CROPMON: HUNGARIAN CROP PRODUCTION FORECAST BY REMOTE SENSING

G. Csornai, Cs. Wirnhardt, Zs. Suba, G. Nádor, L. Tikász, dr. L. Martinovich, A. Kocsis, Gy. Zelei, I. László, E. Bognár

FÖMI Remote Sensing Centre,
Institute of Geodesy, Cartography and Remote Sensing
H-1149 Budapest, Bosnyák tér 5.
Hungary
Phone: +36-1-252-7898, fax: +36-1-252-8282
E-mail: csornai.gabor@fomi.hu

KEY WORDS: crop monitoring, production forecast, drought monitoring, subsidy control, flood monitoring, waterlog monitoring

ABSTRACT:

The Hungarian Agricultural Remote Sensing Program led to a concise methodology that could further be applied operationally. First the main results of a substantial R&D investment and methodology plus validation results are summarized. The crops area assessment, through the processing of multitemporal Landsat and IRS-1C/1D data proved to be efficient at county level because of the accuracy of thematic classification. The novel combined high resolution images + NOAA AVHRR series based crop yield forecast methodology performed well for the major crops (8) at county level. Based on the experiences of the first 5 operational years (from 1997) a general evaluation on the Operational Crop Monitoring and Production Forecast Program (CROPMON) is given. The CROPMON system is a good platform for additional projects implementation as in the case of a serious waterlog assessment and impact analysis in spring, 1999 or flood monitoring in 2000, and the remote sensing control of area-based agricultural subsidies (CwRS), that is carried out operationally for the eight year in 2007 in Hungary.

1. BACKGROUND

Up to 1990 the crop production was based on some 1400 co-operative or state farms in Hungary. The crop information and production forecast system used their reports that were obligatory by law. This information system worked fairly well. Because of the dramatic changes in the Hungarian economy and also in the agriculture, the former crop information system became inadequate. The land privatisation brought dramatic changes in the holdings and parcel sizes, the number of farm owners or operators, the agricultural technology and also in the investment structure. In this very quick transition, the need for an efficient information system became even more imperative.

The priority Hungarian Agricultural Remote Sensing Program (HARSP) was launched in 1980 and has been implemented by FÖMI Remote Sensing Centre (FÖMI RSC). The final objective of the program was to introduce remote sensing to the operational agro information system in Hungary. In the beginning of HARSP (Fig. 1.), the satellite image analysis methods development and validation were the most important (1980-85). As early as in 1984 the reviews of the yield models showed, that the research for a direct relationship between the crop development, the expected yield and the crop canopy - that can be observed by satellite data – could be a good alternative. Despite of the first results in canopy development assessment by satellite data we studied the capabilities of agromet models (WOFOST-MERA, Csornai et al., 1996), but FÖMI put a real emphasis to the remote sensing based model.

The operational system was expected to be capable to monitor crops in the entire country, providing accurate, timely and reliable information on the area of the major crops, their development quantitatively. This should be accompanied by problems areas delineation focusing to drought assessment plus the provision of reliable yield forecast and final yield estimates. These data are to be available at the country as well as the counties (19) levels. The main user of the information included, primarily the Ministry of Agriculture and Rural Development (MARD) and has been indirectly gradually the grain processing and trading companies and associations, the farmers and their different organisations, associations. After a seven year of continuous operations (1997-2003) and having a lot of experience to meet the strict accuracy and deadline requirements there has been a continuous improvement in the technology applied. This led to a number of additional applications offered by this system. Although the CROPMON has been suspended to operate from 2004 because of the national resources are directed to EU memberstate obligations, in more recent cases, definite demand appeared for its revitalization.

2. THE TWO MAIN PERIODS OF THE PROGRAM

The HARSP (1980-) program can be divided into two main periods (Fig.1.):

− the development of the methodology basis, the crop mapping and area assessment methods plus the yield forecast models and validation (1980-96) and

− the operational period (1997-2003).

The final, most intensive period (1993-96) was the breakthrough in the development. This resulted in an operationally ready to use technology that had been validated prior to the operational phase on a 16 counties sample from quite a diverse crop years period: 1991-96 (Csornai et. al., 1998).

2.1. The operational crop area assessment method

The method was developed by FÖMI RSC. It applies high resolution satellite data series (e.g. Landsat, IRS-1C/1D, SPOT) in a multitemporal digital image analysis procedure for the crop identification and area estimation (Csornai et al., 1983). This approach was thoroughly tested by 1990 up to 3 counties region

(Csornai et. al., 1990). It was found that the traditional agro information system in Hungary, can only be surpassed in accuracy if advanced digital image analysis was used (Csornai et. al., 1997). This approach also provides reliable crop maps, which are necessary to the crop development monitoring and production forecast models.

The performance of this approach in crop area assessment proved to meet the strict requirements (Figs. 3.a.b.) both for the validation period (1991-96) and in the operational one. The strong relationship in the Landsat TM derived (FÖMI RSC) and Central Statistical Office, Hungary (CSOH) data for the major crops proved, that this method was independent from the given year or the area, the different terrain and complexity of the counties.

The crop maps, made of high resolution satellite data were supported by a carefully selected area and farms sample. Annually, some 100-200 sets of agricultural fields associations, farms or parts of farms ground data were analysed, checked and got built in to train the classifiers or – on a disjoint subset – to validate the accuracy of the derived maps. Thorough on the spot studies revealed, that 85-95% of the confusion values in the accuracy assessment tables come from existing inhomogeneities on the ground.

This means that the confusion tables incorporate information relevant to the nonuniform development character of the crops. The raw confusion tables and measures showed steady 85-97% overall agreement before the compensation techniques application. Global estimation handled the empirical confusion matrices values (per stratum) that were spatially balanced.

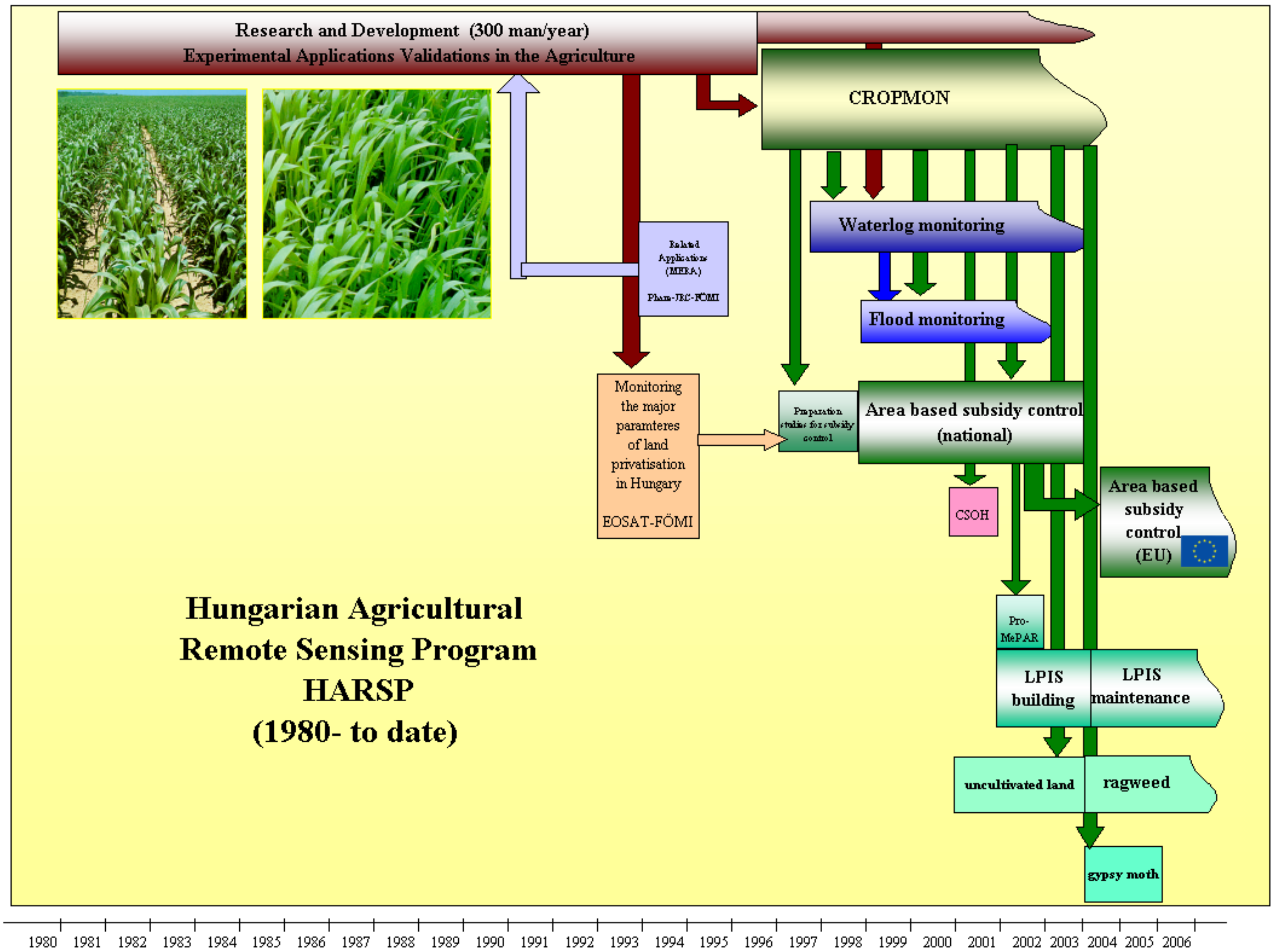

Figure 1. The background and history of remote sensing based agricultural applications in FÖMI RSC, Hungary

2.2. Crop monitoring and yield estimation methods

The novel results of HARSP are the purely remote sensing based crop monitoring and yield forecast models. The models were developed by FÖMI RSC. They integrated NOAA AVHRR and high-resolution satellite data (e.g. Landsat, IRS-1C/D, SPOT). The models combine the benefits of both data sources: the frequency of NOAA AVHRR data and spatial resolution of high resolution images. This approach requires fairly accurate crop maps. Using these crop maps and pre-processed NOAA AVHRR time series a crop development assessment and quantitative yield forecast model was developed. This relies on crop specific AVHRR indices. The model was calibrated at the spatial units level of 400-500 ha. This was the second area where the sample of farms could help. That is the guarantee for its good performance at the counties level (approx. 0,5 million hectare each, in Hungary) and further. That is also why it can produce a crop yield distribution map. The county wheat and maize yields predicted by the model compared favourably to the official data (Figs. 4.a.b.) both in the pre-validation period (1991-96) and in the operational one (1997-2003) as well. The structure of the model is similar for different crops and it does not depend on the area and the given year's weather. It was also found that the timeliness requirement can be met by the yield forecast model.

There was a clear emphasis and determination in the design of our methodology and later system not to get validated by the CSOH county average yield data. We wanted to build an independent crop production model that covers the entire cropland.

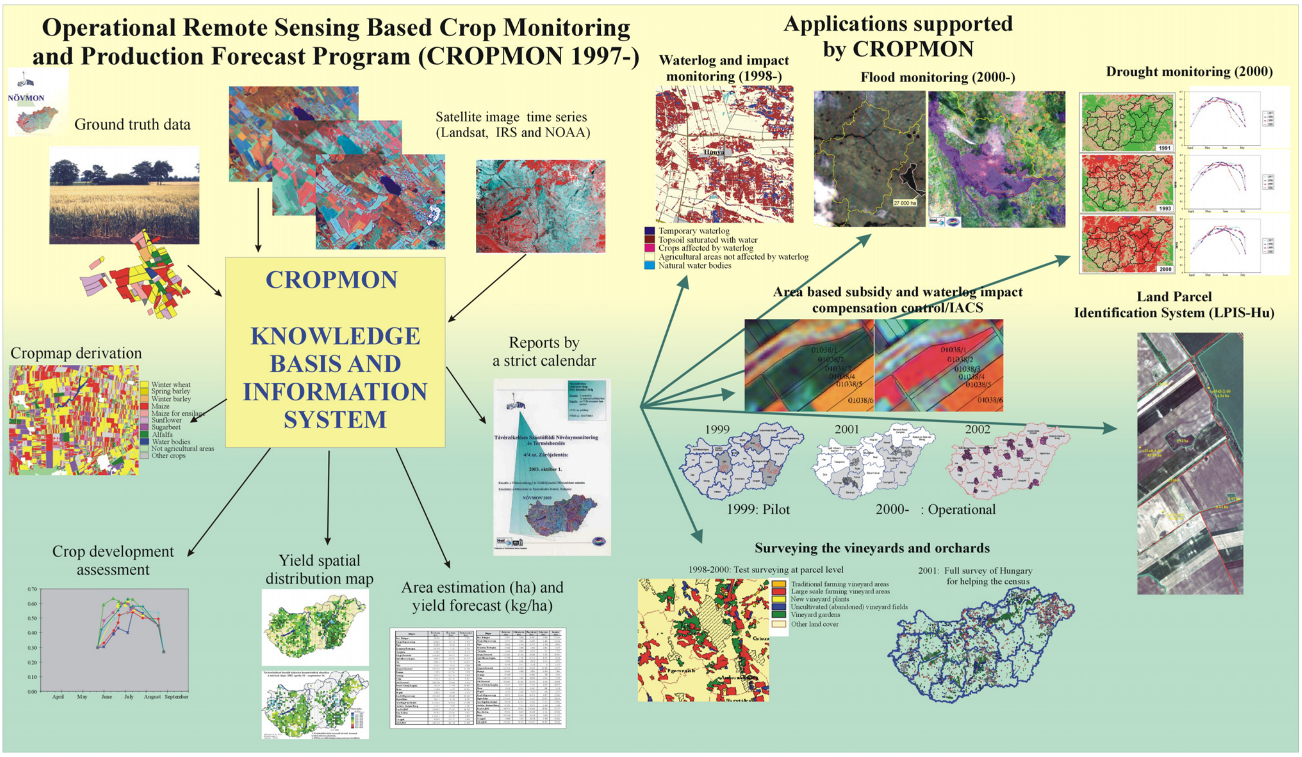

Figure 2. The overall structure of CROPMON and the application supported by it

3. OPERATIONAL CROP PRODUCTION: AREA ASSESSMENT AND YIELD FORECAST FROM 1997-

The substantial R&D and validation provided a firm basis to move forward to an operational program: Crop Monitoring and Production Forecast Program (CROPMON 1997-2003). The crop data-reporting calendar was set by the customer, the Ministry of Agriculture and Rural Development.

It consists of five dates from July 5 to October 1 in harmony with the existing traditional production forecast system of MARD. The area covered directly have been a characteristic subsample (6-9) of all the counties (19). This 40-57 % of the to tal cropland in Hungary was directly monitored, by remote sensing, while appropriate area and yield estimates for the non covered counties were computed by a historical spatial correlation of these values. This relationship was found quite strong suggesting an R^2~0,9 or better fit. Confidence values were also reported. From 2002 the whole country was covered by direct remote sensing measurements. The eight main crops monitored are winter wheat, winter and spring barley, maize, sugar beet, sunflower, alfalfa and maize to ensilage. These crops together represent the 78-82 % of the entire Hungarian cropland.

The crops area assessment is based on the quantitative analysis of multitemporal high resolution images (Landsat TM and IRS-1C/1D LISS III.) from early April (or earlier sometimes) through August, to compensate for the cloudiness. The comparison of the remote sensing results with CSOH data is obviously an indication only. The differences cannot be interpreted, by any means, as errors of the remote sensing technology. On the contrary, the area estimation bases, the crop maps were always thoroughly checked at some pixels detail.

The difference of crop areas estimates of FÖMI RSC and the Central Statistical Office, Hungary (CSOH) is in the range of 0.8-3.7 % for the entire cropland in Hungary. The county crop area differences occurred in the interval of 1.5-21 % depending on the crop and county. However the area weighted average difference was 4.08 %.

This partially can be explained by the main differences in definitions, that is the ownership based sampling of CSOH and the administrative boundary based total coverage of cropland by the satellite images (FÖMI RSC). The actual standard crop maps derived were also provided to MARD.

The crop yield forecast was accomplished by the application of FÖMI RSC developed model which combines high-resolution satellite (Landsat TM and IRS-1C/1D LISS III. or SPOT) data and NOAA AVHRR time series. The reporting dates corresponded to those of the operative Production Forecast System of the Ministry of Agriculture and Rural Development. Both appeared prior to the harvest. The earliest official production data estimates are available after the harvest: by the end of August for wheat and barley and in December (January) for the rest. Until 2002 FÖMI RSC provided yield estimates for the counties (6-9) and expanded these measurements to Hungary using a regional-historical correlation scheme. From 2002 all the 19 counties were covered directly, so there was no need for extrapolation any more. The country average yield data compare favourably with CSOH preliminary values, that appear six weeks later. The differences are less than 1 % for wheat and 4.5 % for maize average yields in Hungary. The differences at county level averages are somewhat bigger. Because of the method applied, yield spatial distribution maps could also be reported for the major crops.

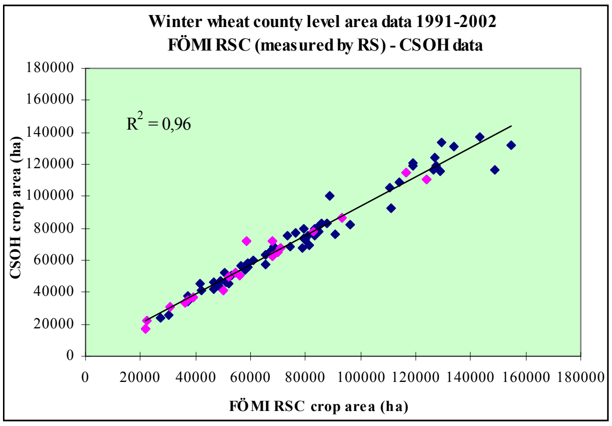

Figure 3.a. The area estimation for winter wheat shows a strong relationship between the traditional (questionnaire) method and the remote sensing one

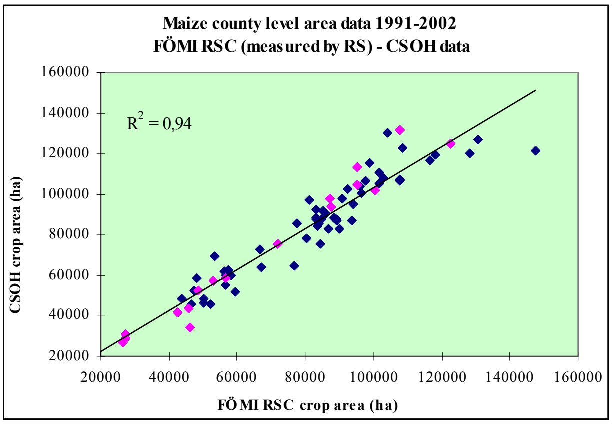

Figure 3.b. The figures compare similarly to those of wheat. The relationship is somewhat affected by the practice and statistics of maize for silage

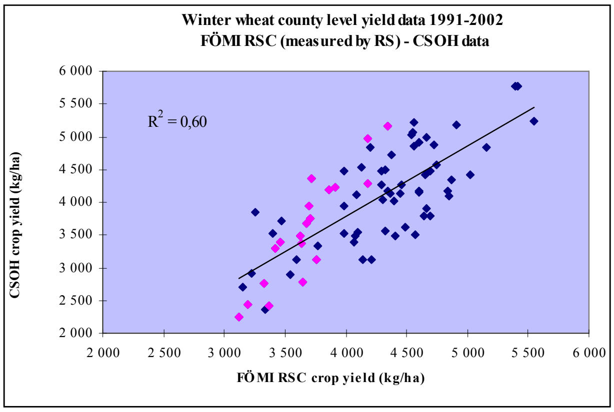

Figure 4.a. The wheat yields can be predicted by remote sensing prior to the harvest. The years covered comprise good and extreme bad ones as well

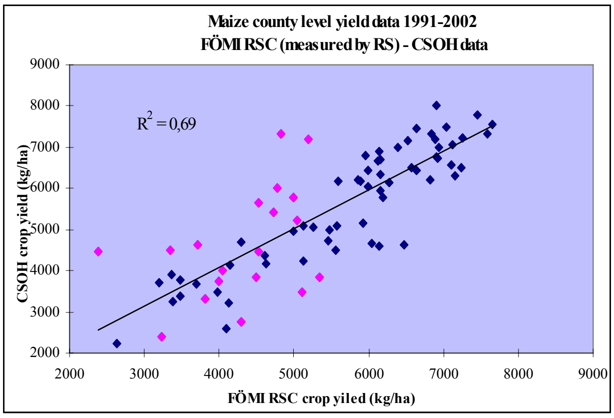

Figure 4.b. The maize yields can be predicted early prior to the harvest. The sample comprises diverse years. No CSOH yield data are available to date for 2001

Beyond the accuracy control built in the area estimation getting helped by the 2-4% ground sample and also the comparative analysis of the CROPMON predicted yield values and the respective farms after harvest data, the comparison to the final CSOH data is meaningful (Figs. 3. and 4.). These comparisons of the county area and CROPMON predicted – CSOH after harvest yields were done by crop. Around 180 data pairs were available either for area or yield to compare in the 1987-2003 period. The differences and R^2 –s should carefully be interpreted!

The inherent advantages and limitations of the traditional and remote sensing methodology suggest the handling of these data. The Ministry of Agriculture and Rural Development selected our data from the second year when there was a conflict.

4. APPLICATION OF THE YIELD MODEL FOR PARCELS AND FARMS

The crop development assessment plus yield prediction model performance suggested a step forward to the parcel level. In 1999 two large farms were studied. IRS WiFS 3,6 ha resolution data were used similarly in a 35 ha average field size environment. The two major crops were estimated: winter wheat and maize. The model seemed to work in this study providing some 3-5% difference between the remote sensing predicted and harvested yield after one year calibration. This could be achieved only to the farm total estimation only. The model may perform definitely better or at least as well in the operational way with a more appropriate field size/pixel ratio. Also, it was suggested that the individual fields' yield (production) values were not very accurate unlike those of the farm totals. This was characteristic in that period.

5. DROUGHT MONITORING AND YIELD LOSS ASSESSMENT (2000-)

The basic idea behind drought monitoring is the comparison of actual year's vegetation index maps (NDVI, MGVI) with the maps representing a mean of the vegetation index maps derived from the maximum value composites (MVC) of a reference period. This is the approach, that is most studies or systems pursue. FÖMI also explored and applied this approach, but having a strong yield prediction model, developed that performed well it was straightforward to use it for drought assessment and alarm. Beyond the widely used methods that apply NDVI or similar indices or their maximum values in a period to indicate the categories of drought or yield losses FÖMI utilized the yield

model for this purpose. The quantitative yield model was used to the characterization the strength and spatial distribution of drought. This is quantitative and provides the expected yield for that particular area. To this not only the compared period – usually 1-3 weeks – but the whole growing season is compared by the model output in the different years.
In the frame of FÖMI-ESA co-operational programs (see 6.) the CROPMON based drought monitoring, crop development and yield loss assessment (2000-2003) activities based on NOAA AVHRR data received at FÖMI satellite station were also continued and developed further (2003-). Other available satellite data (SPOT VEGETATION, IRS WiFS, AWiFS and ENVISAT MERIS) were integrated into the regional drought monitoring model to detect the extension and intensity of the drought at regional or country level (2003-2006).

6. WATERLOG/FLOOD AND IMPACT MONITORING, RAGWEED MONITORING AND CONTROL PROGRAM

As a component of CROPMON, further additional extension of remote sensing based operational applications were launched to extract information about those most significant factors, extreme natural disasters which occur on large areas and produce negative effects on crop development and crop production. Thus, satellite based waterlog/flood and impact monitoring (1998-), and recently ragweed monitoring and control program (2004-) were all growing out from the CROPMON methodology and technology basis.

Waterlog and impact monitoring program was initially launched for MARD, that covered the most affected 4 (in 1998) and 7 (in 1999) counties of about 4 million hectares. Reliable waterlog/flood maps and derived areal measures reflected the static status assessment of the areas under water or having saturated soil. Beyond this, temporal evaluation of waterlog/flood affected areas, impact analysis on the crops and the dynamism of changes could also be monitored quantitatively. During the combats against flood, when serious flood events occurred on Hungary's largest rivers, the Körös and Tisza, in April 2000 and March 2001, FÖMI RSC provided real time satellite data and flood maps for the disaster areas. The extent of flooded areas was evaluated and high-, low- and medium resolution flood maps were forwarded to the central and local management authorities through electronic transmission (Lelkes et. al, 2001). These effectively helped the local water management authorities in planning the necessary steps and managing the fight against the flood. Further improvements of the models to map and monitor waterlog and flood affected areas were also carried out in the frame of FÖMI-ESA co-operational R+D programs (Prodex*: 2000-2004, PECS**: 2004-2007, Csornai et. al 2004, 2007). Yearly monitoring tasks were performed at regional level in 2005-2006 for waterlog and flood assessment using also integrated radar (ERS, Radarsat, ENVISAT ASAR) and optical (IRS WiFS, AWiFS, ENVISAT MERIS Landsat/IRS LISS) satellite data sets.

The technique developed for ragweed monitoring and control (2004-) is based on the methods that had been used in CROPMON. However, the remote sensing identification of the areas contaminated by ragweed is much more difficult than the crop identification. About 80% of ragweed infected areas (of a total of 500.000 – 700.000 hectares) can be pinpointed by remote sensing on the arable land. The reconnaissance of ragweed spots are substantially helped by remote sensing as well as the ground measurement and record by GPS plus integrated GIS tools. The temporal development assessment of ragweed has fundamental importance. FÖMI RSC produces a countrywide ragweed risk map focusing to the most heavily infected croplands. These ragweed risk maps are derived from time series of medium and high-resolution satellite images. In 2005, FÖMI RSC detected about 20 000 heavily infected spots (60 000 hectare) in the country. Applying the procedure of four high tech (two space technology related) areas, the whole system is 4-12 times more efficient than the former ground based one, concerning different parameters.

7. AREA-BASED SUBSIDY CONTROL WITH REMOTE SENSING (CWRS, 1999-)

The methodology and technology basis of CROPMON can be used also to extract information on the agricultural areas at parcel level, thus to control of the agricultural subsidy claims with the use of satellite images. After controlling a 3 counties sample for MARD in a pilot project in 1999, FÖMI extended the remote sensing control of national area-based subsidies to the sample of 4-6% of all the dossiers (160-180 000) between 2000 and 2003. The CROPMON based digital crop maps were very effective tools to access the automatic control of the parcels and were an important part of CwRS technique in Hungary. Since 2004, in the EU system, FÖMI's CwRS control ran on the newly built and updated Hungarian Land Parcel Identification System (LPIS-Hu, 2004-). The total number of submitted claims in Hungary grew to about 200 000 – 210 000. The successful control of the amounts of dossiers (4-6%) within a very short period of time could proved that the only feasible solution to carry out on-the-spot checks is the use of remote sensing and GIS techniques for the majority of the claims.

8. CONCLUSION

Both the validation of the developed remote sensing based crop area assessment and yield forecast methods plus the first Operational Crop Monitoring and Production Forecast Program (CROPMON 1997-2003) in Hungary clearly demonstrated that these methods can be efficiently applied for the entire cropland. Substantial background and investment were certainly needed. About 300 man/year was invested by FÖMI RSC in the framework of the Hungarian Agricultural Remote Sensing Program (1980 to date). The CROPMON reporting calendar was very strictly set up by the Ministry of Agriculture and Rural Development, Hungary, to be in synchron with its existing farms' reports based operational production forecast and monitoring system. The 8 most important crops were covered and monitored merely by remote sensing methods and technology. The CROPMON is objective and validated in a series of years and for very different areas.
Remote sensing could be very efficiently used for precise crop area estimation and provision of crop maps. The results suggest that the necessary classification performance can be obtained in most of the cases, therefore the analysis could be cost effective. The investment to achieve this seems to be worthwhile.
The new primary quantitative crop development assessment and yield prediction model works on the basis of a combined AVHRR and high resolution images based crop monitoring. The quantitative yield prediction model performed properly and efficiently in a more counties' area application and also for the entire country. This model produces spatial distribution map for the predicted yields.
CROPMON was extended into different directions. The model could be adapted to IRS WiFS data applications to farms. Also, CROPMON provided a tool for going far beyond the qualitative

* Prodex= Scientific Experiment Development Programme
** PECS= Plan for European Co-operating States

comparisons of vegetation periods through non crop specific NDVI-values and provided potential yield estimates to characterize the extent of drought.
Parallel to these, many other applications could efficiently be added similarly to the waterlog assessment and ragweed monitoring and the remote sensing control of national area-based agricultural subsidies.

ACKNOWLEDGEMENT

The whole HARSP had been supported jointly by the National Committee for Technological Development and the Ministry of Agriculture and Rural Development, (1993-96) Hungary. The Operational Crop Monitoring and Production Forecast Program (CROPMON) from 1997-2003 had been supported by the Ministry of Agriculture and Rural Development where the program reports were widely used.

REFERENCES

Csornai, G., dr. Dalia, O., Gothár, Á., dr. Vámosi, J., 1983 Classification Method and Automated Result Testing Techniques for Differentiating Crop Types, Proc. Machine Processing of Remotely Sensed Data, West Lafayette, USA

Csornai, G., dr. Dalia, O., Farkasfaly, J., dr. Vámosi, J., Nádor, G., dr. Vámosi, J., 1988. Regional Vegetation Assessment Using Landsat Data and Digital Image Analysis, *Proc. 5th Symp. ISSS Working Group Remote Sensing*, Budapest, pp. 123-128.

Csornai, G., dr. Dalia, O., Farkasfaly, J., Nádor, G., 1990. Crop Inventory Studies Using Landsat Data on Large Area in Hungary, Applications of Remote Sensing Agriculture, *Butterworths*, pp. 159-165.

Puyou Lascassies P., Podaire A., Gay M.: Extracting Crop Radiometric Responses from Simulated Low and High Spatial Resolution Satellite Data Using a Linear Mixing Model: *Int. J. of Remote Sensing*, Vol. 15, no. 18, pp. 3767-3784, 1994.

Büttner, Gy., dr. Csató, É., Maucha, G.: The CORINE Land Cover-Hungary Project, GIS/LIS'95 Central Europe, Budapest, Hungary, 12-16 June, 1995.

G. Csornai: Toward a Remote Sensing Based Crop Monitoring System in Hungary. MERA 1994-96 Results Conference, Bratislava, 10-11 December 1996.

Csornai, G.: Towards a satellite based national monitoring system in Hungary, Eurisy Colloquium, Budapest, Hungary, 15-16 May, 1997.

Csornai, G.: Remote sensing based crop monitoring in Hungary, *Proc. of ISPRS Commission VII Symposium - Resource and Environment Monitoring*, VOL. XXXII. Part 7, pp. 108-113, Budapest, Hungary, 1-4 September, 1998.

Lelkes M, Csornai G, Wirnhardt Cs. Natural disaster monitoring by remote sensing in Hungary: waterlogging and floods in the 1998-2001 period. 21st. EARSeL Symposium, Observing our environment from space/new solutions for a new millenium, Paris, 14-16 May, 2001.

G. Csornai, Zs. Suba, G. Nádor, Á. Csekő, Cs. Wirnhardt, L. Tikász, L. Martinovich (2004): Evaluation of a remote sensing based regional flood/waterlog and drought monitoring model utilizing multi-source satellite data set including ENVISAT data, ESA ENVISAT & ERS Symposium, Salzburg, 6-10 September, 2004.

G. Csornai, Zs. Suba, G. Nádor, I. László, Cs. Wirnhardt (2007): Disaster monitoring with the integrated utilization of ENVISAT and other satellite data sets in the 2004-2006 period in Hungary, ESA ENVISAT Symposium, Montreux, 23-27, April, 2007.