RAPID ESTIMATES OF CROP PRODUCTION USING REMOTE SENSING : EUROPEAN EXPERIENCE

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Abstract

This paper describes a technique in which high-resolution satellite imagery from SPOT and the Thematic Mapper is used in an operational way to provide rapid estimates of annual changes in area and production of various important crops in Europe. The results, produced throughout the crop year, are transmitted to the Directorate General of Agriculture of the Commission of the European Communities and to the Statistical Office of European Communities, where they help to provide precise and up-to-date information on agricultural production.

The agricultural information must be delivered rapidly in order to be of use. The Joint Research Centre, which is responsible for this work, has set a target of 10 days from the date of acquisition to the date of delivery of the information. This tight schedule, and the number of site (53) which are to be monitored, requires a novel and industrial approach to the image analysis. This paper examines the operational implications of these requirements and demonstrates that Action IV system is now fully operational.

Introduction

The Directorate-General for Agriculture (DG VI) of the Commission of the European Communities requires regular and up-to-date information on crop acreages and potential production in order to direct the Common Agricultural Policy. EUROSTAT, the Statistical Office of European Communities, requires similar data in order to maintain its statistical data bases. Together, they have charged the Joint Research Centre of the European Communities (JRC) with the task of introducing remote sensing data into the conventional system of data collection for agricultural statistics (Meyer Roux, 1987). The JRC's MARS project (Monitoring Agriculture with Remote Sensing) has designed a work programme whose various parts (Meyer Roux and King, 1992) are contracted out to national and regional government services, private companies and universities. One such company, SOTEMA, has undertaken the image processing part of "Action IV".

This part of Action IV consists of agriculturally-oriented analysis of high-resolution satellite images acquired either from SPOT or from Landsat's Thematic Mapper. These analyses are designed to provide rapid estimates of annual changes in area under various important crops in Europe, and the potential production of these crops. The estimates must be updated regularly and the results must be in the hands of the DG VI as rapidly as possible. The MARS project has set a target of 10 days from the date of acquisition to the date at which the statistical information is available.

1. USER NEEDS

The steering committees that monitor the European Community's Common Agricultural Policy require (1) basic agricultural statistics that are as up-to-date as possible. The value of these data is inversely proportional to the interval between the observation and reception by the end-user.

Each CAP steering committee specializes on a particular crop or group of crops according to a standard nomenclature. In remote sensing terms, this means that image data must be (2) discriminated by crop.

The data supplied to the CAP committees include both crop acreage figures and forecast productions. The committees reason in terms of (3) year-on-year trends at the (4) Community level.

Decision-making bodies can only make full use of the data they receive if they are (5) self-consistent, reliable, and regular.

2. REMOTE SENSING BASICS

Satellite-based remote sensing is increasingly widely used for observing and monitoring natural resources because it offers four key advantages : repeat coverage, objectivity, accuracy, and (radiometric) information content.

When remote sensing data are used to generate agricultural statistics, a number of constraints must, however, be borne in mind.

First, the imagery returned by "high-resolution" instruments is generally not suitable for discriminating between objects separated by less than 20 or even 30 metres. There can be no question of looking directly at ears of wheat or cobs of maize. Often, it is difficult enough to distinguish one small field from its neighbour.

Secondly, because the observing instruments are carried by orbiting spacecraft, the times when images can be acquired are determined primarily by the satellite orbits. Also, the instruments under discussion here cannot see through cloud, so imagery can only be acquired when there is little or no cloud. (This paper does not address the question of all-weather radar imagery since this is still only at an experimental stage). Although the data gathered are objective, they only correspond to measured quantities of

light reflected by the ground cover. Thus, image data do not provide all we need to estimate crop yields.

Given this mix of advantages and constraints, how will remote sensing data meet the requirements of the CAP steering committees and the EC ?

The approach adopted by MARS is to use low-resolution data to monitor crop health (Action 2), agro-meteorological models to calibrate the satellite imagery, and high-resolution data to compile regional crop inventories (Action 1). Low-resolution data is unsuitable for compiling crop inventories because most fields are much smaller than the image pixels.

And what about the feasibility of using high-resolution satellite imagery for the regular monitoring of crop acreages ? It certainly offers some potential advantages. DG-VI and Eurostat would receive early estimates of crop acreages at intervals throughout the year, complete with forecasts of the likely yields at EC level. Action 4 has been set up to test such a system.

Higher image definition means more data. Because high-resolution satellite imagery is so detailed and accurate, it is impractical to work with or analyse a complete coverage of an area as vast as the EC. Apart from the prohibitive cost, the data processing is well beyond the capabilities of current software. It would also require an enormous number of analysts. A single figure gives an idea of the scale of the problem - one complete coverage of the 12 EC countries corresponds to 650 (cloud-free) SPOT scenes.

The only practicable solution is to sample the target area by selecting a number of so-called "sample sites" suitably distributed across Europe.

Unfortunately the sample sites cannot be chosen solely on the basis of agricultural considerations. Sites also need to be suitably located relative to the satellite ground tracks (and, in the case of SPOT, in such a way as to minimize acquisition conflicts). Sample sites were selected using a grid that is a compromise between the ground track patterns corresponding to the two major satellite systems (SPOT and Landsat TM).

A further limitation of remote sensing is that the crops distinguishable in a satellite image do not necessarily match the conventional nomenclature of agricultural analysis. Where certain crops cannot be discriminated, the image interpreter has no option but to assign a mix of crops to a single class. Since the main aim is to monitor year-on-year trends, the system of classification must be rigorously the same each year... even if crops considered as belonging to a single classification in one series of images can in fact, for one reason or another, be distinguished in another.

3. PROJECT ORGANISATION OR RESOLVING THE CONTRADICTIONS

3.1 EC LEVEL

To monitor EC agriculture the number of sites must be large enough to be representative of European farmland. Within the limits of cost, practicability and available processing resources briefly mentioned above, the number should be as large as possible. For Action 4, the CEC Joint Research Centre (JRC) decided to cover 6% of Europe's utilized agricultural area (UAA) using a set of 53 sample sites, each measuring 40 km x 40 km, and covering all 12 EC countries (figure 1).

Fig 1 Location of th 53 sites

3.2 UP-TO-DATE DATA

To ensure that the data supplied to end-users are up-to-date, each satellite image must be quickly analysed to yield a Crop Status Report. The interval between data acquisition by the satellite-borne instruments and image delivery to the contractor responsible for interpretation must be as short as possible. Then, the specifications stipulate a maximum interval of five days between image reception by the interpretation contractor and delivery, by fax, of the corresponding Crop Status Report.

These deadlines preclude the use of up-to-date ground data. The only alternative is to have the image-interpreters analyse the imagery using a combination of experience and high-performance computer software.

3.3 CROP DISCRIMINATION

Optimal crop discrimination depends on acquiring imagery at the most useful times relative to the crop calendar in each region. This means deciding how many images must be analysed each crop year and when they should be acquired. At this stage of the project, experience suggests that four images is the maximum required for most cropping systems.

Image acquisition by the satellite-borne instrument is determined by the satellite orbit and, in the case of SPOT, the instrument pointing mechanism. Useful imagery can only be acquired if the target area is cloud free, or nearly so. Even with two SPOT and one Landsat spacecraft in orbit, it is not always easy to obtain cloud-free imagery of a target area during critical periods. Although the use of two competing image suppliers improves acquisition efficiency, it makes the management task more complex. Success hinges on constant close contact between all parties : SPOT Image, Eurimage, SOTEMA, and JRC.

The three main steps in image processing for crop discrimination are :

- (a) image analysis by photo-interpretation

- (b) automatic image classification

- (c) final classification using all previous classifications of the same sample site as input.

Although, in terms of crop discrimination, classification generally yields less accurate results than photo-interpretation, it has the advantage of covering the entire site. Given that each sample site covers 1600 sq. km, it would be an enormous task to examine each field individually by photo-interpretation. The interpreters thus analyse in detail a limited number of areas known as "segments", of about 50 ha each (figure 2).

In parallel with this, the computer automatically classifies the entire site. The segment interpretation gives meaning to the computer classification. The bulk of the interpreter's work involves the detailed interpretation of segments, the cornerstone of the methodology.

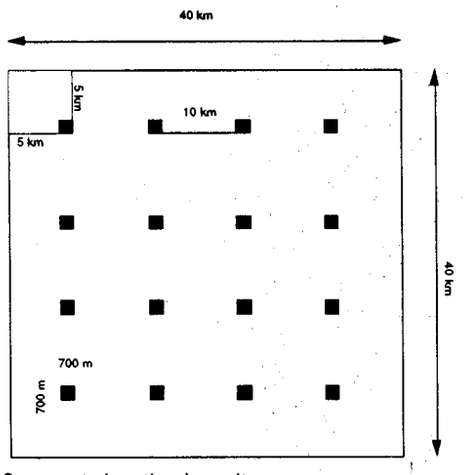

Fig 2 Segments location in a site

3.4 YEAR-ON-YEAR TRENDS

To establish year-on-year trends, the latest imagery must be compared with that acquired the year before. This means that all images must register pixel-to-pixel and be radiometrically calibrated. At this point we become aware of the importance of the idea of always using the same sample sites - the idea of a reference. This concept is central to every aspect of Action 4.

It is no trivial matter to correct images so that they register, pixel for pixel, with a common reference grid. This can only be achieved using a digital elevation model, or DEM. The size of the DEM cells and DEM accuracy must be compatible with the local topography. Full geometric correction must be carried out on a routine basis, preferably without the need for operator intervention. This calls for particularly high-performance software. The MARS project has commissioned purpose-built software, GRIPS (Geometric and Radiometric Image Processing System) which speeds up the process and reduce costs, as each image is corrected in less than 1 hour. All the images are resampled to 20 meters, georeferenced and cut to include only and exactly the 40 X 40 km covered by the site.

Given that it is not possible to obtain realtime data on local atmospheric conditions at the time of image acquisition, the radiometric corrections assume a standard atmosphere (Dedieu and Rahman, 1992).

An operational project must accommodate imagery containing cloud or haze, even when they hide crop combinations of special interest. Statistical estimates based on one image, or series of images, must be directly comparable with those based on other images recorded earlier in the same year or a year or more previous, irrespective of the location and extent of cloud or haze. Over some parts of Europe, cloud and haze can be so persistent as to preclude the acquisition of usable imagery during all periods of interest. Means of overcoming these difficulties must be found.

Each new image is first corrected both geometrically and radiometrically. The interpreter's task is to compare crops in the different segments with those of the previous years. This implies quick and easy access to a large image database. The expertise of image interpreters is focused on the segments they examine in the form of "imagettes" or small zones each enclosing a segment. The "history file" of a

given site is the set of all interpreted imagettes and the corresponding ground data.

3.5 DATA THAT ARE SELF-CONSISTENT, RELIABLE, AND REGULAR

Up to four images of each sample site in each year, for 53 sites, means a total of at least 200 images. MARS is one of the first civilian remote sensing projects to work with such large volumes of data. The project is all the more exceptional in that it involves both large data volumes and very short processing times.

Scheduling is the most critical aspect of the project. The time allowed between data acquisition by a satellite and the delivery of results to the end-users includes preprocessing by the data supplier, data handling and transport, geometric and radiometric correction, interpretation, and classification. These requirements can only be met by organizing production on industrial lines backed by good management, and by a processing chain that is powerful, efficient and reliable. All critical points of the chain must be well designed and managed, and scaled to handle the peak data throughput anticipated during the busy season.

A system designed along industrial lines must guarantee production. The underlying methodology must be reliable, sound and proven. The system must also guarantee interpretation quality, enable statistical agronomists to analyse data from several sources, and transmit the bulletins regularly to the end-users.

In part, this is achieved by optimizing every link in the chain and increased specialization. Image interpreters must get to know the sample sites very well indeed so they can supply refined information to the statistical agronomists who prepare the Crop Status Bulletins at European scale. This division of labour also helps avoid bottlenecks in the system producing fortnightly Crop Status Bulletin.

The image interpreter supplies the statistical agronomist not only with statistical land cover data for each sample site, but also with comments concerning the level of discrimination achieved, the general health of the crops, and any problems encountered during processing.

During the first four years of the project, the results have been validated at the end of the crop year when the estimates prepared by interpretation and computer classification were compared with ground data gathered by field survey teams. During May and June, field teams under contract to the JRC were visiting each sample site to gather ground data on the same segments analysed by photo-interpretation. These ground data were available to the Action 4 team to compare with the year's photo-interpretation results.

The knowledge base concerning each sample site is continually improved and updated. The rules used to discriminate between the various crops are refined as the group's expertise in interpretation increases from year to year.

4. RESULTS

• From 1989 to 1991, Action IV has gone from the "Invitation to Tender" stage to a semi-operational phase. During those three years, the methods and software have been defined, developed and improved. The number of sites analysed per crop year has increased from 4 (in 89) to 30 (in 91). In parallel, the production of results has become more and more rapid and efficient : no constraint was required in 89, when strict time constraints (5 days from image delivery to bulletin edition) were respected in 1991 (Sharman and de Boissezon, 1991).

• From 1992, Action IV has been working fully operationaly : the complete set of 53 sites is analysed with imperative time constraints. Results are sent by fax in fortnightly crop status bulletins publishing european figures for individual crops surfaces and productions (Sharman et al, 1992).

• In the course of these years, the four expressions most strongly associated with Action 4 have been "speed", "volume" and "stable set of sample sites".

"Speed" because the requirement for up-to-date data can only be met by reducing the interval between data acquisition and bulletin production.

"Volume" because the Europe-wide scale of the project calls for the analysis of 53 sample sites and some 200 satellite images during each crop season.

"Always the same sample sites" because year-on-year trends can only be determined by working with the same sample sites and segments year after year.

4.1 UP-TO-DATE DATA

During 1992, Action 4 participants exchanged more than 500 faxes. In all, they purchased about 180 satellite images, 82 % acquired by SPOT. In each window of acquisition (4 per year), the success rate varied from 100 % to 77 % - 100 % of scheduled images were obtained of each of 41 sites, 75 % of each of 8 sites, and 50 % of one site. One site, in Ireland, could only be covered with 1 image.

The 53 sites were analysed on a routine basis.

The volume of data flowing through the system varied considerably as a function of large-scale weather patterns. During the crop year, the number of images acquired per fortnight varied from 3 to 42. More than 95% of the images acquired were analysed within the specified period of five days, with an additional 5 days required from the time of acquisition to delivery of the image data at the contractor's premises. The results were published in 14 fortnightly bulletins.

On the basis of our experience with this operational system, we can now state that it is indeed feasible to use high-resolution imagery for agricultural monitoring. Data can be acquired, processed and analysed, and the corresponding bulletins communicated to CAP Steering Committees in Brussels in just ten days. On the other hand, given the current state of the art, we believe that this time could only be reduced using advanced image processing techniques such as classification by fields.

4.2 CROP DISCRIMINATION AND IMAGE INTERPRETATION

The conventional nomenclature used by agricultural statisticians is not always well suited to satellite image interpretation. For any given site, there is generally a stage in the growing season when, say, maize cannot be distinguished from sunflower, or sugarbeets from potatoes. This is one of the inherent limitations of the method and of remote sensing : light reflected by the earth's surface and recorded at an altitude of 800 km does not always allow to make conventional distinctions between crops.

Photo interpreters provide surface area estimates for groups of crops with comparable radiometry. Statistics bring the information necessary to calculate individual crops evolutions from these mixed figures : using historical data from the previous year, broad groups of crops are divided according to their relative proportion in the same site the year before (Guedes, 1992).

4.3 EUROPE-WIDE TRENDS

Statistical data obtained by analysing sample sites sometimes reveal dramatic changes in the area sown to a particular crop. Local conditions may be good for that crop one year and poor the next. In the MARS project, the sensitivity to change is accentuated because analyses are based on year-on-year trends over the limited area represented by sample sites. We cannot expect to use Europe-wide Crop Status Bulletin information to discern trends in a particular region - natural though it may be to wish to do so.

A specific extrapolation model has been developed to calculate european figures for surfaces and productions (Guedes, 1992). Sites are grouped into zones within crops have comparable agronomic behaviour and occur with similar proportions. Each zone is composed of one or several countries, so that we may use exogenous data (as official acreages figures) to calibrate the model.

Those zones are the basic units to extrapolate the 53 sample results with an iterative method, leading to crop surfaces estimates established at european level.

To provide not only surfaces estimates, but productions figures, yields must be estimated too. Work conducted by the scientific community over the last few years suggests that crop yields can be estimated from high-resolution satellite data, provided a number of conditions are met. As a rule, however, the results obtained under one set of conditions cannot be translated into forecasts under a different set of conditions. Yield forecasting with remote sensing only is critically dependent on luck in obtaining either a long series of multidate images or a smaller number of images at critical crop calendar times. Given the conditions under which Action 4 operates, thanks to the images, we are currently able to forecast yield qualitatively, not quantitatively. The production figures are though calculated by introduction of mean yield level per crop and per zone in the extrapolation model. Qualitative information coming from the photo-interpreters are used to ponderate the mean yield figures.

4.4 VALIDATION AND REFINEMENT OF INFORMATION

The ground data gathered for some 800 segments (425 sq. km) represent 1 part in 200 (or 0,5 %) of the area covered by the sample sites. During the 1992 crop year, field teams inspected some 25 000 fields. The analysis of these results suggests that this volume of ground data is not sufficient, without the contribution of remote sensing, to monitor crop acreages at the EC level. On the other hand, ground data have been essential for validating image interpretation during the first years of the project.

Validation turned up a number of surprises. A significant percentage of segments showed differences between ground data and image interpretation results. Some of these differences were clearly due to interpretation error. In these cases, the photo-interpreters' knowledge base is improved by the ground data. On the other hand, the difficult task of visiting fields and recording observations can give rise to errors that are immediately obvious to the photo-

interpreter. In most cases where interpretation and field data were in disagreement, however, the photo-interpreters were left with a lingering doubt. In these cases, because the interpreters cannot be certain of their analysis, we assume that the ground data were correct.

From 89 to 92, the adequation between ground data and image interpretation has become better and better, and has reached a limit that cannot be improved. Indeed, none of the techniques (ground survey and photo interpretation) can produce perfect results. So, in 93, the JRC has decided not to realize ground surveys because they are not cost effective yet at this stage of the project.

4.5 QUALITY AND PRECOCITY OF THE RESULTS IN 92

The 92 agricultural campaign was the first fully operational year for Action 4 :

- the total sample of sites (53) was analysed for the first time
- the extrapolation model allowed to provide european level results
- the estimations were done not only for surfaces of crops, but for productions too.

So it is now really possible to judge the quality of Action 4 results, as we can compare them with official European figures from Eurostat.

The tables below (tables 1 and 2) list, for each main crop, the Action 4 estimates along the crop year 92 (surfaces and productions), compared to Eurostat figures.

TABLE 1 : Action 4 crop surface estimates compared with official European figures

1000 Ha	ACTION 4				EUROSTAT
	Fax n°3	Fax n°7	Fax n°9	Fax n°14	Fax n°3
WINTER CROPS	11 May 92	6 July 92		12 Oct 92	14 Dec 92
Soft Wheat	13 217	13 491		13 437	13 654
Durum Wheat	3 240	3 210		3 260	3 296
Barley	11 831	11 611		11 841	11 510
Total cereals	35 527	35 365		35 549	35 246
Rapeseed	2 417	2 405		2 376	2 380
SUMMER CROPS			3 Aug 92	12 Oct 92	14 Dec 92
Maïze			3 762	3 846	3 810
Potatoes			1 492	1 535	1 594
Sugarbeets			1 972	1 942	2 014
Sunflower			2 395	2 337	2 774

TABLE 2 : Action 4 crop production estimates compared with official European figures

1000 T	ACTION 4				EUROSTAT
	Fax n°3	Fax n°7	Fax n°9	Fax n°14	
WINTER CROPS	11 May 92	6 July 92		12 Oct 92	14 Dec 92
Soft Wheat	78 461	78 438		74 635	75 732
Durum Wheat	10 617	8 930		8 731	9 673
Barley	50 452	48 305		46 969	43 456
Total cereals	177 240	174 305		171 168	167 117
Rapeseed	7 292	6 293		6 468	6 200
SUMMER CROPS			3 Aug 92	12 Oct 92	14 Dec 92
Maïze			25 634	28 379	28 584
Potatoes			42 424	42 759	46 120
Sugarbeets			95 647	101 901	110 954
Sunflower			3 995	4 007	4 100

We can see that, from the very beginning of the crop year, Action 4 estimates are very close to later estimates from Eurostat. On the 11th May 92, remote sensing figures for straw cereals and rapeseed stabilize themselves and remain very similar to the official estimations for surfaces. On the 6th July 92, production estimates for these same winter crops are close to Eurostat estimates.

Considering the total cereals (including maïze), both surface and production estimates are satisfactory as soon as 25th May 92 : the relative difference between official figures is only 1 % for surfaces and 3 % for production.

In the bulletin issued on August 3rd 1992, Action IV gave satisfactory results, in comparison with the official end-of-year figures from EUROSTAT, for maize, potatoes and sugar beet. The results for sunflowers did not correspond with the official figure ; we believe that this discrepancy can be attributed to the poor condition of the crop in southern countries, where sunflower fields were often indistinguishable from fallow fields on the images.

The 90 % one-sided confidence interval measured at the same date was 2 % for soft wheat, 2,7 % for barley, 5,6 % for rapeseed, about 4,5 % for maize, sugar beet and potatoes, and 9,6 % for sunflowers

5. CONCLUSIONS AND PERSPECTIVES

The results for Action IV in 1992 have shown that the method is capable of giving results, early in the season, that compare closely with the official end-of-year figures for both areas and, to a lesser extent, production. This suggests that Action IV will fulfil its mandate to provide both the DG VI and EUROSTAT with up-to-date and accurate agricultural statistics on a wide variety of crops at the scale of the EC ; that these data are available regularly ; that they are self-consistent and reliable ; and that the synthesised results are available within a very short time of the acquisition of the raw data.

In terms of the mechanics of the operation, we can justifiably claim that we now have a fully operational system. The data flow from satellite to client is fully mastered. Images can be acquired, shipped, processed, and analysed, and the results of the analysis faxed to their destination, in 10 days or less ; this rate can be sustained, with a through-put of some 180 images, for the 6 months of the growing season.

We have achieved satisfactory results for one year. It now remains to be seen that we can repeat this result, and, if possible, improve on it. A second year with good results would suggest that the method is sufficiently robust to be described honestly as "operational". The conditions for the repeat of the experiment are not ideal, however ; as a result of changes in the Common Agricultural Policy, we can expect to see major changes EC agriculture in 1993, our second full-scale year.

If the technique can now be said to be pre-operational, several major tasks remain to be done to make it fully operational. Firstly, the software used at present has been developed as the project evolved, and consists of a rather heterogeneous set of working prototypes. These various programs must be re-engineered into a single, fully professional and industrial product. The final software will also incorporate several methodological improvements, including :

- software-based aid to making decisions, which will change the role of the human from image interpreter to supervisor of the automated process,
- field-by-field, rather than pixel-by-pixel classification,
- incorporation of information derived from low-resolution satellites (especially AVHRR from Action II),
- incorporation of information derived from agro-meteorological models,
- permanent electronic crop status bulletin,
- significant reduction in the dependence of the system on ground data - and the elimination of ground data altogether if possible,
- incorporation of information derived from radar imagery.

As a consequence of the demands of the technique, we therefore confidently expect Action IV to continue to help to drive the development of civilian operational applications of high-resolution satellite imagery.

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