The remote sensing assessment of potential productivity of a field with soil spatial variability

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Abstract

This paper presents a method of mapping the potential productivity of a field located at the Experimental Station of Baborówko, Poland (52.58° N; 16.64° E) and belonging to the Institute of Soil Sciences and Plant Cultivation, State Research Institute (IUNG-PIB). This field is characterised with a significant spatial variability of soil texture. The method used in the research is based on the combined analyses of different types of data derived from remote sensing measurements. The study used aerial photos and satellite images, measurements of electrical conductivity (EC) of soil, and yield maps. Data were compiled by means of geographic information systems (GIS) with geo-processing tools through the use of geostatistical analysis. The results have revealed different potential productivity zones within the tested field. Established methodology made it possible to generalise the result of geoprocessing and mapping of potential productivity, with resolution corresponding to agricultural practices. Moreover, the experimental field has soil conditions characteristic of the Western part of Poland. For this reason, the results obtained can be applied in practice. The correlations of all types of remote sensing data were established. The most significant of them were the relations yield–soil electrical conductivity and yield–NDVI indices. The NDVI map prepared, based on the satellite image, showed the lowest correlation to the other maps. The likely cause is inadequate data for image acquisition, photographed crop (rape) and too low resolution of image.

Key words: Soil spatial variability, correlation coefficient of spatial distribution, remote sensing, precision farming.

Introduction

The methods of precision agriculture in plant production allow for the use of agricultural practices to the actual conditions of arable fields 1-2. This applies in particular to the physical properties of soil that affect the potential productivity of the field 3-4. Evaluation of the actual soil variability can be used for making maps intended for adequate fertilisation, plant protection, seeding, etc. 4-6.

Detailed studies on spatial variability of soil properties on experimental fields have been carried out at the IUNG-PIB since the mid-nineties of the last century. These were the first attempts in Poland to implement the methods of precision agriculture. The present study was launched at the IUNG-PIB Experimental Station (ES), located in Baborówko, Wielkopolska region. To examine the extent of soil spatial variability about a thousand samples were taken from the topsoil, for which the granulometric composition was determined. On this basis, the soil map at the scale of 1:1000 was prepared. Zones of similar soil granulometric composition and agricultural sustainability complexes were marked on the map (Fig. 1). The results of the analysis confirmed the high spatial variability of soil. Five soil sustainability complexes were located within a space of 53.6 ha, such as wheat – good suitability 2; rye – very good suitability 4; rye – very weak suitability 7 and five soil texture classes according to the Polish Society of Soil Science texture classes: loose sand (pl), weak loamy sand (ps), light loamy sand (pgl), heavy loamy sand (pgm), light loam (gl). This indicates the presence of zones with different yield potential.

Another step to implement the “precision” methods was undertaken in 1996 with the use of a combine harvester, equipped with yield sensor and geographical positioning system (GPS). This enabled the determination of significant differences in crop yield. However, the analysis requires advanced interpretation of the measurements obtained during the harvest, as well as the inclusion of elements of crop management, soil abundance in nutrients and weather conditions during the growing season 10-13.

For a complete analysis of the true variability of the field potential productivity, a series of aerial photographs were taken, in the years 2005-2007. These photographs documented the most significant phases of the development of crops: winter wheat, spring barley and oilseed rape. Analyses of the images confirmed the mosaic of soil and the ability to identify compact polygons that have similar spectral properties. The diversity of soil properties can be obtained by interpreting the reflection of radiation from the canopy 14.

With a view to continuing research into the application of remote sensing methods in the assessment of physical and chemical properties of soil, one of the first measurements of electrical conductivity of soils by on-the-go method was performed in Poland.
in 2007 (Baborówko site). Measurements obtained by this method correlated well with the retention capacity of soil as underlined by Brevik et al. Kinematic measurement of soil electrical conductivity, as well as aerial remote sensing, allows to obtain a detailed map closest to the actual spatial variation.

This paper presents a method of mapping the field potential productivity based on the combined analyses of different types of data derived from remote sensing measurements.

### Material and Methods

Modelling the potential productivity of the field is based on data gathered during the research studies conducted from 1994 to 2009 in the ES Baborówko (52.58° N; 16.64° E). On this site, field experiments using the methodology and techniques of precision agriculture are conducted. The experimental field covers an area of 53.6 ha. Winter wheat, spring barley and winter oil seed rape are cultivated in a 3 year crop rotation system. On the experimental fields the optimal agrotechnology is used, considering the guidelines for technologies employed in integrated agriculture. Field No. 2 (area ca. 16 ha) was chosen as a training polygon (Fig. 1).

For the analysis of the potential productivity, the following set of data was selected:

a) Aerial photos, taken with a digital camera (Sony DSC-F828 8M), from the altitude of ca. 1000 m above the ground level. Images represent the state of matured vegetation, which corresponds to the soil mosaic. Plants located on heavy soil are greener.

b) Satellite image taken by the Ikonos satellite; panchromatic channel with a resolution of 1 m and four channels (Red, Green, Blue, InfraRed) at a resolution of 4 m. The image represents the state of fully developed vegetation of crops.

c) Electrical conductivity of soil map, which was interpolated (by ordinary kriging) based on data gathered during “on-the-go” EM-38 (Geonics, Canada) scanning in vertical mode. The vehicle carrying the measuring device moved over the field with a speed of 20-30 km/h, and sensor recorded data with the interval of one second. Logging points, spaced from each other by several meters, make it possible to obtain a high-resolution image of the tested variability.

d) Yield map of winter wheat. For crop registration the combine harvester Massey-Ferguson 32 with Real-Time Kinematic GPS (1.2 s logging interval) and the isotopic measure of yield was used. Records were analysed for their quality and subsequently the map was interpolated by Ordinary Kriging based on a semivariogram analysis.

**Preparation of the data:** Because of the need to adjust the resulting map, and partial maps to the specificity of cultivation which was established in ES Baborówko, all the maps were plotted at a resolution equal to twice the distance between the technological paths (24 m). For this purpose the yield map and EC map have been generalised by assigning to each pixel a major value from the subset of pixels contained in 24 m x 24 m. This way the effect of directional variance was minimised. Directional variance results generally from the presence of technological paths which are well visible on satellite and aerial images (Fig. 2a, b). The direction of driving of the combine harvester affects also the yield map (Fig. 2d). Only the EC map (Fig. 2c) is free from artefacts associated with agronomical practices.
The aerial photo of the winter wheat crop (Fig. 2a) was converted into a map of the Visible Atmospherically Resistant Index - VARI.  

\[ \text{VARI} = \frac{\text{green} - \text{red}}{\text{green} + \text{red} - \text{blue}} \]  

Satellite image of winter oilseed rape crop (Fig. 2b) was converted into a map of the Normalised Difference Vegetation Index - NDVI.  

\[ \text{NDVI} = \frac{\text{infrared} - \text{red}}{\text{infrared} + \text{red}} \]  

Aerial and satellite data were generalised into 24 m x 24 m raster map, in the same way as yield and EC maps. All raster maps (24 m x 24 m) were reclassified into two classes. A subset of pixels with values less than or equal to the median has been assigned a value “-1”. The second subset of values above the median has been assigned a value “+1”. The map of the field potential productivity was generated by summing the “two classes map” by using pixel (image) algebra.

Analyses were performed in the modules: Spatial Analyst and Geostatistical Analyst of ArcGIS 9.3. Aerial photos were calibrated by using FotoLot 1.4 (author’s application of IUNG-PIB).

**Results and Discussion**

Fig. 3 shows the standardised partial maps generated by the above assumptions and the resulting map of field potential productivity (Fig. 3e). Image algebra of four partial maps allows to obtain 235 pixels raster divided into five classes of potential productivity in the range of values from -4 to 4.

Extreme classes (-4 and 4) represent zones which showed the greatest (4) or the smallest (-4) potential productivity on all types of remote data. Classes with values (2) and (-2) represent zones where favourable conditions prevail (2) or not favourable conditions (-2) to productivity. Class with value 0 is hardly definable, therefore half of the input maps have shown conditions above average and the other half below average.

Visual assessment of the four partial maps confirms the existence of spatial dependence between the images representing mapped features and the large spatial variability which form the regional focuses (zones), with greater or lesser intensity. Different resolution of acquisition of remote data and varied intensity of the local variance confirms the validity of the assumption of common format for geo-processing of the four kinds of spatial information (state of developed and matured vegetation, yield and electrical conductivity).

In Table 1, correlation coefficients of spatial distribution for the map of potential productivity (PP) and partial maps: VARI, NDVI, soil EC and yield were tabulated. The correlation was evaluated for all the combinations of pixels-pairs in 235 locations. The results show a strong influence of VARI and yield maps on the field potential productivity map (correlation coeff. = 0.74). Similar correlation between vegetation index VARI and yield were found elsewhere.

A significant spatial dependence was also observed between the map of potential productivity and soil electrical conductivity. Such results are also reported by Aimrun et al. who suggest that EC survey is an interesting tool for delimiting distinct zones of soil conditions. The relationship between soil EC and yield has been reported and quantified in various papers since soil EC and yield measurements provide closely correlated information about crop production.

However, the impact of NDVI map is much lower (correlation coeff. = 0.48). The highest correlation between partial maps occurs in the case of yield and soil electrical conductivity (correlation coeff. = 0.64), the lowest between maps of NDVI and soil electrical conductivity (correlation coeff. = 0.41).

The image analysis of the maps of potential productivity confirms a large spatial variability. Classes do not create dense zones with a regular shape. The largest modelled area belonging to the same class is a 0.86 ha zone, characterised by the least favourable quality for agricultural production. In most cases there are single pixels or their small clusters.

**Conclusions**

This paper presents an attempt to map the field potential productivity based on the comparison of different types of remote data. With the multiplication properties of the
suitable and unsuitable conditions, enhanced spatial information about productivity of high soil diversity of field was obtained. Thus, in these extreme areas it will be easier to choose the appropriate level of agricultural practices through the use of precise methods. The degree of generalisation with the smallest spatial unit of dimensions 24 m x 24 m should ensure a smooth application of the "on the fly" precise treatment, without the influence of inertia effect coming from the devices differing dose.

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