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CROP MONITORING BY REMOTE SENSING

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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 in the paper. 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. A novel robust method that combines land use information with NOAA AVHRR time series for yield prediction is also introduced. Based on the experiences of the first 3 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.

1. BACKGROUND

Up to 1990 the crop production was based on some 1400 co-operative or state farms in Hungary. The crop information 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 investments. 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. 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 users of the information includes, primarily the Ministry of Agriculture and Regional Development (MoARD) and gradually the grain processing and trading companies and associations, the farmers and their different organisations, associations. Even in the third years of operations and having a lot of experience to meet the strict accuracy and deadline requirements there is a continuous improvement in the technology applied. This leads to a number of additional applications offered by this system.

2. THE TWO MAIN PERIODS OF THE PROGRAM

The HARSP (1980-99) program can be divided to two main periods:

- 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 (1997-99).

The final, most intensive period (1993-96) was the break through 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 as 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. 1.a.b.) both for the validation period (1991-96) and in the operational one. These two comprises an 7 years, 33 cases (county/year) sample. 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.

2.2. Crop monitoring and yield estimation methods

The novel result of HARSP are the purely remote sensing 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. With the adaptation and improvement of a linear unmixing model (Puyou Lascassies et. al., 1994) to NOAA AVHRR series a crop development assessment and quantitative yield forecast model was developed. The model was calibrated at the spatial units level of 400-500 ha. 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. 2.a.b.) both in the pre-validation period (1991-96) and in the operational one (1997-99) 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 whether. It was also found that the timeliness requirement can be met by the yield forecast model.

3. OPERATIONAL CROP AREA ASSESSMENT AND YIELD FORECAST FROM 1997-99

The substantial R+D and validation created a firm basis to move forward to an operational program: Crop Monitoring and Production Forecast Program (CROPMON 1997-1999). The crop data-reporting calendar was set by the customer, the Ministry of Agriculture and Regional Development.

It consists of five dates from June 15 to October 1 in harmony with the existing traditional production forecast system of MoARD. The area covered directly have been a characteristic subsample (6-9) of all the counties (19), so that 40-57 % of the total cropland in Hungary have directly been monitored. Beyond the crop area assessment and yield prediction for the counties, these data are expanded to the entire area of Hungary. This expansion uses a subregional temporal correlation analysis plus a direct robust method (see 4.). 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 May 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. A thorough study is under way that will produce confidence values attached to the area estimates. 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 % (Fig.5.a.) 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, topographic boundary based total coverage of cropland by the satellite images (FÖMI RSC). The actual standard crop maps derived were also provided to MoARD (Fig.3.).

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 Regional Development. Both appeared prior to the beginning of harvest. The final official data are available after the harvest: by the end of August for wheat and barley and in December (January) for the rest. FÖMI RSC provided yield estimates for the counties and expanded them to Hungary using a regional-historical correlation scheme. The country average yield data compare favourably with CSOH preliminary values, that appear six weeks later (Fig.5.b.). 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 (Fig.4.) for the major crops.

4. ROBUST YIELD PREDICTION BY NOAA AVHRR SERIES

The primary yield forecast model (see 3.) performed well. There were two reasons to develop a robust yield forecast model:

- the need for a parallel, independent technique to control the primary yield forecast model extrapolation (see 3.) from the average yields of the directly monitored counties to the entire cropland in Hungary and
- the need for a stand-alone method that uses only very basic land use information: the boundary of cropland in the country. This was readily available from the CORINE Land Cover data base in Hungary (Büttner et. al., 1995). Beyond the land use NOAA AVHRR data series make up the basis of the model. The model is directly applied to all the individual counties and also for the national crop production forecast.

The pre-processed and normalised NOAA AVHRR data set is temporally filtered. The average reflectance profile and the NDVI can be decomposed in time by a thorough spectral-temporal correlation analysis. This substantial analysis shows an extremely strong relationship between the predicted county yields by this decomposition method and the CSOH data (Figs. 6.a.-d.). The county data set comprises a 7 years period in which the low and high ends of yields occurred. The model seems to be strong, independent from the year and area. Some hilly, mountainous counties or those that were covered very sparsely by the given crop had to be omitted from the analysis. Having the performance of this model by county (r^2=0,81-0,89) the country level yield prediction seems to be very reliable (R^2 = 0,93-0,98). These preliminary results suggest that a very simple and still reliable yield prediction model can be developed.

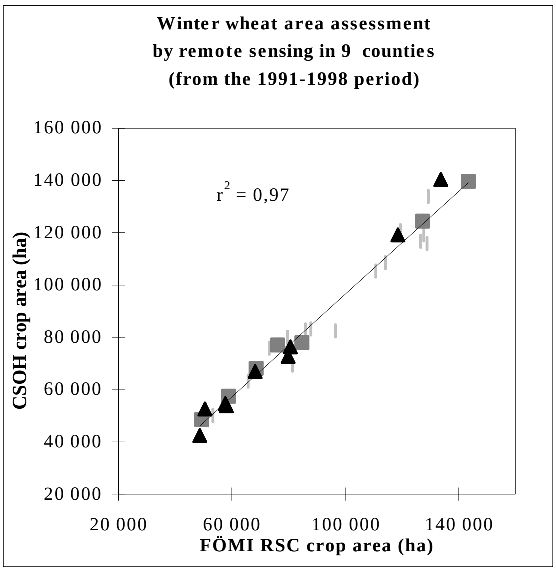


Fig.1.a.

The area estimation for winter wheat shows a strong relationship between the traditional (questionnaire) method and the remote sensing one. Data from 1999 are not public until the end 1999.

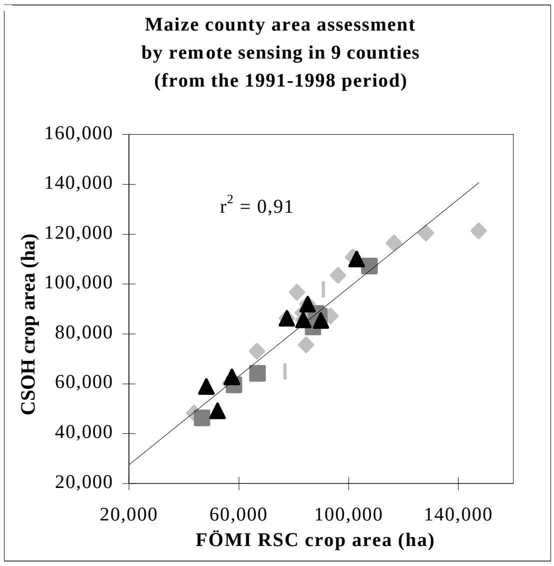
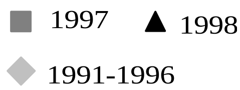


Fig.1.b.

The figures compare similarly to those of wheat. The relationship is affected by the practice and statistics of maize for silage. Only a part of maize is sown originally for ensilage. Many times arbitrary decisions are made along the season to ensilage maize. New methods suggest compensation to this effect.



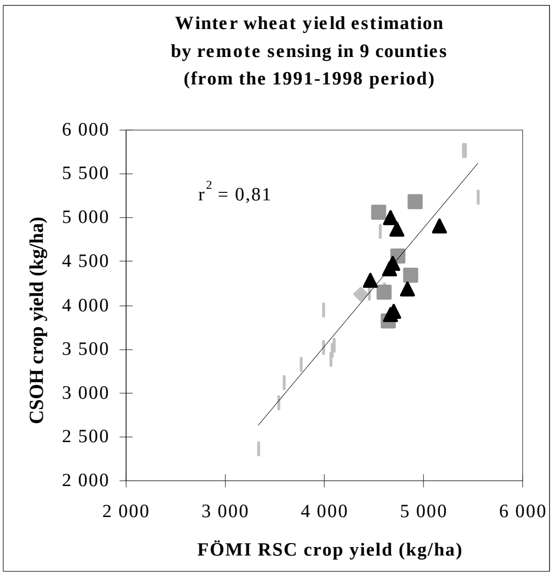


Fig.2.a.

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

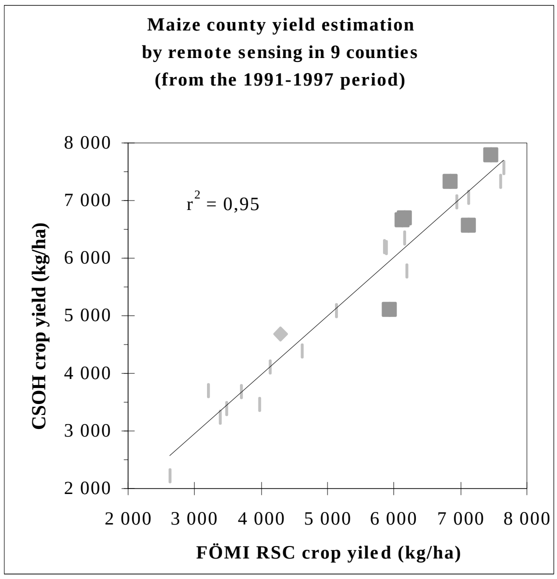


Fig.2.b.

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 1998.

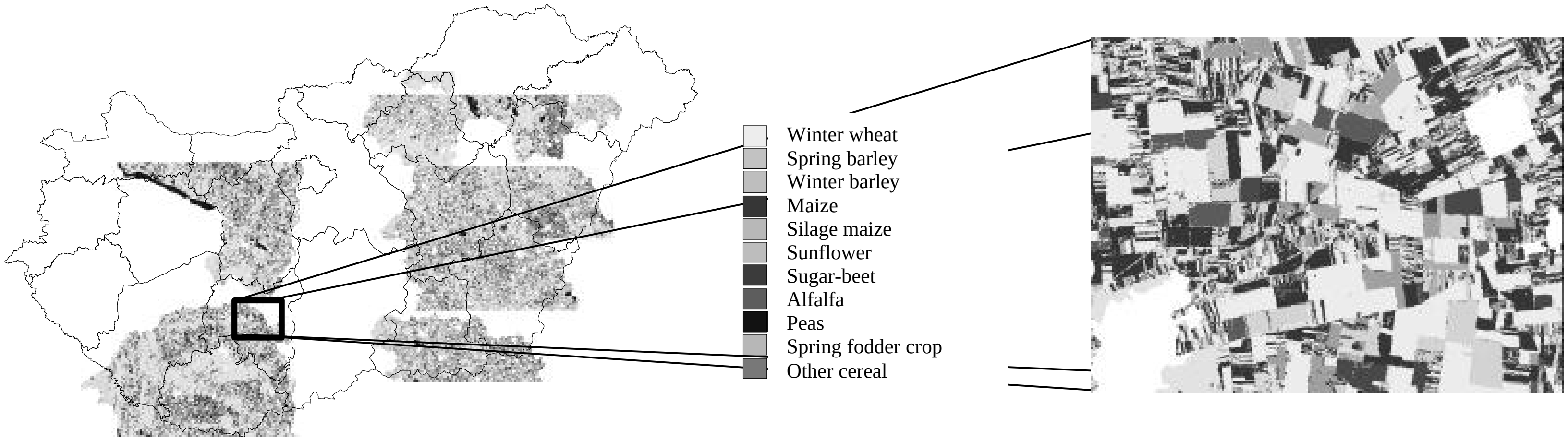


Fig.3.
Crop maps for the 9 counties in Hungary derived from multitemporal high-resolution satellite data (Landsat TM and IRS-1C/1D LISS III.).

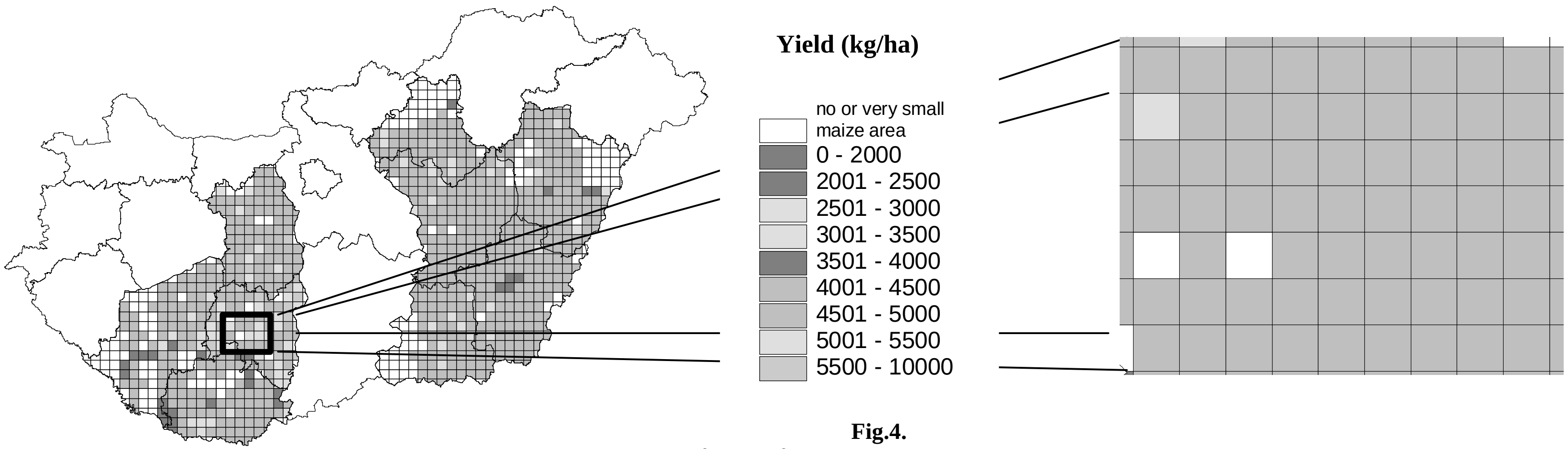
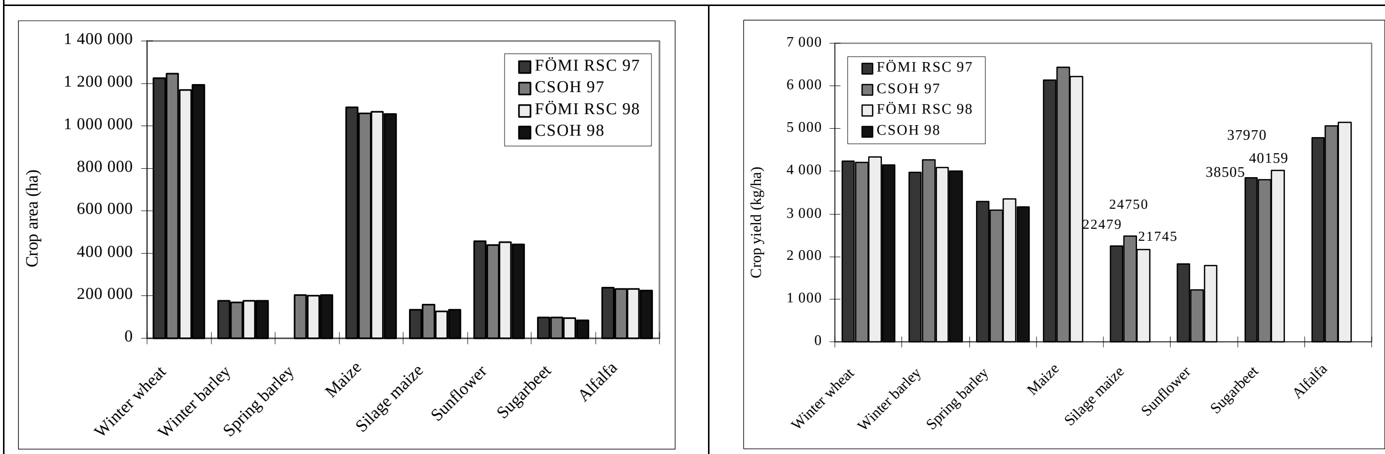


Fig.4.
Winter wheat yield forecast for the 9 counties in Hungary using our developed Landsat TM, IRS-1C/1D + NOAA AVHRR model.

Areas and yields of the main crops in 1997 and 1998 in Hungary

by FÖMI RSC and CSOH*



*CSOH data in "Production data of the main agricultural crops, 1997, 1998"
Central Statistical Office, Hungary

Fig.5.a.b.

Crops assessment (Fig.5.a.) and yield forecast (Fig.5.b.) in Hungary, 1997,1998 by remote sensing (FÖMI RSC) and by traditional methods (CSOH)

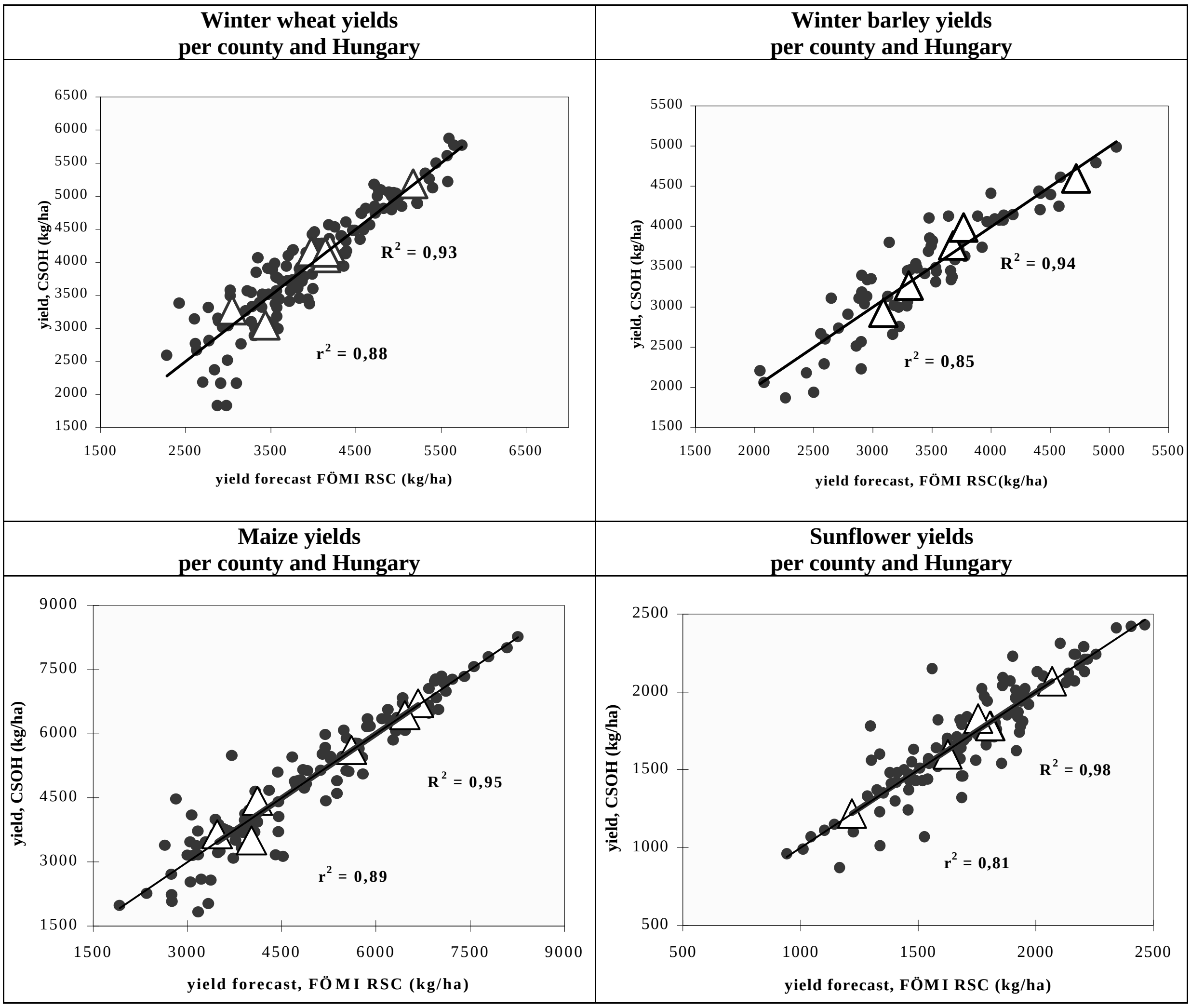


Fig.6.a.-d.

In the 7 years period of 1991-98 (excluding 1994) the predicted county average yields (•) correlated very well (r^2) with the final CSOH data. The predicted average yield to the entire country fitted (R^2) even better (Δ).

5. WATERLOG AND IMPACT MONITORING

In the past years flood and waterlog hit very seriously the country. On the methodology and infrastructure basis a thorough monitoring program was launched. This covered the most affected 4 (1998) and 8 (1999) counties of about 4 million hectares. Reliable waterlog maps and areal measures were derived. Beyond the static status assessment of the areas under water or having saturated soil impact analysis on the crops was also performed. This assessment made use of high and mid resolution optical data, that is Landsat TM, IRS 1C/1D LISS III. and WiFS as well. Because of the vast contiguous areas under water (approx. 0.6 million hectare in spring, 1999) WiFS data could also be used. The lack of mid infrared channel in WiFS data could be compensated. The resulted GIS data base and printed maps were utilized by MoARD intensively.

6. 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 1997-1999) in Hungary clearly demonstrated that these methods can be efficiently applied. Substantial background and investment was 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 is very strictly set up by the Ministry of Agriculture and Regional Development, Hungary, to be in synchron with its existing farms' reports based operational production forecast and monitoring system.

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 combined AVHRR and high resolution images based crop monitoring and 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. The second, the county level AVHRR based crop yield prediction model worked very well and seems to have a real potential on areas, having quite different cropping pattern.

Being in the third operational years of CROPMON gradual extension of the directly observed counties is under way. Parallel to this, many other applications can efficiently be added similarly to the waterlog assessment and monitoring.

6. ACKNOWLEDGEMENT

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