Spatial analysis of the electrical conductivity of the subsoil in various production technologies

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Abstract. The cultivation technology that is used has a very large impact on changes in the physical and chemical properties of the soil. Depending on the machines used and doses of added fertilizers, the changes may concern shallow or deep soil layers. The most commonly used method to quickly determine spatial variability is the measurement of the electrical properties of the soil using the EM38 conductivity meter. The aim of the study was to analyse the spatial variability of the electrical conductivity of the subsoil in fields where traditional cultivation technology and precision farming technology were used. The research consisted of scanning the soil with the EM38 probe at 4 experimental sites and subjecting the results to spatial analysis in the GIS software. The analysis of the obtained results showed that the soil electromagnetic conductivity variability testing method identifies the actual soil variability very well. It should be noted, however, that the lack of additional classical validation measurements may lead to erroneous conclusions. Even with similar soils in the fields, there may be significant differences in mean values (103 - 190 mS · m⁻¹) and variability (18 - 41%).

1. Introduction
The applied cultivation technologies contribute to a greater or lesser degree of change in the physical and chemical properties of the soil in its shallow and deep layers. Spatial variability of soil properties is one of the reasons for the application of crop differentiation and the introduction of precision farming technology [1,2]. The use of variable fertilization, irrigation [3], sowing or soil cultivation requires obtaining information about the variability of soil conditions [1]. Performing standard analyses of soil samples requires a long time spent on waiting for the results, which is often troublesome given the limitations imposed by the adopted cultivation technology of a given plant. A great facilitation in collecting data about soil, and above all a quick solution, is the use of electrical properties of soil [3-10]. One of the basic methods used to determine the spatial variability within the field is the measurement of the electrical conductivity EC (Electrical Conductivity) using the EM38 electromagnetic conductivity...
The preparation of spatial variability maps and their spatial analysis requires the determination of the position of the device on the basis of information from the GNSS receiver.

2. **Purpose and scope of research**
   The aim of the study was to analyse the spatial variability of the electrical conductivity of the subsoil in fields where traditional cultivation technology and precision farming technology were used. The conducted research consisted in scanning the soil with the EM38 ‘figure 1’ probe on 4 experimental (test) sites and subjecting the results to spatial analysis in the GIS software.

![Figure 1. Measurement of electromagnetic conductivity with an EM38 probe.](image1)

3. **Methodology**
   The research was carried out on two cultivated fields designated as P1 and P2, where two cultivation technologies have been used for 3 years. The area of the P1 field was 26.04 ha, and the P2 field 18.99 ha. The yield on the designated measuring sites was similar, regardless of the cultivation technology used. Measurement data was collected and recorded using the EM38 probe at all test sites at 20 m ‘figure 2’ intervals. During the research, over 1700 points were registered at the proving grounds with cultivation in the precision farming technology and over 1400 points at the proving grounds with cultivation in the traditional ‘figure 2’ technology.

![Figure 2. Recorded measurement points in two fields (P1, P2) and 4 experimental areas with cultivation in the technology of precision agriculture (PA) and traditional technology(T).](image2)
Statistical analysis of point data and spatial statistics was performed in the Farm Works Office software. The IDW interpolation method was used to create raster maps from point data. During the interpolation, 10 m was assumed as the raster size of the resulting map, and the 10 closest points within a radius of 50 m were selected to calculate the mean value. Soil samples were also collected from the study fields from evenly distributed measurement points using a Trimble Nomad GPS receiver and Farm Works Mobile software. The results of the analysed soil samples showed the same soil in both fields and it belongs to the clay dust 'Table 1'.

Table 1. Soil texture on experimental fields*.

| Field | Area (ha) | Fraction content (%) |
|-------|-----------|----------------------|
|       |           | sand 1.0 – 0.1 | silt 0.1 – 0.02 | clay <0.02 |
| P1    | 26.04     | 1.2                | 60.5              | 38.3       |
| P2    | 18.99     | 5.3                | 54.7              | 40.0       |

* according to standards of The Polish Soil Society BN-78/9180-11

The presentation of the results of the soil analysis in terms of the content of floatable parts demonstrated a very similar spatial distribution of values in the studied fields 'Figure 3'. Greater differentiation in terms of the distribution of floating parts in the soil was observed in the P2 field.

Figure 3. Spatial distribution of areas with different contents of floating parts.

4. Results and analysis
The summary of the point results of the performed measurements and the basic statistical data are presented in Table 2.

Table 2. Results of soil scanning with the EM38 probe at four experimental fields.

| Technology            | Field | Number of points | Area (ha) | Min. (mS·m⁻¹) | Max. (mS·m⁻¹) | Average (mS·m⁻¹) | Coefficient of variation (%) |
|-----------------------|-------|------------------|-----------|---------------|---------------|-------------------|------------------------------|
| Traditional           | P1    | 800              | 11.89     | 51            | 176           | 103.07            | 19.49                        |
|                       | P2    | 633              | 8.31      | 74            | 477           | 155.63            | 29.98                        |
| Precision agriculture  | P1    | 936              | 14.15     | 44            | 169           | 103.55            | 18.56                        |
|                       | P2    | 765              | 10.68     | 96            | 590           | 190.32            | 41.23                        |

On the basis of the data presented above, it can be noted that in the case of the P1 field, regardless of the cultivation technology used, the average values of electromagnetic conductivity were similar and
differed only by 0.48 mS·m⁻¹. The coefficient of variation of the measurement values oscillated from 18.56 to 19.49% and lower values were observed in the case of precision farming technology.

In the P2 field, despite a similar particle size composition of 'Table 1' as in the P1 field, the results were more diverse. The average values were at the level of 155.63 mS·m⁻¹ for the training ground traditionally farmed and 190.32 mS·m⁻¹ in the case of using the precision farming technology 'Table 2'. The coefficient of variation of the measured values fluctuated from 29.98 to 41.23% and lower values were observed in the case of the traditional technology. The obtained results show that the introduction of variable cultivation technology does not always allow to reduce the diversity of factors in the field.

The geographical coordinates of the measured points recorded in all measurements enabled the execution of digital maps of the spatial variability of the soil electromagnetic conductivity 'Figure 4 and 5'. Due to large discrepancies in the values recorded on the experimental fields determined in the P1 and P2 fields, the ranges of values for the legend were prepared separately for P1 and P2.

![Figure 4](image-url)

**Figure 4.** Experimental fields with cultivation carried out in the technology of precision agriculture.

The analysis of the spatial distribution of values on the electromagnetic conductivity maps demonstrated that in the case of cultivation of fields in the technology of precision agriculture, the mean values of 'Figure 4 a, b' occupy the largest area. However, in the case of experimental fields cultivated in a traditional way, the largest areas have values in the very low 'Figure 5 a, b' range.
Figure 5. Experimental fields with cultivation carried out in traditional technology.

5. Summary
The comparison of the maps of spatial variability of the electrical conductivity of the subsoil showed different indications for the compared production technologies. Changes in the distribution of measurement values in the proving grounds cultivated with the same technology were similar despite the differences in soil properties. The analysis of the obtained results demonstrated that the electromagnetic method of soil variability testing very well reflects the real soil variability, however the lack of additional classical control measurements may lead to erroneous conclusions. Even with similar soils in the fields, there may be significant differences in mean values (103 - 190 mS · m⁻¹) and variability (18 - 41%).

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