Forecasting of National Crop Production: the Methodologies Developed in the Joint Research Centre in Support to the Commission of European Communities

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ABSTRACT
In support to the Commission of the European Community, the Agricultural Information Systems Unit of the Institute for Remote Sensing Applications is presently developing a system for the timely forecasting of the production of the E.C.’s most important crops. The outputs of the system refer to quantitative assessments of yields and crop acreages and to qualitative crop state monitoring. For the assessment of crop acreages, a methodology for the use of SPOT and LANDSAT TM satellite imagery, has been developed and validated for large regions in France, Germany, Greece, Italy and Spain. For the quantitative crop yield prediction, agrometeorological models using surface observed meteorological data, soil information and research based knowledge on crop growing conditions are being developed. For crop state monitoring, NOAA-AVHRR satellite information and meteorological data will be used. The qualitative monitoring is areawise and the expected resolution is of the order of 50kmx50km for the agrometeorological models and approximately 25kmx25km for the remote sensing models. In order to improve both the timeliness and the spatial resolution of the agrometeorological model outputs, the development of applications for the use of satellite information in the models is planned for the future.

INTRODUCTION
In order to upgrade the existing national and its own agricultural statistics systems, the Commission has set up a Pilot Project to introduce remote sensing into the European Community agricultural statistics system. The project is being realised in the framework of the Agricultural Information Systems Unit of the Institute for Remote Sensing Applications of the Joint Research Centre. Its main activities relate to:

1. **Crop inventories**: quantitative estimation of the acreages occupied by the various crops in a given region or country;
2. **Crop yield forecasting**: forecasting of the mean crop yields per country and per large region;
3. **Vegetation and crop state monitoring**: areawise monitoring of the state of the vegetation and of crops;
4. **Rapid and timely estimation of the E.C.’s total production** of the most important crops;

In the present paper, these four activities are presented briefly and some examples of operational results are given.

1. CROP INVENTORIES
The objective is to know, for a given region or country, the total area occupied by a given crop and during a given season. The methodology consists of a combined use of a (relatively) limited number of ground observations and of remotely sensed information, in order to make it possible to extend the results of the ground observations to the whole of the area. The most usual technique to integrate a ground survey and satellite observations is the Regression Estimator. The technique has been adapted and validated by the Agricultural Information System Unit for several regions in the E.C. and is described in Delincé (1990) and Gallego and Delincé (1991).

If the validity of the regression estimates is acceptable then they are applied to the strata and the region as a whole and result in an estimate (the ‘regression estimate’) of the acreage occupied by each crop. However, for those crops for which the validity of the relations is weak, the regression estimate method is not applied and the acreage of the crop is estimated by extrapolation over the whole
stratum of the field sampling results. Such is mainly the
cases for crops of minor importance in a given stratum,
when the dates of the images are not suitable for a good
classification of the crops, resulting in possible confusion
between crops (e.g., potato and sugar beet). The analyses
also provide interesting additional information regarding
the approximate geographical distribution of the crops and
land utilisation.

**Presentation of some results:** In Table 1, some acreage
estimates obtained with remote sensing are presented.
(Source: Delincé, 1992).

**Table 1: Some examples of 1991 regional crop acreage esti-
mates (x 1000 ha) obtained with remote sensing.**
(Source: Delincé, 1992). (The figures between brackets are the %
coefficients of variation; n.a stays for not available.)

<table>
<thead>
<tr>
<th>Region:</th>
<th>wheat acreage</th>
<th>barley acreage</th>
<th>maize acreage</th>
<th>sugar beet acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makedonia (G)</td>
<td>465 (&lt;4)</td>
<td>63 (8)</td>
<td>88 (11)</td>
<td>20 (13)</td>
</tr>
<tr>
<td>(Kavouri &amp; Ditiki)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Castilla Leon (E)</td>
<td>331 (4)</td>
<td>1037 (2)</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>(Burgos, Palencia, Valladolid,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zamora)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catalunya (E)</td>
<td>46 (12)</td>
<td>263 (4)</td>
<td>30 (9)</td>
<td>n.a.</td>
</tr>
<tr>
<td>Emilia Romagna (I)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>80 (8)</td>
<td>106 (7)</td>
</tr>
<tr>
<td>Region Centre (F)</td>
<td>892 (2)</td>
<td>197 (5)</td>
<td>209 (5)</td>
<td>26 (18)</td>
</tr>
<tr>
<td>Ile de France (F)</td>
<td>264 (3)</td>
<td>56 (11)</td>
<td>53 (9)</td>
<td>44 (6)</td>
</tr>
</tbody>
</table>

2. CROP YIELD FORECASTING

2.1 Objective and limitations

The overall objective is the timely, quantitative, forecast-
ing of the expected mean crop yields per country and per
large region. The crops of interest are: wheat, barley, grain
maize, rice, sugar beet, potato, oilseed rape, sunflower,
soya-bean, cotton, vine grape and olive. The objective is
clearly not to produce yield forecasts at the level of fields,
areas, villages or small regions such as districts or coun-
ties. Such would even be impossible, as will appear from
what follows. Indeed, the implementation of the objective
goes along with the following five problems that need to
be solved:

a. **A change of scale:** from site-specific input information,
to forecasts that are valid for large regions or countries;

b. **A limited precision of the input information,** for
example, the information contained in the 1:1,000,000
soil map is already a generalised synthesis of the original
field observations; the meteorological conditions at
the level of the weather stations are not always com-
parable with the weather conditions in the farming areas,
nor with the weather conditions that were recorded at
the research sites were the relations between crop
growth and weather conditions were established; plant-
ing dates, crop cycle lengths, etc., can only be estimated
with a precision of approx. 5 to 10 days; part of the
available input information is only valid within national
boundaries (e.g., the soil classification criteria and the
and type and installation characteristics of the meteorologi-
cal instruments).

c. **A limited spatial resolution of the input information.**
For example, the E.C. soil map has a real resolution of
approximately 5km x 5km; the number of reliable, daily
reporting weather stations in the E.C. is limited to ap-
proximately 600; complete and reliable time series of
crop yield, needed for the validation of any model or
method, are only available for the E.C. large NUTS 1
regions; for what concerns crop growth conditions,
farming practices, etc., information is often only avail-
able for very large regions of several 1000s of square
kilometers.

d. **Non-availability of part of the input information.** For
example, the exact profile available water capacity of
the soil (PAWC); the depth of the soil and rooting depth;
the soil occupation by the various crops in a region; the
relative importance of the various crop varieties that are
planted in a given region; also, the information on farm-
ing practices and farmers decision making mecanisms
the can not be made timely available.

e. **Limited knowledge on the relations between regional
crop yield and the agro-pedo-meteorological growth
conditions.**

2.2 Preparatory activities

To solve part of the listed problems, the following activ-
ities were undertaken in the framework of the Agriculture
Information Systems Unit:

a. **Establishment of agro-pedo-meteorological crop in-
ventories.** For most of the crops that are commonly
cultivated in the E.C, literature and expert-knowledge
based information was collected on (1) statistics on
cultivated surfaces and yields, (2) regionalized pheno-
logical crop calendars and (3) the environmental re-
quirements of the crops. Inventories are available for:
most crops of Italy, Greece and Spain (Narciso et al., 1992), Belgium, The Netherlands and Luxembourg (Falsle, 1992), the United Kingdom and Ireland (Hough, 1990), grapevine in France (Carbonneau et al., 1992) and Barley (Russell, 1990), Maize (Bignon, 1990), Potato (MacKerron, 1992) and wheat (Russell, 1993) in the E.C.

b. Potential evapotranspiration (PET). PET is a key input variable in many crop yield forecasting models. A method for the calculation of this parameter, that at the same time gives reliable estimates of ten day totals and are valid for all of the EC-regions has therefore been developed by Choisnel et al. (1992).

c. The 1:1,000,000 soils data base and Profile Available Water Capacity (PAWC) map of the European Community. The information contained in the existing 1:1,000,000 E.C. soil map (C.E.C., 1985) was updated and completed with information available in the original archives that were used for its elaboration. This resulted in Version 2.0 of the E.C. soil map (King and Daroussin, 1991). From this version, a Profile Available Water Capacity Map is presently being derived by the Joint Research Centre in collaboration with the Pedological Service of the French National Institute for Agricultural Research (I.N.R.A.).

d. Establishment of a data base with meteorological data. The data base contains historical series of daily data for approximately 350 stations and for the following parameters: rainfall, temperature, vapour pressure, sunshine duration, windspeed, cloud cover. The data were provided by the national meteorological services of the E.C. countries and by the services of Poland, Slovenia, Austria and Switzerland. In addition, real time meteorological data (temperature, rainfall, windspeed, etc.) and derived information (estimated PET, estimated solar radiation, sums of temperature above a given base temperature, etc.) from approx. 650 stations throughout geographical Europe (U.S.S.R. not included), are received on a daily basis.

e. Spatial interpolation of meteorological input data. The European meteorological network is relatively sparse considering the large range of elevations. A provisory technique has been developed for the interpolation of data from the existing network. The estimates of the meteorological conditions that are relevant for crop growth are fairly accurate at a spatial resolution of approximately 50km x 50km. The technique is described in van der Voet (1991). From what proceeds, it follows that the yield forecasting methods that use meteorological information, can not give reliable outputs at the local scale and that the agrometeorological data or model outputs obtained for a given station or gridcell, can only serve as areawise or regional indicators of the quality of a cropping season. To use the information for quantitative yield forecasts, it is necessary to calculate regional averages of local outputs, that are preferably weighted for the area occupied by the crop in a region, the occupation of the different soil types by a crop and the major farming practices in the region.

2.3. Methods for timely crop yield forecasting, under development for the C.E.C.

Within the C.E.C. context, several methodologies are presently being developed and tested. The most important method consists of the use of agrometeorological crop growth simulation for annual crops. Simulation models are presently under development by the Dutch Institute for Agricultural Research, based at the Staring Centre in Wageningen.

The models use daily meteorological data but run with 10-day time intervals. Model outputs are available a few days after the end of a 10-day period. Farming practices (e.g., plant population density, weed control, etc.) and soil fertility (fertiliser supply) are assumed to be not variable from year to year (always optimum or “average”) and rainfall, (soil moisture status), temperature and sunshine duration are considered to be the only factors inducing interannual variability in the growing conditions (start of the season, dry matter production, etc.). This is of course not true in reality and the exact quantification of the average production level of a region and of the possible technological trend are thus important steps in the model validations. The models are crop specific, meaning that a crop only grows and develops if certain environmental requirements, that are specific for a given crop, are satisfied (see hereafter). The models are driven by a combined energy balance / waterbalance module which compares real transpiration with calculated potential transpiration (through a light interception / CO2-assimilation / water requirements / water availability sub-module). For crop growing to be possible, a number of basic requirements have to be satisfied. The general example of model that will be applied for crop growth simulation is given in the Figure 1 (adapted from Vossen (1990). Crop-specific model characteristics can be found in the literature, in the previously listed agro-pedo-meteorological inventories and in van Heemst (1988).

The outputs of the models are threefold:
a. **Agricultural season quality indicators**, for example: estimated actual soil moisture reserve; differences as compared to the previous dekad; state of advancement of the cycle during a given dekad; sum of temperatures cumulated since the start of the active growth; percentage departures from the long term mean or median.

b. **Alarm warning**: Detection of abnormal weather conditions during a dekad, or cumulated since the start of the season.

c. **Mapped outputs**: Figure 2 illustrates some of the outputs that are already being generated by the Agricultural Information Systems Unit.

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**Fig. 1 - Example of a general type of agrometeorological model:** (AET, MET = actual and maximum evapotranspiration; AR, AWC = actual and available water capacity; P = planting; CE = crop establishment; E/F = earing and flowering; MR = milky ripeness; R = maturity; D_c = critical daylength; T = temperature; Σ(b) = sum of temperatures (base: b).
RAINFALL SUM
PERCENT DEVIATION FROM LONG TERM MEAN
1992
third decade of march
cumulated since the first decade of october

percent
- no data
- +50
- -50 to -20
- -20 to -10
- -10 to 10
- 10 to 20
- 20 to 30
- 30 to 50
- > 50

Fig. 2 - Example of an output presently produced by the Agricultural Information Systems Unit.
2.4. Interfacing remote sensing and agrometeorological modelling

The use of agrometeorological models for timely quantitative crop yield forecasting on a regional or national scale, has two major disadvantages: first of all, the input data have to be obtained from the relatively sparse European meteorological network, which does not allow to retrieve reliable weather information for areas smaller than approx. 50kmx50km. Secondly, because ground observed information (farming practices, planting date, stand density, variety, soil type, crop development stage, etc.) cannot be made timely available for the whole of the E.C., the model outputs themselves for each 50kmx50km gridcell have a limited precision. As a result of both facts, the quantitative yield forecasts can only become reliable when they are applied to large regions or countries. The introduction of remotely sensed information into the models is likely to significantly improve the spatial representativity and the trustworthiness of both the model inputs and outputs. Such improvements are expected from an appropriate use of AVHRR information, especially for the following applications:

a. the spatialisation of inputs such as meteorological data and of certain outputs such as, for example, drought severity indicators;
b. a 1:1 000 000 soil occupation zoning of the E.C.;
c. an improved, more reliable and spatially correct depiction of alarm situations such as droughts, extreme colds and abnormal high temperatures;
d. the possible direct input of remotely sensed information, such as estimated solar radiation and rainfall, into the agrometeorological models.

2.5. A geographical information system (GIS)

Working on a continental scale, with its diversity of climates, crops, soils, agricultural practices and technologies, requires powerful computer software to overlay, combine and possibly integrate all this data and information. The Pilot Project has therefore installed a Geographic Information System, which occupies a central position, not only in the implementation of the activities related to crop yield forecasting, but also in the integration of all the other activities of the Project. The general design of this System is illustrated below (Figure 3). The system is described in detail in [Burrill and Vossen, 1992].

3. MONITORING OF THE CONDITION OF THE VEGETATION AND YIELD INDICATORS

The main objective of this activity is the timely, qualitative and areawise monitoring of the condition and the state of advancement of the main crops and of the vegetation. This information can then be used as qualitative indicators of crop yield. The second objective is to issue alarm warnings in the case of abnormal conditions.

The information is derived from the data sensed by the AVHRR (Advanced Very High Resolution Radiometer) sensor on the NOAA (National Oceanic and Atmospheric Administration) meteorological satellite. The normalised difference vegetation index (NDVI) and estimated surface temperatures (T_s) are calculated that are useful to assess the state of advancement, the condition and the water status of the vegetation. However, so far no operational method exists for the exact quantification of regional biomass production, nor grain production, in the E.C.

The expected outputs are cartographic products of areawise qualitative yield indicators, that are produced with 10-day intervals, for example: state of advancement of the vegetation, as compared to a reference year; the intensity of possible drought stress of the vegetation; the relative biomass production as compared with a reference year;

The expected, mean resolution of the cartographic products is approx. 25kmx25km, but depending upon the region, the resolution can be higher or smaller. The cartographic units are the E.M.U.'s (Elementary Monitoring Units), which are geographical areas of variable surface, that show a relative homogeneity in the environmental characteristics that contribute to the spectral signature and the water status of the vegetation (e.g., the botanical composition of the vegetation as such, the soil types, the altitude, the cropping pattern, the size of the fields, the farming practices, etc.)

4. RAPID AND TIMELY ESTIMATION OF THE TOTAL ACREAGE AND YIELD OF THE E.C.'S MOST IMPORTANT CROPS

The objective of this activity is the timely and rapid elaboration of information bulletins on the modifications of the acreages occupied by the E.C. major crops as compared to the previous year and on the interpretation of the yield indicators of these crops. The scale of the activity is Europe, meaning that crop production information becomes only available for Europe as a whole, and that the information is not broken down into information per country. Such would also be impossible, as will appear from the description of the applied methodology.

For a sample of 53 sites of 40kmx40km in the E.C., high resolution satellite imagery (SPOT or LANDSAT TM) is
acquired and analysed, if possible 4 times per year. For the estimate of the current year’s production, no field observations are used to help to analyse the images. However, information that is available from the previous years may be used (e.g., the exact location of fields and crops). The images are acquired at representative dates of the development stages of the major crops in a region. Careful analysis allows then the stepwise analysis of the data and the identification of the crops on the image. Additional analysis allows also to derive information on yield indicators such as advanced or delayed development stage of (part of) the crops, possible waterstress, biomass as compared with previous years, etc.

An example of results: The total E.C. area occupied in 1991 by sugar beet, as compared to the values reported for 1990 by the National Statistical Services, is estimated to have decreased by 1.9%. (Source: Delincé, 1991, pers.comm.). The figures for the total area occupied by cereals is +5.1%.
CONCLUSION

For the estimate of crop acreages on a regional scale and the rapid estimation of the E.C.’s total agricultural production, the system for the timely forecasting and assessment of the crop production is entirely based on the operational application of remote sensing techniques. Also for the timely monitoring of the condition of the vegetation, remote sensing techniques are used in an operational way. But the quantitative assessment of crop yields is still entirely based on methods and models that use surface observed data as an input. The techniques and methods themselves and the limited precision and resolution of most of the input data, do not permit the use of the outputs for spot evaluations of the crop production at a given site, village or small region. All of the outputs, based on any of the methods that are presently under development (be it the remote sensing techniques, the agrometeorological models or a combination of both) can only provide information that is reliable at the (large) regional, national or continental scale.

REFERENCES


