REVIEW OF THE MAIN REMOTE SENSING METHODS FOR CROP AREA ESTIMATES

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ABSTRACT:

This paper is a complement to two review papers published in the last years (Gallego, 2004, Carfagna and Gallego, 2005). In these papers an analysis is provided on the different ways satellite images can be used in for crop area estimation. We can group the methods into three categories:
- Pixel counting or similar approaches, including sub-pixel analysis : Estimates coming essentially from remote sensing. Ground data have a secondary role: training data for image classification, or sub-pixel analysis. In general this type of approaches should not be used unless there is no reasonable alternative. The statistical justification for this type of methods is very weak and there is a very high risk that the final estimates come essentially from the a priori belief of the analyst.
- Methods combining exhaustive but inaccurate information (from satellite images) with accurate information on a sample (most often ground surveys): Main types of methods in this category are regression, calibration and small area estimators. This is often the soundest way to use remote sensing for area estimation.
- Satellite images are used as support to build area frame surveys: to define sampling units, for stratification; as graphic documents for the ground survey, or for quality control.

Cost-efficiency is discussed: Operational use of remote sensing had reached the cost-efficiency threshold in some types of landscapes (large fields and few crop types) with Landsat TM images. New assessments are needed now for other image types. Some comments are made on the reason why many administrations are reluctant to integrate remote sensing in the production of area statistics.

The specific experience of the MARS Project on area estimation is reported here with more detail on three activities:
- Regional crop inventories (1988-1993), that combined ground surveys and satellite images with a statistically consistent regression estimator. The remote sensing part that did not reach the cost-efficiency threshold at that time.
- Rapid Crop Area Change Estimates (Action 4 or Activity B). This was an attempt to provide area estimates without ground surveys. The reasons for the failure of this activity are briefly analysed.
- Eurostat's LUCAS 2006 survey: the main contribution of remote sensing was a stratification of a large pre-sample of points by photo-interpretation on aerial orthophotos.

1. INTRODUCTION

Land cover area estimation is one of the most obvious applications of remote sensing. However the use of satellite earth observation tools for the production of official statistics has remained modest. In the field of agricultural statistics very few operational activities remain. One of the reasons of such a low level of development is the lack of continuity of the Landsat program. Alternative images of similar type are now available but little enthusiasm is shown to assess their use. Part of the problem may be the over-marketing in the past of methods that were not sufficiently solid from the statistical point of view. This paper gives an overview of different ways to use satellite images for land cover area estimation. It provides a complement to two previous papers (Gallego, 2004, Carfagna and Gallego, 2005). Approaches are grouped into three categories:

1.1 Pixel counting and sub-pixel analysis.

Using remote sensing as the primary information source. Ground data, are used as auxiliary tool, mainly as training data for image classification, or sub-pixel analysis. Area estimates from pixel counting are sometimes used without a solid statistical justification. The main limitation of this approach is that there is little guarantee of unbiasedness: image classification can be tuned to get the number of pixels we wish in a given category. The bias of area estimation can be potentially nearly of the same order of the commission or the omission errors. An image classification error of 20-30% can be considered a good result, but a bias of that order is generally not acceptable for land cover area estimation. These limitations and risks apply both to pixel counting approach and to polygon measurement in a land cover map, such as CORINE Land Cover. Additional problems appear if land cover maps are used for direct area estimation: bias coming from scale and incompatibility of statistical land cover maps nomenclature with statistical needs.

1.2 Regression, calibration and small area estimates.

Methods, such as regression, calibration and small area estimators, combining exhaustive but inaccurate information (from satellite images) with accurate information on a sample (most often ground surveys). The statistical basis of this category of methods is generally solid, but they require a knowhow that is generally not available in official institutions. Combining a sample of high or medium resolution images with a blanket coverage of coarse resolution images provides a solution to area estimation problems when ground surveys are not feasible because of difficult access or high cost. The need of qualified staff to carry out this type of methods is a limitation for official organisations, but this approach should be re-assessed with new image types (DMCII for example).

1.3 Supporting area frame surveys.

Satellite images can support area frame surveys in several ways: to define sampling units, for stratification; as graphic documents for the ground survey, or for quality control. We give an estimation of the relative efficiency of the point sampling plan of the Eurostat LUCAS survey (Land Use/Cover Area-frame Survey). The sampling plan of LUCAS (Delincé, 2001) is based on unclustered points that are sampled with a two-phase scheme: A systematic sample in the first phase is stratified by photo-interpretation. The second phase subsampling concentrates the sample on the most agricultural strata. The efficiency of different point sampling approaches comes from three sources: systematic approach in the first phase, separating strata (post-stratification) and applying unequal probability to subsample in each stratum. The efficiency due to each of the three reasons is estimated separately.

2. THE EXPERIENCE OF THE MARS PROJECT IN THE 90'S

2.1 : Area Sampling Frames in the Regional Crop Inventories.

The method was applied to a number of selected regions in different EU countries. It was based on two elements: a ground survey on a sample of pieces of land (segments), and an optional improvement of the results with high resolution satellite images (Gallego, 2000, Taylor et al, 1997). The size of the segments usually varied from 25 ha to 200 ha depending on the agricultural landscape, especially on the size of fields. For the area survey, surveyors located the segments, delineated fields on a transparent sheet placed over an aerial photograph, and wrote down their land use. About 5% to 10% of the segments were visited again by supervisors to assess the quality of the ground work. Area estimates and their standard error were computed with usual formulas for stratified sampling. A major component was the assessment of area frames in the EU, in which geographic elements are sampled instead of farms (FAO 1996, FAO 1998); satellite images are a major tool to define such frames.

Comparisons were made between different types of area sampling frames:

- Frames based on the so-called segments with physical boundaries (Cotter and Tomczac, 1994) as used in the June Enumerative Survey (JES) by USDA.
- Geometrical, usually square, segments (Gallego, 1995).
- Point frames, as used for example in the French TER-UTI survey.

Square segments and segments with physical boundaries gave similar results (González et al, 1991); square segments were preferred because there were cheaper. Point surveys turned out to be less appropriate for geographical co-registration with satellite images, but had in general better cost-efficiency for a ground survey, needed less infrastructure for data management and avoided the bias due to the elimination of thin "linear elements".

A method was developed to sample farms through a sample of points (Gallego et al, 1994), that avoided some complications of traditional approaches to sample farms from area segments (Hendricks et al, 1965), known as open segment, closed segment and weighted segment. The main limitation was that a bias can appear if the concept of Utilised Agricultural Area (UAA) used at the sampling stage does not coincide with the concept of farm area used by surveyors when they interview the farmer.

Stratification based on a coarse photo-interpretation of satellite images was cheap and proved to be cost-efficient, in spite of moderate values for the relative efficiency. A further analysis suggested that better efficiencies can be obtained with CORINE Land Cover as a basis for the stratification (Gallego et al, 1999).

2.2 Remote Sensing Correction.

A careful image classification Landsat-TM or SPOT-XS images in the EU can give an accuracy of 70-80% when the region is not too complex and the classification nomenclature is not too detailed, for example 4 to 6 main crops and another 6 to 8 land cover categories. However the MARS project confirmed that image classification often becomes poorer in an operational context with large, heterogeneous regions and operators working under time pressure to obtain results within a narrow deadline. Table 1 gives a summary of average user and producer accuracy for main crops in pilot regions for regional inventories between 1988 and 1993. We can check that the accuracy is not always satisfactory.

Crop	producer accuracy	user accuracy
All Wheat	66%	61%
All Barley	45%	51%
Maize	42%	54%
Rice	56%	89%
Dried pulses	50%	57%
Oil seed rape	56%	65%
Sunflower	41%	49%
Sugar beet	46%	57%
Wood	79%	82%

Table 1. Average classification accuracy for crops in pilot regions for regional inventories (1988-93)

Regression estimators were used to integrate classified images as auxiliary information to improve the accuracy of the estimates from ground surveys. An alternative procedure based on confusion matrices (Czaplewski and Catts, 1992) has been tested with results that are very close to those of the regression estimator (Gallego, 1994).

The regression estimator is not very exigent in terms of pixel-by-pixel accuracy; in the Regional Inventories the relative efficiency of regression has been often of the order of 2 with classification accuracy values around 50%. This surprising result is partly due to collocation inaccuracy between the ground survey drawings and satellite images when no orthophotos were available and common aerial photographs were used as ground survey documents. Collocation inaccuracy can make that correctly classified pixels appear as errors, but has little impact on the regression estimator, that only uses the global number of pixels per class in the segment. The regression estimator is unbiased if ground observations are unbiased even if the image classification is biased.

The economic assessment of remote sensing can be made through the relative efficiency (table 2), a concept based on the ratio of estimator's variances. The efficiency of remote sensing is better if the landscape has large fields with few dominant crops. For example the USDA reached the cost-efficiency threshold of remote sensing with the regression estimator on Landsat-TM images in the mid-late 90's (Hanuschak et al 2001).

	EC 1988-92
Wheat	2.11
Barley	2.04
Maize	1.68
Oil seeds	1.80
Dried pulses	1.77

Table 2 : Median values of the relative efficiency of remote sensing in the European Union from 1988 to 1992

An efficiency of 2 means that the accuracy obtained with a sample of 1000 segments and remote sensing is the same as the accuracy with a sample of 2000 segments without remote sensing. The cost efficiency threshold can be different with two different points of view: In this simple example, with an efficiency value of 2 for remote sensing and a sample of 1000 segments, we can look at it in two different ways:

- If we introduce remote sensing we can reduce the sample to 500 segments instead of 1000. Therefore remote sensing will be cost-efficient if its cost is less than the cost of surveying 500 segments.
- If we introduce remote sensing the variance will be divided by a factor 2. To obtain the same result enhancing the ground survey, we should increase the sample size from 1000 to 2000 segments. Therefore remote sensing will be cost efficient if its cost is less than the cost of 1000 segments in ground survey.

This simple example illustrates also that the value of remote sensing in the context of a regression or calibration estimator is proportional to the effort made in the ground survey, since the efficiency is approximately independent of the sample size.

The MARS Project concluded in the late 90's that remote sensing could become cost-efficient in Europe with Landsat-TM images, but this option is not any more applicable. New assessments are necessary with new sensors of comparable resolution and possibly wider swath.

2.3 Rapid Estimates of Crop Area Changes in the EU.

The objective of the "rapid estimates of crop area changes in the EU" also called "Activity B" or "Action 4" of the MARS Project was to provide early information on changes in crop acreage each year compared with the previous year, as well as qualitative indicators of potential yields. We make here some comments about the area change estimation. Area estimates for year *t* were obtained by applying the estimated area change rate to official statistics for year *t-1*. The targeted crops were: common wheat, durum wheat, barley, grain maize, field peas, rapeseed, sunflower, rice, potatoes and sugar beet. A long term objective of the activity was to develop a method that could be applied outside the EU as an alternative to the approach of the USDA Foreign Agricultural Service (Taylor, 1996), that combines reports from the agricultural attachés in the embassies around the world with satellite image analysis to identify or quantify major anomalies.

The size of the study area (the whole European Union) did not allow to regularly acquire an exhaustive coverage of high resolution images. Hence a set of 60 sites of 40 km × 40 km was selected. The activity made frequent use of the SPOT satellite's technical capacity for off-nadir pointing (taking an image out of the vertical). The size of the site was determined to ensure that the area could be included in a SPOT image, whatever the viewing angle. The size of the area represented in a SPOT image with a vertical view is approximately 60 km × 60 km. Some Landsat-TM and IRS-1C images were analysed as well. Since these images covered a much larger area, only pieces of a suitable size were delivered. For most sites the target is acquiring four high-resolution satellite images during the main season of crop activity. For some sites with less intensive agricultural activity, one image in the agricultural season is considered enough.

Images were analysed with a method that involved multi-step computer assisted photo-interpretation and pixel clustering (unsupervised classification) leading to an image classification. Until 1995, most pixels were labelled as belonging to a land cover class, such as "winter cereals", "summer crops" or "grassland". About 8% of pixels received multiple or generic labels, such as "sunflower or fallow", or " light reddish turning to light greenish". In 1996, the labelling system changed and become something similar to a fuzzy classification. Each cluster of pixels was linked to one or several land cover classes through a correspondence table used later to compute estimates. The operator could tune the cluster labels. to modify the number of pixels for each class to a certain extent (±10% to ±30%). This gave a flexibility to combine image classification with general information, such as knowledge of the Common Agricultural Policy for the current year or information provided by national publications. In other words the result could be adjusted to match the a priori information of the analysis team and it is not clear that remote sensing had an influence on the final estimates of area change.

In Activity B it was improper to speak of standard error of the estimates, because the panel of sites was not a sample in the strict sense and the degree of mutual dependence of the estimates per site is difficult to assess because the labelling system in the basis is not formula-driven. However it is easy to compare the estimates every month with the official Eurostat figures known at the end of the year. Table 3 gives the mean square accuracy provided by these comparisons. In April the system had very few or no images. We can interpret the accuracy in April as the accuracy that can be obtained from simple expert knowledge. The improvement along the year can be interpreted as the contribution of remote sensing. In 3 cases (common wheat, durum wheat, rapeseed) the accuracy becomes worse; for maize it remains more or less constant. This means that the contribution of remote sensing to the quality of the results is very debatable.

A comparison was made in 1996 of the area change estimated in each of the 40 km × 40 km sites from image analysis and from ground surveys. The values of r^2 were lower than 0.1 for most crops. This means that the change estimated in each site by remote sensing was essentially independent of what was observed on the ground for that site. This confirms that the estimates were more driven by external information (a priori belief) than by image analysis.

	April	May	June	July	Aug.	Sept.	Oct.
Common wheat	1	1.2	1.9	1.6	1.5	1.4	1.4
Durum wheat	2.1	3	2.8	2.6	2.7	2.7	2.6
Barley	4	4	3.2	2.5	2.7	2.4	2.4
Rice	7.7	9.9	9.6	6.1	5.7	5	5
Maize	4	2.5	2.4	2.8	4	4.3	4
Total cereals	1.4	1.3	1	0.9	0.8	0.7	0.7
Sugar beet	6.7	4.6	4.4	2.8	4.3	2.9	3
Sunflower	16.6	12	6.5	7.4	6.3	6.7	7.3
Rapeseed	6.3	9.6	9.8	11.5	11	10.4	10.3

Table 3. Average RMS errors of the rapid estimates of area changes along the year.

A general reflection on the objectivity of remote sensing can be made around the comments in the previous paragraph: satellite images are perfectly objective as radiometric measurements, but extracting information from these images involves an important human input, that becomes essential when the ground data are scarce.

For the area change estimation without ground data of the current year, as in the "rapid estimates" of the Actibity B, the number of pixels classified into each class can be adjusted by the operator to a certain extent, that depends on the classification accuracy for this class. For classes such as winter cereals the flexibility margin may be around 10% to 20%, so that general knowledge may be included to adjust the classification. For example if the compulsory set aside rate (% of arable land that farmers have to leave uncultivated to be eligible for subsidies) goes from 5% in year *t* to 10% in year *t+1* , the area of cereals may be expected to slightly decrease. A priori information can be often found in national publications, such as provisional estimates published by ministries of agriculture. The amount and quality of this type of external information integrated in the procedure determines to a great extent the quality of results.

3. POINT PHOTO-INTERPRETATION FOR STRATIFICATION: THE CASE OF LUCAS 2006.

LUCAS (Land Use/Cover Area-Frame survey) is a point survey run by Eurostat. It was carried out in 2001 and 2003 with a two-stage systematic design in EU15, i.e. the 15 countries that were member states in 2001 (Delincé, 2001). Primary Sampling units (PSU) were selected with a grid of 18 km without stratification. Each PSU is a cluster of 10 points following a 5x2 rectangular pattern with a 300 m step. The "point" is conceived as a circle of 3 m diameter. LUCAS has a double nomenclature: each point has a land cover code (57 classes) and a land use code (14 classes).

A test was made in the whole territory of Greece in 2004 with a different sampling scheme, inspired on the Italian AGRIT survey (Martino, 2003). The test in Greece clearly proved that a stratified sampling scheme of unclustered points is more efficient than the previous system and was applied for the new LUCAS 2006 survey (Jacques and Gallego, 2005). The new sampling scheme is based on a single 2 km grid that covers EU25 with about 990,000 points that have been photo-interpreted for stratification with a simple nomenclature of 7 categories.

1. Arable land
2. Permanent Crops
3. Permanent Grassland
4. Wooded areas, shrubland
5. Low or rare vegetation
6. Artificial land
7. Water, wetland

In most cases the photo-interpretation has been made on aerial orthophotos, but Image2000 (JRC-EEA, 2005) has been used in some areas, mainly due to the high cost of the copyright of orthophotos Each class or stratum is subsampled with a different rate for the ground survey: in most cases 50% for agricultural strata (1 to 3) and 10% for the rest. In 2006 the ground survey has been carried out in 11 countries, that represent the 73% of the agricultural land of EU25 and the 75% of the arable land. The final sample for ground survey in these 11 countries has 169,000 points. For points of very difficult access, the ground observation is substituted by photo-interpretation.

Ground obs / strata	Arable	Perm. Crops	Perm. Grass	Wood, shrub	Bare	Artificial	Water	Total
Arable land	**61165**	1894	18728	2139	5846	1611	255	*91638*
Permanent Crops	410	**9536**	601	630	217	172	6	*11572*
Permanent Grassland	4210	682	**29068**	4340	1187	1425	421	*41333*
Wooded areas, shrubland	1220	930	9725	**84715**	1245	2225	805	*100865*
Bare land or low vegetation	75	65	505	530	**725**	395	195	*2490*
Artificial land	365	170	2255	520	245	**9280**	90	*12925*
Water, wetland	15	10	100	70	45	20	**2765**	*3025*
Total	*67460*	*13287*	*60982*	*92944*	*9510*	*15128*	*4537*	*263848*

Table 4: Confusion matrix of the photo-interpretation for stratification with the ground data (weighted observations)

A confusion matrix of the photo-interpretation is reported in table 4. Observations in strata 4-7 have been weighted inversely to the sub-sampling probability, i.e. if points in the stratum "forest" are sampled with a probability 5 times lower than in the agricultural strata, each point has a weight 5 times higher.

We can observe in the confusion matrices that stratum 1 (arable land) is strongly overestimated. This has an impact on the efficiency of the stratification (that remains still at a good level), but does not introduce any bias in the estimates, as long as it is used for the stratification and not to substitute ground observations. Photo-interpreted observations to substitute ground survey can be used nevertheless without generating any bias on the agricultural estimates when the absence of agriculture is guaranteed (mountains, for example). If the total area of arable land had been estimated by photo-interpretation the bias would have been around 35%.

3.1 Efficiency of the LUCAS 2006 stratification.

We study here the efficiency of the point sampling scheme used in LUCAS 2006 compared with other possible single-stage sampling schemes. The variance comparisons have been made using always LUCAS ground observations on different subsamples and involve some approximation. The subsamples used have different sizes. The relative efficiency of the sampling approach A compared with the sampling approach B has been always computed as:

$$Eff(A/B) = \frac{Var(B)\times n_B}{Var(A)\times n_A} \qquad (1)$$

Where *Var(A)* is the estimated variance for a given land cover type with the approach A and n_A the sample size. The approaches considered are:

1. Simple random sampling (srs). We cannot make an exact estimation of the variance of area estimators for srs because we do not have an srs. We make an approximation applying the srs variance estimation formulas to the LUCAS systematic sample. This corresponds to the variance of random subsamples of the available systematic sample.
2. The second alternative considered is a pure systematic sample. LUCAS 2006 does not fully fall on this type, but pure systematic subsamples with an 18 km step can be extracted. We have selected in the LUCAS 2006 sampling plan the first 8 replicates, that were chosen in all strata. Thus we have a systematic sample that repeats a pattern of 8 points every 18x18 km. There is no unbiased estimator for the variance under systematic sampling. We have used an estimator based on the comparison of each point with the observations in its neighbourhood.
3. A third alternative is defined with the same systematic samples exploiting the information provided by the photo-interpretation of the 2-km grid (post-stratification).
4. The fourth alternative is the actual LUCAS 2006 sampling: systematic sampling, i.e, two-phase systematic sampling with subsampling mainly concentrated on agricultural strata.

There are several implicit assumptions in this comparison:

- That the cost of the survey per point is the same in any of the sampling schemes.
- That the bias of the variance estimator used is of the same order in all cases. In fact this assumption is reasonable for the different systematic sampling options

Efficiency	Systematic (2/1)	Post-stratification (3/2)	Unequal probability (4/3)	Total (4/1)
Cereals	1.11	1.40	1.26	1.95
Common wheat	1.11	1.16	1.42	1.83
Durum wheat	1.43	1.29	1.41	2.60
Barley	1.15	1.17	1.40	1.88
Maize	1.21	1.19	1.43	2.06
Potatoes	1.09	1.06	1.36	1.57
Sugar beet	1.05	1.01	1.59	1.69
Sunflower	1.09	1.07	1.88	2.19
Rapeseed	1.07	1.10	1.50	1.77
Temp. Grass	1.20	1.21	1.28	1.85
Olive groves	1.63	1.82	0.89	2.63
Vineyards	1.43	1.55	1.44	3.19
Forest	1.00	1.74	0.38	0.66
Perm. Grass	1.12	1.38	0.64	1.00

Table 5: Relative efficiency between different point sampling approaches

The efficiency of remote sensing with the LUCAS 2006 stratification approach is estimated multiplying the second and third column of table 4 and is in general satisfactory.

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