CROP YIELD FORECASTS DERIVED FROM AGRO-METEOROLOGICAL MODELS: THE MARS PROJECT

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Introduction

The MARS (Monitoring Agriculture with Remote Sensing) project is a European Commission project, which was set up upon EU Council decision in 1988. The objectives up to 1998 were to:

- Facilitate the use of remote sensing based techniques as a tool to ameliorate national agricultural statistical systems at national level when required.
- To supply estimates before harvest of areas and crop yield at European level.
- Set up of an agricultural information system, combining different information sources organised in several actions.
- To extend the applications to other countries than EU-15.
- To research advantages from the introduction of other satellite sensors (for instance radar).

The need of a system like MARS derives from the necessity to compensate some weakness of the agricultural statistics at the EC level. The needs of the Commission are to obtain rapid and timeliness information covering all Europe according to a harmonised, accurate, consistent and independent methodology (from private and national interests).

The MARS project has been running at the Space Applications Institute at the EC Joint Research Centre since 1988.

In the framework of these objectives a crop yield forecasting system was developed and is running operationally since 1993 on behalf of the Directorate General Agriculture of the European Commission.
The crop yield forecasting system is composed of three main elements (Genovese, 1998):

1. Crop growth simulation models (agro-meteorological models);
2. Low resolution satellite observation on the vegetation;
3. Statistical analysis of the indicator obtained to generate yield forecasts.

We will focus here on the description of the MARS crop yield forecasting system and in particular on the use meteorological data in this context.

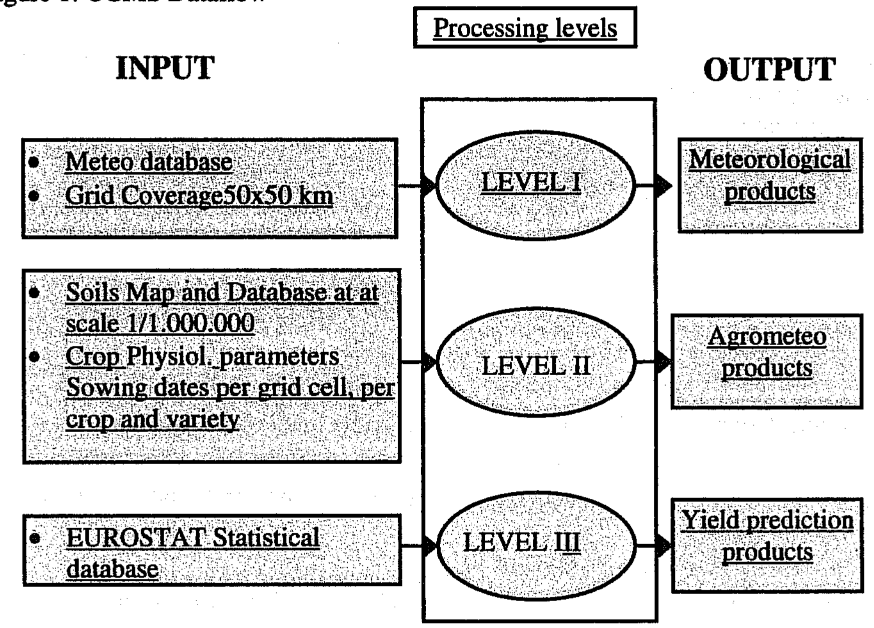
1. The Agro-meterological system

The Crop Growth Monitoring System (CGMS) is driven by meteorological conditions, modified by other environmental factors such as soil characteristics and crop parameters (Terres, 1998). This mechanistic approach describes the crop life cycle from sowing to maturity on a daily time scale. Crop growth is simulated (i.e. leaf area index, biomass, storage organ) in combination with phenological development.

The main characteristic of CGMS lies in its spatialisation component. Meteorological data, soil map and crop parameters have been spatially integrated through an Elementary Mapping Unit (EMU) concept, used as basic simulation element by the crop model WOFOST (Vossen, Rijks 1996, Supit *et al.* 1996).

The system data flow is divided into three levels as described by the following figure:

Figure 1: CGMS Dataflow



The first level includes the interpolation of meteorological data acquired in near real-time from the WMO network of synoptically ground stations. The second level is the transformation of the level I data through parameterised crop physiology into crop growth indicators such as: development stages, above ground biomass, leaf area index, weight of the storage organs, water consumption and soil. These indicators are calculated taking into account soil characteristics and crop phenology.

The set of indicator obtained are then used to fit regression models to derive a crop yield forecast at national and then EU level.

2. The use of meteorological data

The meteorological coverage for the European continent (up to western Russia), Maghreb countries and Turkey includes around 1400 ground stations providing about 30 parameters collected daily. Main parameters are rainfall, temperature at different hours, cloud cover, vapour pressure, wind speed. An archive of 30 years of meteo data is also used to generate climatic reference.

The meteorological module processes daily meteorological observations from weather stations to regular grid-cells of 50x50 km with an interpolation procedure developed ad-hoc for the application. The procedure consists of selecting for each grid the best combination of surrounding meteorological stations, the grading being a function of distance to the grid, distance to coast, altitude difference and climatic barrier; then in performing for each relevant parameter the average of the observations from the stations, except for rainfall which is taken from the most suitable station.

The following maps show an example of interpolated temperatures, rainfall and water balance. The maps are deviations of current values cumulated on a given period from the average.

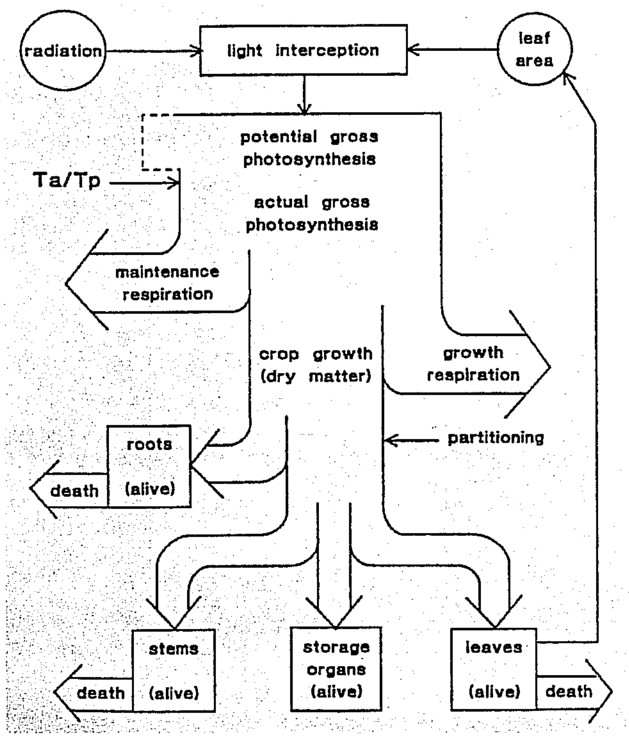


Figure 3: the energy balance scheme of WOFOST

Soil characteristics are derived from the European Soil geographic database (scale 1/1million) and the FAO soil map (scale 1/5million) (Terres, 1998). Both soil databases have associated attribute tables characterising the soil typology in terms of soil name (nomenclature FAO 1985), texture, phase, rooting depth, slope, salinity, alkalinity, drainage. The hydraulic properties of soils (water content at saturation, field capacity and wilting point) are estimated through a set of pedo-transfer rules [King et al., 1995]. These parameters are deduced for each soil type and, together with the rooting depth, they provide the required elements for the soil moisture calculation.

Because the lack of a homogeneous pan-european detailed land-cover map, land evaluation rules are applied to restrict crop growth simulation on suitable soils only. Suitability criteria were defined for each crop in respect of the following parameters held in the soil database: slope, texture, phase, alkalinity, salinity, maximum rooting depth and drainage.

The following figure shows the 1:100,000,000-scale soil map (Montanarella, 1996) which is integrated in CGMS.

Figure 4: the EU 1:1,000,000 soil map

Results of the simulation are then aggregated to the administrative region or to the grid. Then simulated yields are further aggregated at the national level, using the official statistic crop areas within each administrative sub-region.

As for level 1, crop simulation results can be mapped by linking the simulated crop growth indicators table to grid coverage or the administrative regions coverage.

Output can also be given as by regional profiles as shown in the following pictures:

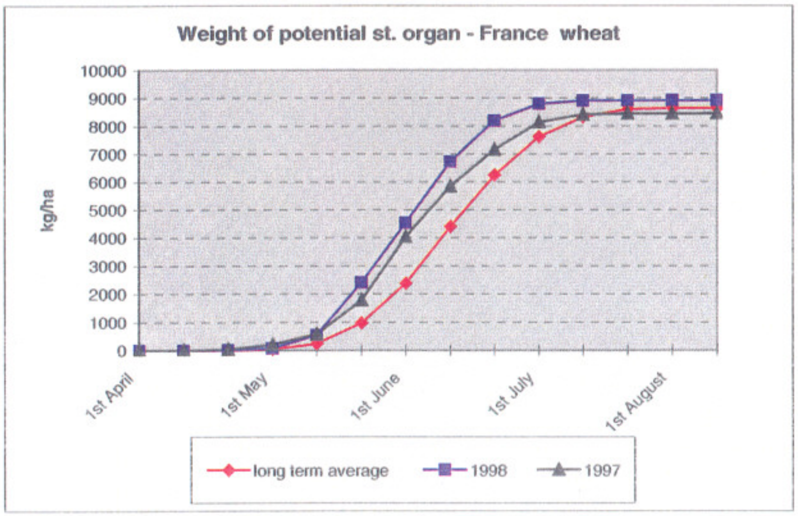


Figure 5: examples of CGMS simulation for winter wheat.

4. Forecasting and data integration

Simulated crop growth indicators (above ground biomass and storage organ) are then used as observation versus official national/regional crop yield time series to calibrate a prediction model.

The approach is the classical multi-regressive where the prediction is explained by past behaviour of observed variables.

Crop yield = f (time trend and/or agro-meteorological indicators and/or low resolution satellite indicator)

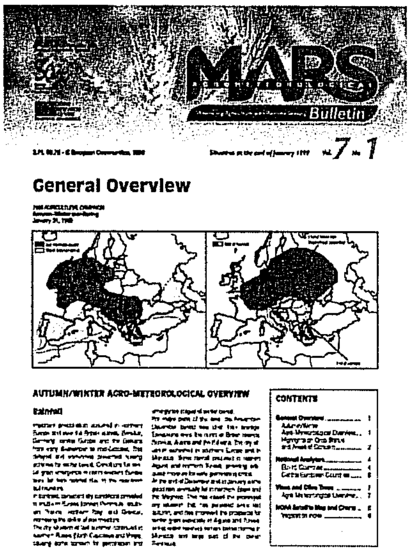
The average error of the crop yield forecast at EU level obtained through the MARS system ranges from 3% (Barley-end of August, whilst it is below 5% at the beginning of the year) to 12% (Durum wheat-end of March, then in decrease to about 8%). The accuracy depends of course on the moment of the forecast and on the climate dependency of the crop.

Multivariate data analysis, like principal component analysis and cluster analysis, are used to characterise similar years and thus describe the residual uncertainty. The residual uncertainty is due to the lag between the moment of the forecast given by the classical approach applied at a given moment of the agricultural campaign and the final yield observed at harvest. The nature of this uncertainty is due to unknown weather until the harvest period. Provision of crop yield scenarii are based on this technique.

It is envisaged to test the ECMWF seasonal weather forecast into the CGMS model (in the level 1 module) to simulate crop growth indicators until maturity at any time of the crop growth cycle. The first part of the simulation will be based on past observed meteorological data, while the remaining part of the cycle until maturity would be simulated with seasonal weather forecast. This should result in decreasing the uncertainty of agro-meteorological indicators at the end of the season with an improvement of the crop yield forecast error early in the agricultural campaign.

5. The MARS bulletin

Each month the MARS data are analysed and forecast generated. The results are published in a public bulletin about 8 times during the agricultural campaign.



MARS

Bulletin

General Overview

AUTUMN/WINTER AGRO-METEOROLOGICAL OVERVIEW

Rainfall

CONTENTS

Figure 6: the MARS bulletin. The bulletin is available on an Internet address: http://www.aris.sai.jrc.it/marsstat/bulletin

References:

MONTANARELLA, L. (Editor), 1996. Soils Information for Europe. EUR Publication N° 16423 Office for Official Publications of the EC. Ispra (I), 21 pp.

GENOVESE, G., 1998. The methodology, the results and the evaluation of the MARS crop yield forecasting "system". In: Agrometeorological Applications for Regional Crop Monitoring and Production Assessment. Rijks, Terres, Vossen eds. EUR Publication 17735 EN, 1998, Ispra, Italy, 100p.

King, D., Le Bas, C., Daroussin, J., Thomasson, A.J., Jones, R.J.A., 1995. The EU map of Soil Water Available for Plants. European Land Information System for agro-environmental monitoring. Office for Official Publications of the European Communities, Luxembourg. Report N° EUR 16232 EN, 296pp.

SUPIT I. - Global Radiation. EUR Publication 15745 EN, 1994, SAI, Ispra.

SUPIT, I., HOOIJER, A.A., VAN DIEPEN, C.A., Edts, 1994 (reprint 1996). System description of the WOFOST 6.0 crop simulation model implemented in CGMS. Volume 1: Theory and Algorithms. EUR Publication N° 15959 EN of the Office for Official Publications of the EC. Luxembourg, 146 pp.

Terres. JM., 1998. The Crop Growth Monitoring System implemented by JRC/ARIS unit for the information needs of the EC DG VI – Agriculture. In: Proceedings Computer technology in agriculturalagement and risk prevention. 7th International Congress for Computer Technology in Agriculture, 15-18 November 1998, Florence, p46.

VOSSEN, P. RIJKS, D., 1995 (third print, 1996). Early crop yield assessment of the EU countries: the system implemented by the Joint Research Cenre. EUR Publication N° 16318of the Office for Official Publications of the EC. Luxembourg, 182 pp.