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Abstract of PhD thesis

Comparable analysis of remote sensing techniques in agricultural model areas

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1. Background of the study

1.1 Actuality of the subject

Nowadays, rapid information technological development provides us such methods, like global positioning, spatial informatics, remote sensing, by which living organisms and inorganic parts of the surface can be analyzed in a rapid and inexpensive way, in large areas. Besides (instead) traditional, ground point-sampling data, with the help of remote sensing, now it is possible to gain information about wide areas, at the same time.

In parallel to informatics, remote sensing also shows significant development. Gained information from data sources is improving; today it is possible to examine characteristics which were hidden when traditional methods were applied. New remote sensing tools appear in the space, as well as images of increasing radiometric resolution, some of which can be used for observation of global and meteorological processes, while others can be applied in precision techniques. In addition to visible light range, satellites equipped with multispectral sensors are able to take images of medium and high resolution in near- and mid-infrared ranges. In the last decade, hyperspectral remote sensing and image analysis became one of the most rapidly developing areas. In addition to near ground and aerial sensors, satellites also appeared, which are equipped hyperspectral sensors capable of taking images of high radiometrical and geometrical resolutions, such as HYMAP. In case of multi- and hyperspectral remote sensing, besides developing capabilities of sensors, data processing and data interpretation are also challenging.

Environmental monitoring and models, as well as precision agriculture require more and more accurate soil and vegetation maps, for which data can be provided with rapid and inexpensive analysis of great amount of samples, and analysis of images taken with the help of remote sensing. In the European Union, space images are integrant parts of precision agriculture (e.g. FARMSTAR program) and checking cultivated lands (MARS), while in Hungary, the same applies to the cultivated parcel identifying system (MEPAR) and vegetation monitoring program (NÖVMON), coordinated by the Institute of Geodesy, Cartography and Remote Sensing (FÖMI).

As a result of rapid development of remote sensing, newer data sources and data processing methods are available, which have several advantages as well as application limitations that need to be confirmed with scientific approach. The PhD work summarized here is based on this professional challenge, providing results that support further development of the area.

2. Objectives of the study

For the analysis, different remotely sensed data and methods were applied in model areas that brought up the following questions:

- What are the possibilities and limitations of the application of some remotely sensed data sources?
- Which image processing method and model give the most precise data for the images used for the analysis?
- How can the precision and effectiveness of the applied remotely sensed data processing methods be improved?
- Which water management parameters can be examined based on remotely sensed data sources?
- How can the remotely sensed data be integrated into the various GIS databases and water management models?

The aim of the study was to use different types of remotely sensed data having various geometrical resolutions for the examination of cultivated lands. Connecting to it, the following questions were to be answered:

- What are the radiometrical and geometrical features of the applied remotely sensed images?
- By using near ground remote sensing, with what reliability can different plant species, coverage of weedy plantation and leaf area be measured, and what are the limitations of the applied methods?
- Based on spectral information provided by remotely sensed images of intensively cultivated lands, how can the spatial variations of the biophysical and soil properties determining the agro-ecological and cultivation characteristics be estimated?
- Which methods are applicable to quantitatively examine the agricultural lands for the determination of the various land-use categories in parcel size, via the analysis of the used data sources?
- How can the analysis of the classification results of parcel-size be carried out in a way to provide information of area basis?
- What method can be applied to integrate data sets obtained from time series image processing with high resolution remotely sensed data and other databases?

3. Materials and Methods

3.1 Model areas

The studies were carried out in model areas of different size and geographical location. Most of the analyses were carried out in Tedej-puszta (1500ha) and ***Szolnok-Túri-sík*** (~100000ha). ***Tedej-puszta*** is located in the North-Plane Region, north to the town Hajdúböszörmény. In the model area of 1500ha involving unbroken, large parcels, intensive agricultural cultivation is typical, the cropping data of which, gained from land herd-book data and digital soil maps of high resolution, were used to generate an integrated database. Based on the land herd-book data and field survey, at the time of taking the remotely sensed image, 43 physical blocks were separated in the model area, which were grouped into 6 groups as follows: ploughing, stubble-field (corns and lucerne), lucerne, maize, sugar-beet, and grass. The exact isolation was necessary to demonstrate the actual state, as well as to reduce the disturbing spectral effect of sides, drains, constructive works, etc.

The ***Szolnok-Túri-sík*** model area, in the area of Jász-Nagykun-Szolnok County Plant Protection and Soil Conservation Service (NTSZ), includes Mezőtúr, Túrkeve, Örményes, and partly Fegyvernek and Kétpó administrative areas. The model areas were pointed out based on the advice of the NTSZ staff, with the help of a GPS, and according to the physical blocks determined in 2003.

For the coverage analysis of the model areas used for strain research and plant protection tests, several different images were taken, which can be characterised as follows: In the area of the ***University of Debrecen, Centre of Agricultural Sciences, Látókép Cropping Pilot Ranch***, the leaf area of 6 maize hybrids were examined. In the pilot ranch, several different cropping models are tested, from which 5 hybrids examined in different small parcel tests were selected. Images were taken in the ***Keszthely model area*** of the University of Pannon, Faculty of Georgikon, in the parcels used for plant protection examinations. In this area, weed composition (coverage and species) of the parcels is examined, which are treated with NPK fertilizers of different active agent content, and manure, and where rotation of maize – winter wheat – winter barley is applied. Detailed characterization of the treatments and weed survey was published by Lehoczky et al. (2006). Further investigation was made for crop protection purpose as a part of the survey for „Program for Pollen Information System" in the reference area of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI), in the ***Újfehértó model area*** located in the North-Plane Region, in 2005. For the purpose of a detailed weed survey, two average parcel-sized lands of 7ha characteristic of the region were pointed out, one was covered with weed, and the other was the control parcel covered with sunflower, the soil of both is acidic sandy, and the dominant weed species is ragweed (*Ambrosia artemisiifolia).* The detailed weed survey was carried out on 18th June, 2005.

3.2. Remotely sensed data used for the analysis

In the study, different geometrical data with different spectral resolution were applied, from the images taken with a multispectral TETRACAM ADC digital camera having near ground broadband 3 channels (blue, red and near infrared) to the MODIS space images with low geometrical resolution. Most of the space images used for the analysis were archive, thus at the exact time of taking the photo it was not possible to carry out in situ sampling in each case. In case of the TERTACAM ADC multispectral camera, in parallel to the image taking it was possible to design and carry out a precise field sampling.

Table 1 contains base data from the data sources used for the analysis. In case of the MODIS, only channels of 250m spatial resolution were known.

Table 1: Summary of remotely sensed data sources used for the analysis

remotely sensed image	size of the image (km)	spatial resolution	number of bands	bands (μm)	date of image taking
MODIS	2330 (bandwidth)	250m	36	1. 0.62-0.67[1] 2. 0.84-0.87[1]	01.03.2003.- 30.09.2003. (30pcs)
LANDSAT 7 ETM+	170×183	MS: 30m TIR: 60m PAN: 15m	7+1 (PAN)	1. 0.45-0.515 2. 0.525-0.605 3. 0.63-0.69 4. 0.75-0.90 5. 1.55-1-75 6. 10.40-12.50 7. 2.08-2.35	19.08.2002.
SPOT 5	60×60	MS: 10m PAN: 5/2.5 m	4	1. 0.50-0.59 2. 0.61-0.68 3. 0.78-0.89 4. 1.58-1.75	08.05.2003. 11.08.2003.
DAIS - 7915	3.99×8.73 [2]	5m[2]	80	1.-32. 0.40-1.00 (Si)[4] 33.-40. 1.50-1.80 (InSb)[4] 41.-72. 2.00 – 2.50 (InSb)[4] 73. 3.00-5.00 (InSb)[4] 74.-79. 8.00-12.60 (MCT)[4]	19.08.2002.
TETRA-CAM ADC	0.42×0.50 [3]	0.5m[3]	3	1. 0.52-0.60 2. 0.62-0.75 3. 0.75-0.95	-

1: channels with 250m spatial resolution
2: at 2000m flying height
3: at 300m flying height
4: DAIS sensor types

3.3 Other cartographical data sources

For the geometrical correction of the remotely sensed images of the ***Tedej model area*** the digital versions of EOTR topographic maps of 79-112, 79-121, 89-334, and 89-343 profiles having scale of 1:10000 and the orthophotos with 0.60m spatial resolution, taken in the year 2000. The renewed soil information system about the area was worked out in 2000, as well. The digital soil map contains the main physical and chemical soil properties, which based on soil profiles' samples were analyzed by the Hajdú- Bihar County Plant Protection and Soil Conservation Service, and used for creating a detailed soil genetic map. By using ortho photos, parcel borders were determined for the classification and qualitative analysis of the images. Data of the parcel herd-book as well as that of filed survey were linked to the vector dataset. About the model area, detailed GIS database was available, which contained soil, cultivation and nutrient management parameters. For the geometric correction of the ***Szolnok-Túri-sík*** model area, DTA-50 digital database was used to determine the GCP points. In case of the near ground images about the other model areas, there was no need for other mapping databases.

3.4 Field sampling

At the ***Látókép Cropping Pilot Ranch***, for the near ground images, the area calculation was carried out for the plants individually by using the Montgomery method (Petrasovits, 1988). In addition to the total leaf area, the photosynthetically active green and dry leaf areas were also measured. In case of the ***Újfehértó model area***, the analysed points were selected randomly within the quadrates of 70×70 m, determined by the FÖMI. Positions were pointed out with the help of a DGPS tool having sub-meter precision. The weed survey was carried out according to the Balázs-Újvárosi method (Újvárosi, 1973), and images were taken with a TETRACAM ADC camera about areas of 1×1 m. Using the results of the weed survey, weed map was generated by using ArcGIS geo-statistical algorithms, and kriging, corresponding to the map segment and the LANDSAT pixel values. Further leaf area analysis was carried out with various weed species, where it was possible to collect the plant leaves and measure the exact leaf area with the help of a flat bed scanner, right after taking the image.

In the ***Tedej-puszta model area***, in addition to the data of parcels for the purpose of the analysis of land-use and vegetation as well as the herd-book data, field samples were also collected. In case of the model area P5, for the examination of salt content variation, soil samples were taken and certain plant features were analysed. Confirming the results, data of the previously examined area P8 were also included.

In the area of 100x250m, a part of the parcel P5, geodesic measurement and soil sampling were carried out after the winter wheat harvest (02. 08. 2004.). In the area, a 10×10m grid was used to give the elevation values of the cross points with the help of a geodesic tool, the x and y coordinates were recorded with a Trimble DGPS tool. For the measurement of the salt content, disturbed soil samples were taken from the depth 0-0.3m for the laboratory analysis. From the air-dried and ground soil samples, soil: water suspension of rate 1:2.5 was made to determine pH and electric conductivity ($EC_{2.5}$) according to the relevant standard. In the examined area, the surface salt content distribution showed similar spatial pattern as in case of parcel P8, which confirms the alkalization phenomenon detailed by Tóth (2002).

In parcel P8, in the model area selected for cercospore examination in large parcel scale shroud protection experiments, rhizomania tolerant species (Triplex) were used, with same treatment in each parcel. Te examination included the analysis of effects of chemicals' treatment time, treatment number, and different fungicides. For the determination of the cercospore leaf spots (*Cercospora beticola*), bonitation were applied in a way, that vegetation were examined in each parcel 10 by 10m, than an average was calculated.

4. Main conclusion of the theses

The spatial and temporal variables of soil and biophysical parameters of agricultural areas were investigated by remote sensing methods that proved more effective tool than traditional sampling methods. The researche relate to soil and biophysical parameters that influence the water management like electric conductivity of soil, leaf area, biomass, etc. Same phenomena were observed between the processed different type images and the biophysical parameters however we should have applied suitable image processing methods because of the difference radiometric and geometric parameters of the images.

The geometric parameters of the TETRACAM ADC multispectral camera - used for the near-surface and low altitude airborne imaging - were examined then its applicability for fast field measurements/surveying were determined. A strong positive regression between vegetation coverage and NDVI were detected - within the range of 5-80% coverage - on images taken on different plant species with the camera. The camera proved to be a fast, accurate and cost-effective means of surveying weed infected crops with near-surface and low altitude airborne imaging.

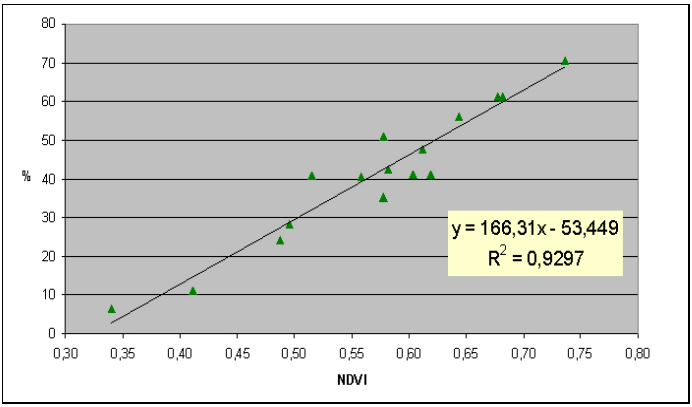

Figure 1. Linear regression between the NDVI and Canopy (%) at Keszthely sample site

The camera was used for the examination of winter wheat crop in a salt affected area with airborne imaging. The obtained NDVI, derived from the taken image, demonstrated its efficiency for the estimation of leaf-area index (LAI), stem height and seed production of winter wheat crop. Winter wheat indicates changes in the conductivity of the upper soil layer; therefore the calculated NDVI not only allows the estimation of certain biophysical parameters of the crop, but the spatial variance of the salt content of the soil, as well. It was concluded that the increasing salt content of the upper soil layer negatively affects plant biomass (plant/stem height, seed production).

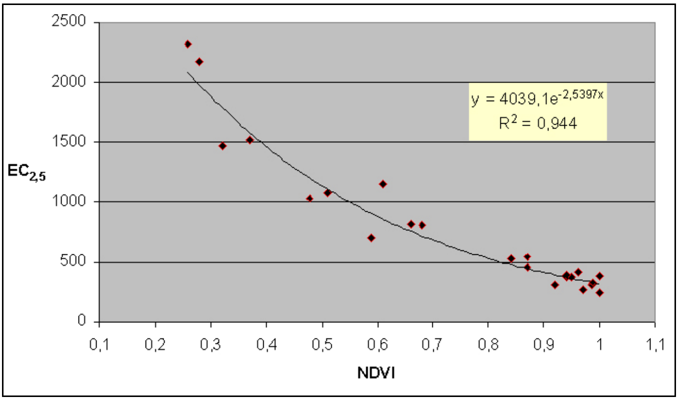

Figure 2. Regression between the NDVI from TETRACAM ADC and Electric Conductivity ($EC_{2,5}$)

Examinations of salinization were also carried out by the analysis of hyperspectral images. At the time the image was taken the investigated model area was covered with a mixed composition of plant species. Only the value of a few reflectance/radiance bands of the applied DAIS 7915 hyperspectral image showed statistic connections with the changes in the salt content of the soil. Based on the examination of the model area it could be concluded that the most accurate estimations of salt content changes could be achieved with the application of certain wavelengths within the MIR and TIR range.

The examinations of the spatial variability of sugar beet leaf area were performed in the frame of a large scale field pest control experiment in the Tedej model area. The effects of different pest control treatments on leaf area - applied on the model area - were studied by processing DAIS 7915 images. The spatial pattern of each treatment was examined by principal component analysis using the values representing the variability of vegetation as the principal component.

Based on the regression analysis it could be concluded that each NIR channel is suitable for the estimation of leaf area changes, although MIR and TIR range is less sensible to vegetation changes. In the course of calculations NDVI, REP values were obtained from pre-processing and compared to values of leaf contamination/infestation. The highest regression rates could be estimated from the iteration model (R^2 =0,731, p<0,05) calculated from the 1,668 μm range (*Figure 3*).

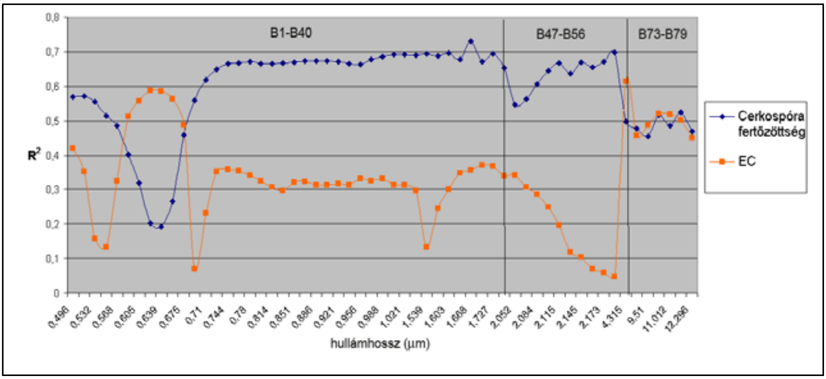

Figure 3. Deterministic coefficients (R^2) of cercospore leaf spots (*Cercospora beticola*) (%) and electric conductivity ($EC_{2,5}$).

Cercospore map was made by image processing from the B37 band of georectifed hyperspectral data. This map shows the spatial distribution of the disease inside the parcel (Figure 4).

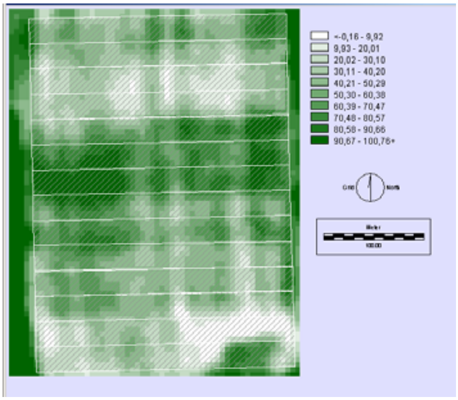

Figure 4. Cercospore leaf spots map and the investigated parcelles.

Changes in weed coverage and composition were investigated in sunflower crop infested with common ragweed (*Ambrosia artemisiifolia*) on acidic sandy soil. The results of sampling were compared with reflectance data of LANDSAT ETM+ images. Weak deterministic relationship were discovered between the calculated NDVI data and total coverage, however the identification/estimation of weeds at a species level from LANDSAT data could be performed only with a high level of uncertainty.

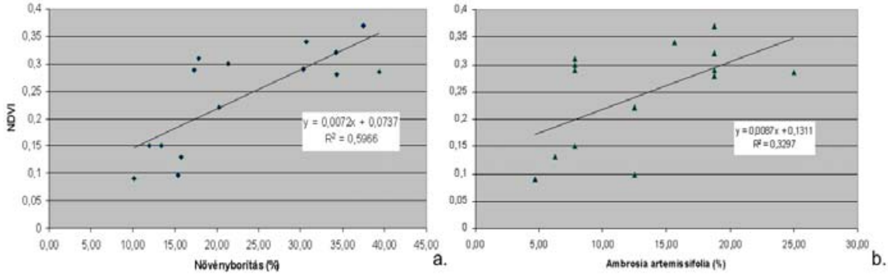

Figure 5. Linear regression between NDVI from LANDSAT images and canopy (%) (n=15) (a.), and between NDVI from LANDSAT images and *Ambrosia artemisiifolia* (n=15) (b.).

The applied multispectral and hyperspectral images had different geometric and radiometric parameters however the research was improved could be evaluated several variables with applying suitable image processing methods (Figure 6.).

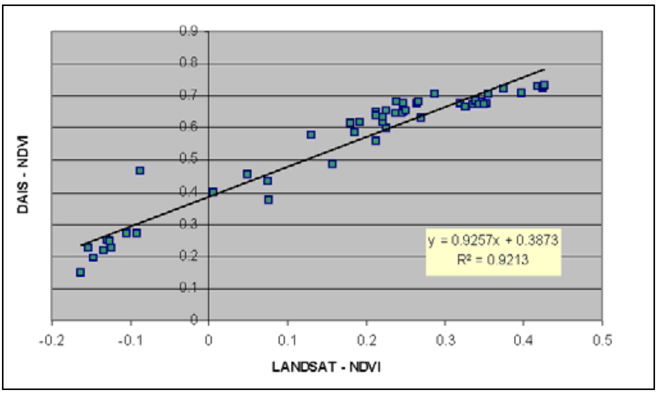

Figure 6. Linear regression between NDVI from LANDSAT 7 ETM+ image and NDVI from DAIS 7915 hyperspectral image.

There were a strong correlation between surface temperature was calculated by DAIS 7915 images and NDVI. Decreasing biomass makes increase the surface temperature (Figure 7). The regression between the TIR band of the LANDSAT

ETM+ image and the surface temperature was lower than in case of DAIS 7915 data.

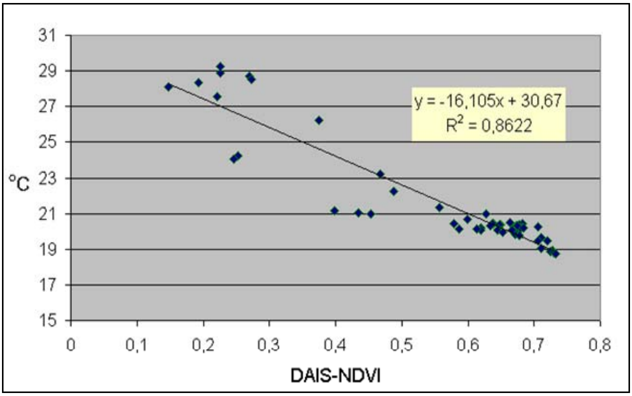

Figure 7. Linear regression between NDVI from DAIS 7915 and surface temperature.

Six land-use categories were examined in the Tedej model area with LANDSAT ETM+ and DAIS-7915 images, where supervised and unsupervised classification was applied. Accuracy could be improved by masking sample areas and by increasing repetitions of hyperspectral images. The accuracy of classification in hyperspectral examinations could be improved by the application of principal components calculated with principal component analysis for the reduction of channel number. The accuracy of classification could be improved by masking sample areas and by increasing repetitions when using K-means method. Among the different classification methods the most reliable results were provided by the *maximum likelihood* method, average accuracy being 78,22% in case of LANDSAT and 85,52% in case of DAIS 7915.

Table 2. The results of the confusion matrixes

Image classification	Data	Accuracy	stubble	plough	lucerne	meadow	maize	sugar beet	Overal accuracy	Kappa index
K-Means * +mask	LANDSAT	Production	89,04	73,44	50,65	0,69	92,52	0,15	66,97	0,56
		User	96,85	10,46	83,49	15,72	71,95	0,89		
K-Means * +mask	DAIS	Production	86,00	9,96	38,64	19,00	71,69	20,71	57,87	0,43
		User	89,63	7,57	99,56	27,66	55,35	14,21		
K-Means ** +mask	LANDSAT	Production	96,29	35,79	59,84	72,43	98,84	92,26	74,97	0,68
		User	45,73	16,89	93,55	98,24	53,01	96,68		
K-Means ** +mask	DAIS	Production	69,98	21,10	67,30	27,74	64,33	3,22	56,64	0,43
		User	91,48	9,77	95,38	21,30	59,70	2,15		
K-Means ** +mask	DAIS (PCA)	Production	98,01	96,37	67,27	37,85	68,18	89,69	77,27	0,71
		User	97,67	41,01	94,27	10,76	88,34	80,34		
Maximum likelihood	LANDSAT	Production	94,62	81,83	73,11	70,67	85,72	73,48	78,22	0,72
		User	95	85,55	98,85	97,5	14,55	99,88		
Maximum likelihood	DAIS	Production	93,14	81,22	78,51	91,43	84,84	84,68	85,52	0,81
		User	98,84	100	99,7	20,28	99,01	99,89		

*iteration = 1, **iteration = 10

In the Szolnok-Túri-Plain model area regional scale land-use analysis was performed with the application of SPOT-5 multispectral images. Images were transformed to the Hungarian national projection system (EOV). The most reliable results for the classification of the images were achieved by the *maximum likelihood* method with supervised classification. Between the two examined moments the early autumn date provided more accurate results, which could be further improved by merging/contracting the two moments.

Table 3. The results of the confusion matrixes

Osztályozás	Felvétel	Pontosság	Borsó	Cukorrépa	Gyep	Kukorica	Lucerna	Napraforgó	Öszi búza	Repce	Rizs	Tavaszi árpa	Teljes pontosság
Maximum likelihood	SPOT 02	Production	31,68	82,7	69,14	55,85	75,11	45,9	68,03	34,01	55,94	48,03	**57,79**
		User	16,52	71,66	94,4	68,68	57,15	59,09	76,54	18,59	67,18	16,54	
Maximum likelihood	SPOT 01	Production	43,86	82,79	62,22	12,69	67,84	46,25	30,65	30,82	69,26	58,71	**34,35**
		User	22,47	20,92	84,03	46,7	37,58	31,18	81,94	5,7	15,73	17,24	
Maximum likelihood	SPOT 0102	Production	50,51	83,26	66,49	64,48	77,3	64,08	71,54	20,29	54,7	58,4	**66,73**
		User	54,67	83,43	94,66	69,96	64,21	49,34	85,84	61,33	98,95	35,37	
K-Means	SPOT 0102	Production	26,17	86,66	77,79	34,75	69,01	32,43	35,84	17,89	0,02	1,85	**35,94**
		User	8,5	26,72	21,96	56,82	67,6	42,66	84,72	1,67	0	1,04	

SPOT01: 2003. 08. 11.-én készített SPOT 04 felvétel, SPOT02: 2003. 05. 08.-án készített SPOT 04 felvétel
SPOT0102: A SPOT01 és SPOT02 felvételek összevonásából készített felvétel

The majority of errors in the examination of classified plots could be linked to geometric correction, errors in plot measurement and border effect. For the evaluation of the classification such a method was used which - unlike the traditionally used error matrix - examined the accuracy of classification by plots and the results could be queried by plots, too.

For the time-series examination of vegetation MODIS images were used, where spatially homogenous sample areas were defined for the examinations. Atmospheric correction was carried out on image pairs after the geometric transformation of images in order to select cloudy areas. NDVI - calculated from MODIS images applied in the regional examinations – was used for calculating the time series of vegetation growth dynamics (Figure 8.), then define the dynamics of vegetation by drawing trend lines (Figure 9).

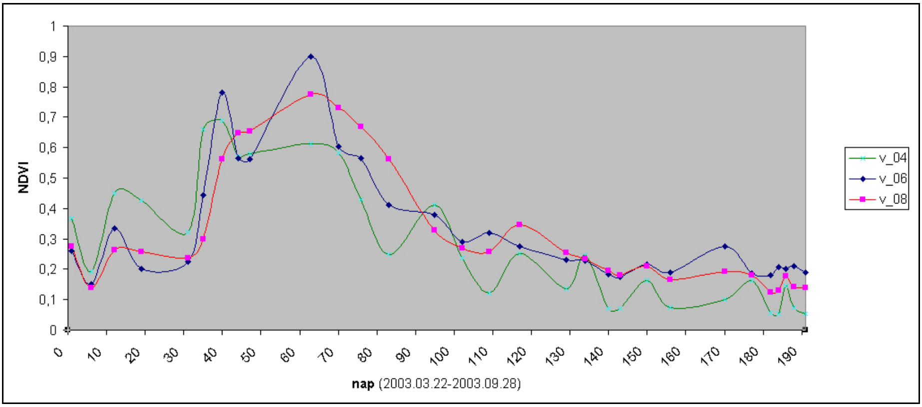

Figure 8. NDVI time series of wheat parcels

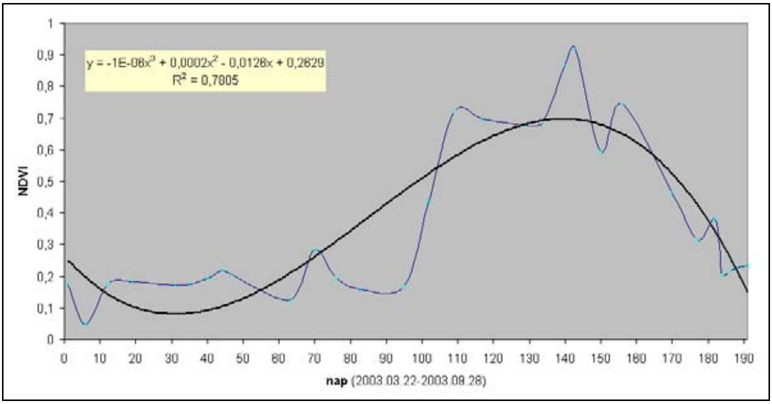

Figure 9. NDVI time series was calculated by maize reflectance values from MODIS data

A draft concept model was developed - based on the plots computed from the SPOT-5 classification and the MODIS time series data - which could be applied as input parameter for regional water management models in case it is supported by further research.

5. New scientific and practical results

5.1 New and innovative results

In my PhD thesis, based on my studies detailed above, the following new and innovative scientific results are stated:

I. I determined the possibilities and limitations of near ground application for the TETRACAM ADC digital multispectral camera in the examination of vegetation cover and leaf area (LAI).

II. Based on NDVI index calculated from the images taken at low height, I mapped some biophysical parameters of a winter wheat cultivation, and indirectly, the electric conductivity of the soil surface.

III. I determined, which wavelength ranges of the mid-infrared (MIR) and thermal infrared (TIR) spectra are sensitive to the soil electric conductivity in case if the vegetation in visible (VIS) and near-infrared (NIR) ranges does not indicate it obviously.

IV. As part of the analysis of the spatial pattern as a result of shroud protection treatments, I concluded, that the variation in leaf area can be estimated with all NIR channels.

V. The method, I developed for the analysis of remotely sensed image classification, oppositely to the traditionally used error matrix, gives the precision of the classification parcel by parcel, with query also parcel by parcel.

5.2 Practical results

Based on the result of my studies, the following can be concluded:

I. Based on comparison of different remotely sensed images, I found, that hyperspectral images processed in the right way, give more precise assessment for the soil and vegetation parameters, than the images of mid-resolution (LANDSAT ETM+), thus I recommend to apply them more widely in the agri-environmental analyses.

II. During the data processing, my results confirmed the importance of the appropriate pre-processing, i.e. selecting the right channel or channels, similar or better results can be achieved, that using all spectra or their transformed versions.

III. I concluded that using vegetation index calculated from the MODIS images of low resolution, the growth of agricultural plants can be modelled well in cultivated lands of great size.

Scientific publication list

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3. *Burai P.,* Pechmann I. (2005): Talajdegradációs folyamatok vizsgálata nagy felbontású távérzékelt adatforrások alapján. Agrárközlemények, Acta Agraria Debreceniensis, Debreceni Egyetem. 2005/16, pp. 145-149.
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