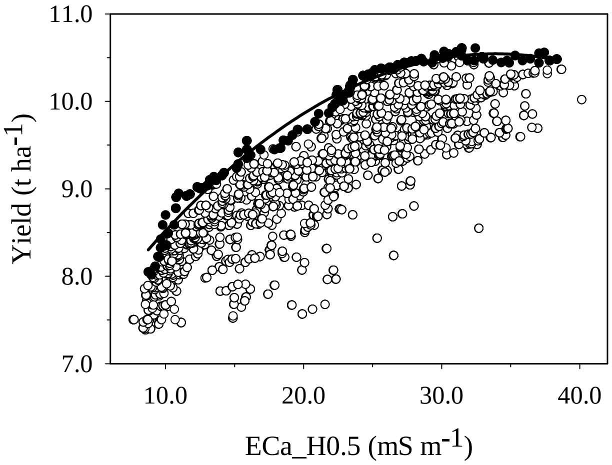

Figure 3. Boundary line analysis of wheat yield as a function of ECa. Only the full dots were included in the curve fitting, the other points are considered to have other yield limiting factors than ECa_H0.5.

Conclusions

Top-soil ECa, pH and elevation are strong candidates for generic key properties to delineate management zones in most central European landscapes. However, specifically for wheat yield prediction in the sandy area, soil pH failed to make a significant contribution, but an excellent (R^2 = 0.97) quadratic boundary line relationship was found with ECa.

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