PhD Thesis Abstract
Doctoral School of Earth Sciences

Application of Geographical Information System and Remote Sensing in precision (site-specific) agriculture

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Title of the Doctoral School: Doctoral School of Earth Sciences

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1. Introduction

The background of my research work is related to the aim of University of West Hungary, Faculty of Agricultural and Food Sciences, Institute of Biosystems Engineering, Precision Agriculture Research Group, which established precision agriculture in Hungary and still is one of the most outstanding institutes in the field of research of the technology. Engineering background of this technology has been investigated by the Institute since 1998. Parallel to the engineering knowledge – such as special machines, sensors, and measurement units – it is mandatory to understand and know the special agricultural softwares. Agricultural softwares are based on Geographical Information Systems (GIS) softwares. GIS in undoubtedly related to Geography due to the fact it is a spatial science.

It was mandatory to investigate the possibility of application of GIS softwares in precision agriculture with geographical knowledge background from the point of view of the practice. Other possible application applied in precision agriculture in the future is remote sensing (RS). Satellite based remote sensing is a reliable database for precision agriculture, however application of the technology in Hungary is not widely known, therefore not widely used among farmers. Starting in 2007, a new piece of equipment – a hyperspectral airborne scanner (AISA Dual system) – is available for research in Hungary. Due to its advantages (spectral and geometric resolution) it was reasonable to investigate the usability of the equipment in my research field.

The dissertation introduces the research methods that have been used following the approach of geospatial sciences applied in the practice in precision agriculture. Therefore the results can be used for precision agriculture applying farmers as well as for geographers collecting information from the surface by various remote sensing methods.

With the rapid development of the technological elements investigated from the precision agricultural point of view – remote sensing and GIS – services in the near future will be available applying such systems. Global Positioning System (GPS) is mandatory for precision agriculture, therefore in the dissertation this technology and application of the technology is introduced in brief as well.

2. Objectives

General objective of the dissertation is to summarize the Geographical Information System (GIS) and Remote Sensing (RS) knowledge needed for precision agriculture, as well as to investigate the role of Global Positioning System (GPS) in the technology. Based on these ideas the specific objectives are the followings:

2.1. Evaluation of the role of **up-to-date satellite based Global Positioning System** from the viewpoint of the practical application in precision agriculture. Also investigation of the effect of the development in accuracy and reliability of the GPS systems on precision agriculture.

2.2. Analysis of the role of **Geographical Information Systems (GIS)** in the realization of the technology as well as publish the GIS experiences related to the practice.

2.3. Evaluation of the possibility of application of satellite based remote sensing in the decision making process and monitoring for precision agriculture.

2.4. Evaluation of possible applications of **hyperspectral** /airborne/ **imaging** during precision agriculture applications, as well as investigate how this new technology can add new approach to the site-specific applications. Also how can the information be input data for various other scientific research fields, like geography.

2.5. Comparison of conventional (multispectral, satellite based) and modern (hyperspectral, airborne) **remote sensing processes**, investigating the advantages and disadvantages of the two technologies.

2.6. Geostatistical based **comparison of the layers** derived from various sources, evaluation of the predictions based on diverse data collection methods as well as study the role and reliability of these layers in precision agriculture.

3. Materials and methods

As a mandatory expectation positioning of the various measurements were carried out with the actual needed accuracy at all times. During data collection carried out by manually handheld GPS receiver (Garmin Etrex) was applied, during harvest submeter accurate differential GPS (CSI wireless Max), for the data georeferencing of the airborne hyperspectral image base receiver helped unit was applied completing the work with post processing methods. The coordinates measured by the various instruments were transformed with the help of the EEHHTT (EUREF-EOV – Official Local Spatial transformation) Software from the WGS-84 (GPS) projection system to the Unified National Projection System (EOV).

Protein content and Yield maps (layers) – in connection with the manually collected data and data collected during harvest were created by ArcView/ArcMap GIS softwares. The collected data was vector based dataset in both cases. Several interpolation techniques and changes in the output cell size (pixel size) were also investigated in order to create the most appropriate result map.

Based on the available remotely sensed images vegetation indices layers (raster) were created. Using the data set for 2001 and the yield map created according to the measurements during harvest yield estimation possibilities were evaluated as a function of time. For the year 2007 spring barley was analyzed focusing on yield estimation. As an addition protein content measurement and protein content estimation was carried out.

I monitored the data collection and preparation method of AISA (Airborne Hyperspectral Imaging System) Dual from the beginning in cooperation with several research institutes from Hungary. Based on the spectral signature of various materials available between 400 and 2450 nm on 359 bands, with the help of ENVI software the most appropriate bands were pointed out in order to be able to predict the quality parameters (protein content) of spring barley. Furthermore, based on the 1 m sharp airborne image I created the layers of the hyperspectral vegetation indices that could be used later on for the geostatistical analysis of the data derived from the airborne image.

Based on the different data sources, geospatial layers were created in order to be able to apply the measurement raster based data in geostatistical data analysis methods. Geostatistical comparisons were carried out by means of IDRISI Kilimanjaro software. Applying regression and multiply regression analysis I investigated the differences of output layers caused by various interpolation methods, compared the layers (maps) created on the basis of data collected during harvest with multispectral and hyperspectral image based, predicted yield and protein content, as well as evaluated the connections between hand collected data based and remotely sensed data based layers.

4. Results

4.1. The role of up to date satellite based positioning in precision agriculture.

It has been concluded that the improvement of accuracy and reliability of up to date satellite based positioning systems (GPS) has a positive impact on precision agriculture. Nowadays reliability of satellite positioning (secure of signal receiving) has reached 99% level. Satellite based positioning applied during the dissertation work has been applied on the most appropriate and needed level at all time. Applying handheld GPS the accuracy has reached 2-5 m. During data collection at harvesting and site specific fertilizing accuracy of the satellite based positioning stayed beyond 1 m. For georeferencing the airborne hyperspectral image the outline of the field was surveyed by high accuracy GPS system, data was corrected with post processing method therefore accuracy stayed beyond several centimetres. It has been also concluded that in case the precision agriculture technology requires, satellite based positioning can be increased to 2-3 cm accuracy. In this case within row agricultural work can be done relied on GPS systems. Continuous investigation of the technology is required, integration of the new independent European satellite system (Galileo) can be the next challenge for the receivers in the future.

4.2. The role of GIS in the practise of precision agriculture.

Geographical Information System (GIS) has similar role in precision agriculture as satellite based positioning. The two systems complete each other, for precision agriculture application of both systems is mandatory. Geographical Information System (raster and vector based as well) adds so much for the data preparation that by now it has become the tool of decision making. It is mandatory at the same time to keep in mind that during application of such systems false data or not satisfactory application of the software's can result inappropriate layers therefore false decision can be made.

Interpolation has to be made at all cases according to the required output cell size (pixel) in order to create comparable layers with other data collected by different methods. The output cell size has major role on the result layers (Fig 1.).

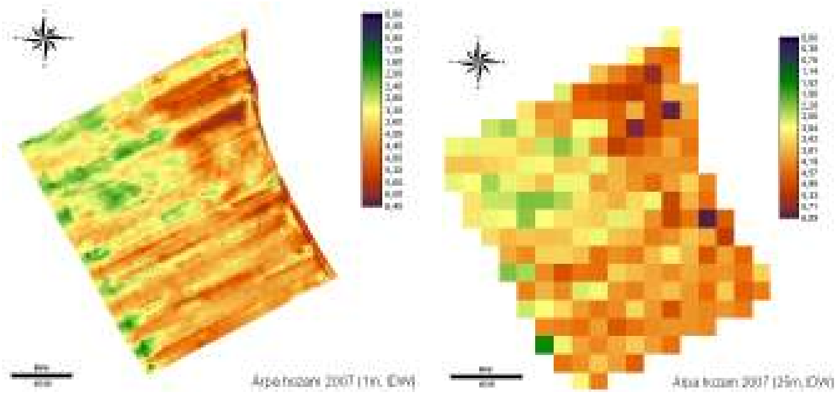

Figure 1.: 1 m /left/ and 25 m /right/ pixel size yield maps

4.3. Application possibilities of satellite based images in the decision making and monitoring system of precision agriculture.

Satellite based data collection – in case Landsat images are used for analysis – can be limited by the 16 days revisiting time due to satellite path of cloudy situation. In case the meteorological situation is satisfactory, satellite based remote sensing can be an important data source for precision agriculture.

Satellite images can be represented as separate pictures band by band or as merged layers as well. Choosing and applying the most appropriate bands (R, G, B, NIR, MIR) normal and false colour pictures can be represented. With the help of such pictures differences occur in various part of a field can be seen for the first sight. Interpretation of the satellite images are in raster format, therefore they provide map-like pictures for precision agriculture.

Based on the different layers (one or more bands) or vegetation indices expected yield as well as quality parameters can be predicted. The time of image collection for different plants play major role on the success of the prediction.

In case of maize (year 2001) image collected at the end of may has slightly differed from the best result of prediction based on image collected at June (r=0,6336 /n=205/).

In 2007 for spring barley the best result was achievable by the image collected in mid June (r=0,6241 /n=206/). The quality (protein content) parameter prediction resulted better correlation than quantity (yield) prediction.

Multiply regression analysis of the multispectral satellite image for grain protein prediction has resulted approximately R^2=0,7 correlation, which is a good result in the practice. Comparison based on the satellite image collected in beginning of June has resulted r=0,8701, /n=206/ values.

In this case the Inverse Distance Weighting (IDW) interpolation method has showed better correlation with the predicted data.

4.4. The role of hyperspectral /airborne/ imaging from the point of view of site specific plant production. The role of hyperspectral data collection in other disciplines, for example in applied geography.

The advantages of the hyperspectral images compared to satellite based multispectral images are: more precise image collection timing, better geometric resolution (up to 1m) and due to more spectral bands combination of the bands gives more possibilities.

Due to the significant increasement of the geometric and spectral resolution, various factors influencing precision agriculture can be interpreted which was not visible earlier even in the visible light range. Observing the picture a line shaped infrastructure (most probably a buried pipe), and a buried river bed becomes visible which are influencing the water management, leaching and fertilizing management as well. (Fig. 2.). These quality differences can increase the accuracy of source data for the appropriate application in geography as well.

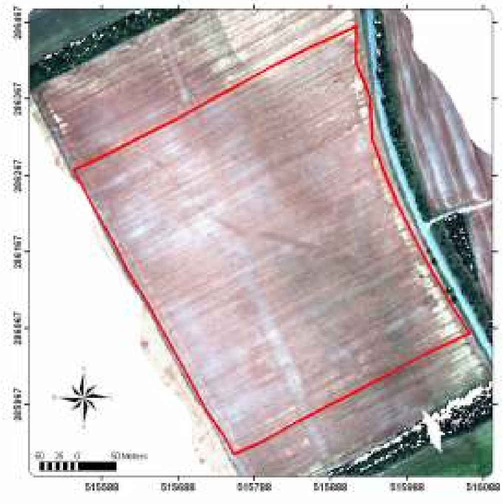

Fig. 2.: RGB composite of the 80/1-es research field based on B65, B30 and B 14 hyperspectral bands. (Source: MILICS G., 2007)

4.5. Comparison of the long established (multispectral, satellite based) and modern (hyperspectral, airborne) remote sensing.

The long established multispectral, satellite based remote sensing compared to the modern, hyperspectral, airborne imaging has some disadvantages due to geometric resolution and satellite paths. Comparing the 25 m geometric resolution of the satellite pictures to the 1m airborne images the resolution of the earlier one has some disadvantages. (Fig. 3.). Since the revisiting time in case of Landsat image collection is 16 days and the data collection with airborne method depends only on the cloud coverage, airborne imaging is more reliable and accurate.

Better spectral and radiometric resolution of hyperspectral imaging is a further advantage supporting the airborne system. The Landsat satellite image has only 7 wide bands, while the hyperspectral imaging system in this case collected images in 359 various bands. Compared to the satellite image 8 bit colour scale the hyperspectral system scans the images in 12 and 14 bits, which means 16384 colour shade in the greyscale compared to the 256 different colours.

It has to be noted however that geostatistical analysis did not prove the reliability of the yield and protein content prediction expected from the increasing and better spectral resolution.

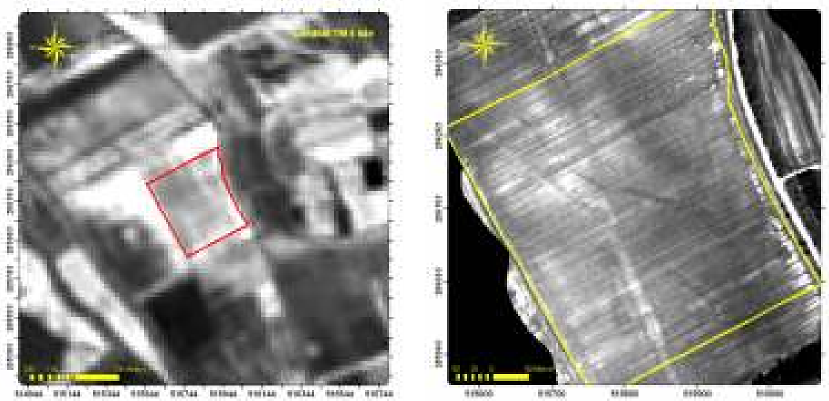

Figure 3.: Differences between the geometric resolution of satellite and airborne image
(Source: MILICS G., 2007; Background: ©: ESA, EURIMAGE and FÖMI, 2007)

4.6. Evaluation of geostatistically compared, different data source based layers; the role of reliability of predictions of several different data collection methods and predictions based on the layers applying the data in precision agriculture.

Depending on the interpolation technology applied (IDW or kriging) comparing the yield data created for investigating the correlations with Landsat satellite images (geometric resolution 25 m) 206 separate pixel can be investigated in the research field. The regression between the two interpolation method based layers is R^2=0,8946 /n=206/. The correlation between the two pictures is very strong (r=0.9458). The number of useful pixels with the 1 m geometrical resolution picture has increased to 155.350. The correlation between the IDW and kriging method applied pictures is r=0,9431. The regression is R^2=0,8896 /n=155350/.

Yield in case of maize applying the middle infrared bands can be predicted as early as the end of May. In case of maize, the best result was shown in the satellite image collected at end of June (r=0,6336 /n=205/), while in case of spring barley the image collected in mid June showed better correlation (r=0,6241 /n=206/).

The timing of the image collection has a major role on vegetation indices and has influences the applicability of the indices.

Prediction of quality parameters versus prediction of quantity parameters has shown better results using satellite images as well as applying hyperspectral airborne based images.

Multiply regression analysis of multispectral satellite image for prediction of protein content has shown approximately R^2=0,7 correlation r=0,8701 /n=206/, which is relatively good result in practice.

Choosing the best ten bands (independently shown correlation with grain protein content layers) from the available 359 hyperspectral bands the multiply regression analysis has reached R^2=0,6 /n=155350/ (Fig. 4.).

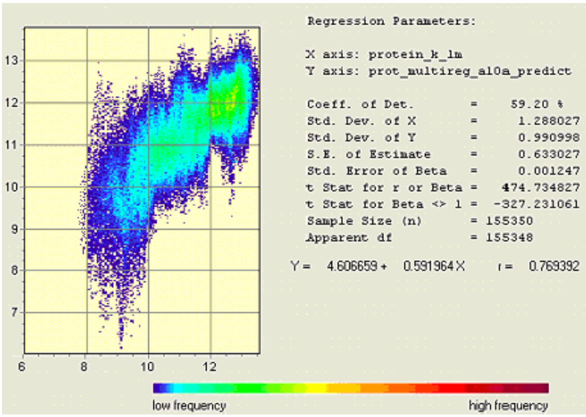

Figure 4.: Regression parameters at hyperspectral image analysis
(Source: Milics, 2008)

In case of proper timing, prediction of the quantity parameters can be carried out based on the airborne hyperspectral image.

Application of on-line grain protein content measurement in spring barley in the year 2007 was not successful. The reason for this could be false calibration, as well as the continuous pollution of the sensor heads (Zeltex Accuharvest On-Combine Grain Analyzer) due to dust.

5. Further research directions

In 2007/2008 agricultural year maize is planned to be planted in the investigated research field. The autumn fertilizer replenishment has been carried out, the spring replenishment has to be done according to the variable rate application requirement of the precision agriculture practise. In order to further study the applicability of airborne based yield prediction imaging between May and August should be done at least four times. Geometric resolution for precision agriculture can be decreased to 4 m by 4 m, therefore imaging can be broaden to the surrounding fields. At the same time at least some of the technological elements (yield mapping at least) should be applied in these fields as well.

Calibration of the Zeltex On-Combine Grain Analyzer (applied for the quality parameter measurements) and operation of the instrument is among the highlighted research focuses. In case we have enough experience in the calibration and application process, the instrument can become a new tool for precision agriculture.

For storage reasons, the measurement of grain moisture content of the corn is mandatory. The different measurement methods (capacitive and Near Infra Red, NIR) applied for the moisture measurement has to be comparable in order to evaluate the reliability of the methods. Applying the possibilities provided by GIS methods, grain moisture maps have to be drawn and in case any difference should occur the reasons for the difference have to be investigated.

Publications

a.) Publications related to the dissertation

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