APPENDIX 1

Mapping arable crops in Eastern England from satellite imagery as an input for nitrate modelling

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Abstract

Crop maps are required as an input for this programme on predictive nitrate modelling. The use of satellite remote sensing for the extensive mapping of arable crops is described here. The methodology extends the single 'tilled arable land' class of the Land Cover Map of Great Britain (LCMGB) using two different methods: i. reallocation of existing LCMGB spectral subclasses with reference to contemporary ground-based crop data; and ii. new statistical training to define samples of crops and reclassify crop types through extrapolation.

The original spectral classes of LCMGB 'tilled land' were interpreted and allocated to six individual arable crops. Correspondence with ground reference data was measured at *c.*70-75% on a pixel-by-pixel basis or *c.* 80%, assessed parcel-by-parcel; there was little improvement through new training. Most areas recorded on the ground as wheat, potato, and sugar beet were classified correctly but some areas barley, oilseed rape and beans were misclassified (variously as as wheat, urban or grass). Some discrepancy in classification is inevitable due to i. the overlap of spectral reflectances of different cover types; ii. the differences between grid-based and vector recording and the different rules they use to generalise within and between land parcels. Assessing classification results by land parcels rather than by pixels (i.e. matching the method of field recording) gives a better correspondence with ground data.

Remote sensing using optical satellite data may need supplementary information to consistently map the entire range of crops, with a high level of accuracy. This is especially true when, as here, the images are not specifically chosen to complete this task. However, remote sensing is the only technique that enables general crop mapping to be conducted on a field-by-field basis, over extensive areas; and relatively high levels of accuracy can be obtained by careful seasonal timing of image acquisition and improved data processing such as classification per parcel.

1. Introduction

A nitrate modelling programme is being conducted by a consortium, led by IACR-Rothamsted, and aims to develop a system of predictive models to support the Ministry of Agriculture, Fisheries and Food (MAFF) nitrate policy in England and Wales. The outcome will comprise a decision support system based on a set of robust and well validated models. The system will simulate nitrate loss at farm, catchment, regional and national scales, to assess the impact of changes in agricultural practice or land use on nitrate movement from soil to natural waters. The models require data on land use which might take the form of generalised national cover or detailed, site specific, local cover when working on catchments and sub-catchments.

In practice, such data are not routinely available. The Land Cover Map of Great Britain (LCMGB) shows the spatial distribution of a 'tilled arable land' class; the MAFF Census data give specific details on crops, but these are summarised per-parish. An integrated approach, exploiting the spatial and thematic capabilities of the two datasets, has provided the main landuse dataset required for modelling. However, there is the possibility to use remote sensing to provide both the spatial and thematic detail. This study aims to explore those capabilities.

The LCMGB was constructed by a classification of combined summer and winter Landsat satellite images, from the period 1988-1990 (Fuller *et al.,* 1994b). The LCMGB records 25 generalised land cover classes on a 25 m grid (Fuller *et al.,* 1994a). Tilled arable land is just one of the 25 classes. Underlying this general arable cover class are *c.* 20 spectral subclasses per summer-winter composite scene. These were mapped as 'anonymous' intermediate outputs during the classification process. The spectral subclasses relate largely to specific crop types; they might therefore be re-interpreted to give spatially referenced crop information.

Similarly, for modelling the movement of nitrates, grassland must be subdivided according to landuse; amenity grassland has to be treated differently from agricultural grassland grazed by animals and subjected to extensive nitrate fertilization. However, the spectral subclasses for grassland within the LCMGB are related to the species and green biomass within the sward and not directly to landuse. Supplementary information is required from other sources such as the MAFF Annual Census in order to apply the necessary subdivisions; unfortunately, the Census data are aggregated and supplied as summary coverage per Parish. Other LCMGB categories such as woodland, urban and rough grassland classes may be regarded as sufficiently stable and uniform in the context of nitrate movement to be used directly as input data.

The general solution for modelling purposes has been to combine LCMGB data on the distribution of cropped land with MAFF Annual Census data which gives the necessary temporal resolution and the proportions of individual crops. For this purpose, both datsets have been summarised onto a 1 km grid, the LCMGB data being spatially aggregated and the Census data generalised, assuming an even distribution within each parish. However, to assess the potential to provide exact cropping practices at a field-by-field spatial resolution, an evaluation of remote sensing has been based on the reprocessing of that part of the LCMGB covering East Anglia and surrounding areas; this is described here.

2. Aims

- To demonstrate and evaluate classification of satellite data to map a range of arable crops over an extensive area of Eastern England using two different methods:

  i. The reallocation of the underlying subclasses of the single tilled/arable class of the LCMGB to show individual crops; the subclasses are allocated to crops with reference to contemporary ground data.

  ii. The reclassification of the original satellite imagery by using contemporary ground data to identify new sample 'training' areas for individual crops and combining these with original training data to extrapolate and map crop classes

- To gauge the levels of correspondence between satellite and ground-based data and to demonstrate the difference in correspondence at spatial scales of pixels (25 m square) and of parcels (fields) for the two methods.

3. Methods

3.1 Remotely sensed data

Landsat Thematic Mapper images record radiance measurements in seven spectral wavebands covering visible and infrared wavelengths. The LCMGB was made from composite summer-winter images. Each composite image consisted of the three most important wavebands for assessing vegetation cover (i.e. Landsat bands 3,4 and 5 - red, near-infrared, and mid-infrared) from each summer and winter image resulting in a six band composite scene. The original satellite images recorded data at a spatial resolution of 30 m pixels; in geo-registering the images to the British National Grid, the data were resampled and presented as 25 m pixels.

There are only a few areas where the LCMGB was compiled from a single cropping year, i.e. a summer image combined with an image from the preceding winter. The best example is Eastern England where scenes were derived from the 1988/89 cropping year – the dates of image acquisition being 21 February and 15 July 1989. This study was conducted using two sequential Landsat TM scenes (each 185 x 185 km); East Anglia North and East Anglia South (path 201 row 023 and 024).

In the production of the LCMGB, the satellite scenes had been classified by a supervised (maximum likelihood) method, whereby, sample data obtained by demarcating 'training' areas of cover types on the image were extrapolated to classify all pixels in the image into classes/subclasses according to their spectral characteristics. The two East Anglia scenes had been classified from the same underlying training set but extra scene-specific subclasses were added.

The spectral subclasses for the arable class relate largely to specific crop types; although in mapping the original 25 classes there was no attempt to identify the specific crops. This present study involves reallocating these underlying subclasses to show individual crop types. Each spectral subclass is associated with a particular crop, but with some spectral distinctions based upon the different stages of growth or the variable soil backgrounds. The maps of crops take their cover class from the summer image. Essentially, the main role of the winter data in crop discrimination is to help confirm that the arable fields were under tillage rather than permanently vegetated. However, if the summer/winter data come from a single cropping year, then the characteristic winter appearance of a particular crop may reinforce the summer-based classification.

3.2 Ground data

Ground reference information on crops growing in Eastern England in the summer of 1989 was obtained in two forms. The principal dataset consisted of detailed crop maps supplied by farm managers for 11 selected areas of farmland (in seven geographical areas, Table 1); two sites occurred on the narrow overlap area common to both Landsat scenes. For each site, field boundaries were digitised and transformed into polygons (geo-registered to the British National Grid) with crop identification in ARC/Info. These vector data were then transformed to raster in the form of 25 m pixels to conform to the format of LCMGB data. Supplementary data were provided by crop identifications within individual fields which had been recorded during the compilation of the LCMGB by annotation on paper maps. These covered another 8 selected areas (Table 1) and were not digitised.

3.3 Data processing - integrating satellite- and ground-based data and reallocation of LCMGB subclasses

For each of the ground-based crop maps for individual sites, identical sections of the subclass version of the LCMGB were extracted and a cross-comparison of the two sets of pixel data produced correspondence matrices. These matrices were analysed to determine which known crop corresponded with each of the LCMGB arable subclasses. For each map, each subclass was allocated to a specific crop class that corresponded with the maximum number of pixels. Correspondence matrices were constructed for individual sites, geographical areas and both Landsat scenes.

The supplementary ground-based data collected in 1989 covered areas with a wider geographical range than the digitised farm maps. These data were compared with the subclasses of the LCMGB in a parcel-by-parcel comparison. The LCMGB was displayed in a form that allowed the individual subclasses to be identified and a visual comparison was conducted to match subclasses to crops using the original annotated maps in which the subclass that predominated in individual arable fields was recorded against the observed crop. Correspondence matrices were compiled for the areas covered by these ITE data and this parcel-by-parcel comparison was extended to include the farms already compared in the pixel-by-pixel exercise. Table 1 gives locations and the extent of cross-comparison data.

The results of these comparisons allowed most of the arable subclasses to be allocated to specific crop types, thus enabling the LCMGB to be reinterpreted to show the original arable class divided into individual crop categories. Outputs were initially at 25 m resolution but were also summarised within 1 km squares for ongoing nitrate modelling.

Table 2 shows a sample dataset in which pixel numbers are given for individual subclasses of the LCMGB against known crop types based on farm records. Initially results were processed retaining distinctions between winter and spring sown crops where given (e.g. for wheat, barley and beans) but the winter sown crops predominated and such distinctions were not always clear in the original written records, so a more general crop identification was adopted.

3.4 Data processing - reclassification of arable crops

In order to test whether a classification specifically tailored to detecting individual crops would offer improved levels of correspondence with ground-based data, a new classification of arable land on the southern Landsat scene (East Anglia South) was produced by using the ground-based crop data to identify new training areas in arable crops and combining these with original training data for other LCMGB classes.

The spectral signatures (means, ranges, and standard deviations of the digital levels within the six spectral bands) of the original arable subclasses were examined and compared with those of the new subclasses. All but two of the original subclasses were replaced by new ground-based subclasses (see Results) and those new subclasses that were spectrally overlapping with each other were either deleted or amalgamated. This new range of arable subclasses formed the basis of a new training set and a new Maximum Likelihood Classification of the original imagery was carried out. In order to retain the results of masking procedures that had reallocated various subclasses if they occurred within designated urban or coastal zones (Groom *et al.*, 1996), the original non-arable LCMGB classes were kept intact and the new classified output was inserted where the original classification had recorded arable land. Correspondence between mapped subclasses and known crops was examined by repeating the pixel-by-pixel cross-comparison exercise using the same datasets of ground-based data.

4. Results

4.1 LCMGB data reinterpreted to show individual crops

Figure 1 shows a sequence of images for an area of farmland (Boxworth, Cambridgeshire) to illustrate the procedures for constructing a crop map by reinterpreting LCMGB subclasses. The first image shows the raster version (25 m pixels) of the digitised ground-based crop data, then the equivalent area mapped into the broad classes of the LCMGB with most pixels belonging to the single arable class. The third image depicts the underlying subclasses of the LCMGB in shades of grey, and the fourth image shows the final satellite-based crop map derived from reallocating LCMGB subclasses to crop categories. Despite generally meaningful results, within-field variation is apparent and some misclassification has occurred (e.g. fields classified as urban (i.e. bare) due to early cropping). Figure 2 shows examples of crop mapping for three other sample sites. For each site, the images show respectively: digitised ground-based crop data, crop mapping from reallocated LCMGB subclasses, and crop mapping from reclassification using new training data (see section 5.4). Figure 3 shows a more extensive area of Cambridgeshire mapped first by the LCMGB and then with crop mapping from reallocated subclasses. The new crop classification displays a clear distinction between the fenland at the top of the map, where many fields grow sugar beet and potatoes, and the more typical cereal farmland elsewhere, dominated by wheat.

4.1.1 Pixel-by-pixel comparisons of satellite and ground-based data

Results were summarised for both of the Landsat scenes and presented as tables with correspondence between satellite and ground-based data expressed as pixels per thousand pixels with an overall figure of percentage correspondence for all arable data

The East Anglia North scene contained 56 spectral subclasses of which 22 were arable and East Anglia South had 58 subclasses, 19 of which were arable (but these arable subclasses included several empty or near empty subclasses that were the product of masking/knowledge-based correction procedures which identified spurious cover types out of context (e.g. coastal habitats) and re-classified them to the nearest appropriate class (e.g. sometimes unknown arable crops - see Groom *et al.*, 1996). Tables 3a and 3b show the objective allocation of arable subclasses to crops if based on data from all sites for both Landsat scenes as well as for the individual sites or geographical areas. Consistent agreement on the allocation occurred between sites in East Anglia South but less so for sites in East Anglia North where datasets were smaller and the range of crops present at the different sites varied quite widely.

With the subclasses allocated according to the correspondences listed in Tables 3a and b (using all available data), Tables 4 and 5 give overall per pixel correspondence figures of 74.6% for East Anglia North and 71.2% for East Anglia South. While most areas recorded on the ground as wheat, potato, and sugar beet have been classified correctly, a large proportion of the other crops (such as barley and beans) have been misclassified as wheat, urban or grass

4.1.2 Parcel-by-parcel comparisons of satellite and ground-based data

Data from all locations listed in Table 1 were compared at the scale of individual fields. In contrast with the pixel-based comparisons, Tables 6 and 7 show improved overall percentage correspondence when measured per-parcel using the same allocation of subclasses to crop types. This is due in part to measurement on a parcel basis having removed within-parcel heterogeneity. Because the parcel-by-parcel comparisons were based on larger and more geographically extensive datasets than the pixel-by-pixel comparisons, the objective allocation of subclasses to crops was slightly different: only by one subclass for East Anglia South but more for East Anglia North. Applying these revised allocations of subclasses produced a further improvement in correspondence between classes (Table 8) to 78.4% and 83.5% for the northern and southern scenes respectively.

4.1.3 Reallocation of LCMGB arable subclasses for crop identification

Table 8 shows details of the difference between the pixel-by-pixel and parcel-by-parcel allocation of subclasses to crop types, together with the percentage correspondence values. The latter allocation was used to reconstruct the LCMGB for East Anglia South. The original 25 classes of the LCMGB are supplemented by an additional seven crop classes that replace 'tilled/arable land': wheat, barley, oilseed rape, beans, potatoes, sugar beet and unallocated arable. The latter class of unallocated arable contained those original arable subclasses that did not coincide with any available ground-based crop data and were almost entirely empty subclasses that were a product of masking procedures.

Many rarer crops are not included in this list. Correspondence matrices and radiometric data from the training statistics showed that some overlapped spectrally with mapped crops e.g. oats with wheat, linseed with wheat (see Table 2), whereas others did not occur within the ground data acquired. The latter category would include some vegetable crops that do occur extensively, for example in parts of Lincolnshire; thus, the East Anglia North scene might not be mapped as effectively as East Anglia South where the six crops mapped individually do give a good representation of the range and spatial distribution of the major crop types.

4.2 LCMGB data reclassified to show individual crops

A completely new reclassification of arable land was confined to the East Anglia South scene as more ground-based data were available than for East Anglia North. New arable subclasses were established to provide a complete range that would encompass all arable land without reference to the original classification. Between five and ten visually similar training areas were selected for each subclass, where the crop type was known with certainty from the ground-based crop datasets. Training and classification is an iterative process and training sets had to be refined by the removal or reselection of training areas to avoid statistical anomalies (e.g. bimodal spectral distributions, Kershaw & Fuller (1992)) and ensure that the new subclasses were as tightly defined spectrally as the original subclasses.

Two of the original arable subclasses were retained; they could not definitely be associated with any known crop identified from the ground and were spectrally distinct from the new subclasses. In the pixel-by-pixel comparison they were most closely associated with winter wheat, so this is their eventual allocation if an unallocated arable category is not acceptable.

Comments on individual subclasses and crops:

- many new subclasses were statistically near identical to the original ones e.g. potato and sugar beet involved just a straightforward replacement of old subclasses with new (a single subclass for each of these crops);
- the new classification resolved confusion between some crops in the old training set e.g. an improved distinction between oilseed rape and barley and a single more tightly defined subclass for field beans;
- the new classification provided a range of subclasses to cover wheat (four subclasses) and to a lesser extent barley (three subclasses) that encompassed different growth states and canopy coverage;
- some temporary subclasses were established for a few selected known examples of other crop types e.g. oats, linseed and onions to see whether their spectral signatures were likely to be covered by more important crop types, for example, oats was found to be similar to one of the wheat subclasses.

The reclassified version of the LCMGB for this area contains the same classes as used in the reallocated version (section 4.1.3), i.e. 25 original classes with class 18 arable replaced by 7 new crop classes (i.e. classes numbered 26-32). Examples are shown in Figure 2 in a comparison of the two methods. Only minor differences in classification are apparent but the reclassification products appear to have a more uniform classification within fields, and the field boundaries are more distinct.

Table 9 shows the results of a pixel-by-pixel comparison of the reclassified LCMGB data with the ground-based crop data available for East Anglia South. If the two subclasses retained from the original training set are allocated to wheat (as suggested by the pixel distribution in the correspondence matrix) rather than to an unallocated arable class, then the level of correspondence rises from 71% to 74%. This is only slightly better than the 71% correspondence using reallocated subclasses; however, the output map appears more homogeneous. A major improvement compared with the reallocation of original subclasses is that there is less misclassification of other crops as wheat.

4.3 Additional crop data from the Midlands

Additional ground-based crop data had been made available for four farms within designated Nitrate Sensitive Areas in the Midlands (of England). In the LCMGB, this area had been mapped from a summer-winter composite (Landsat TM scene path 203 row 024) from different cropping years. The summer data were from 1 August 1990 and the winter from 30 October 1988. Ground-based data matched the summer satellite data which also determined the cover classification.

A pixel-by-pixel comparison (Table 10) shows a 75.5% level of correspondence, despite the lack of data from a single cropping year. However, only those pixels outside a 50 m buffer zone had been compared i.e. all the pixels on or near field boundaries had been excluded. This is a technique that can be applied if a dataset with field boundaries is available within a GIS. Much information from small and medium fields is lost but the remaining data are more homogeneous than in the East Anglian datasets.

5. Discussion

This study demonstrates how satellite-based remote sensing can provide classifications of major crop types and, specifically, how Landsat TM imagery can be used for general crop mapping over an extensive area of Eastern England, supplying products that are available as data inputs for predictive modelling of nitrates. By reallocating spectral subclasses of the LCMGB, six specific arable crops were mapped (with a seventh 'unallocated arable' class) with a correspondence of *c.*70-75% measured on a pixel-by-pixel basis or *c.* 80% assessed parcel-by-parcel. Most areas recorded on the ground as wheat, potato, and sugar beet were classified correctly but some areas of barley, oilseed rape and beans were misclassified (variously as wheat, urban or grass).

More extensive ground-based data might have improved the accuracy slightly (especially for the northern of the two images, where less ground data had been used) but some discrepancy in classification was inevitable due to two reasons. First, there is spectral variation within crop types, spectral overlap between crop types and also between crops and non-arable cover types; the spectral variation of even tightly defined subclasses of crop types include reflectances of different crops and it is the more extensive crop that dominates the allocation to a particular crop class (probabilities for a range of crop types could be assigned to each pixel but spatial information would be lost). And second, grid-based and vector recording use different rules to generalise within and between land parcels. Vector-based ground information shows specific linear features, field boundaries and tracks, and assumes that fields contain a single uniform crop Remotely-sensed raster data show within-field heterogeneity due to uneven crop development, weeds, trees and bare soil but contain misclassified mixed pixels at field boundaries. Hence, assessing classification results by land parcels rather than by pixels (i.e. matching the method of field recording) gives a better correspondence with ground data. It also gives a better means of classification: CLEVER-Mapping (Smith *et al.*, 1997a & b) is an ITE programme which has developed per-parcel classifications procedures.

Some general conclusions can be drawn from published results on crop mapping and our own studies. Improved spectral information allows better opportunities for detailed crop classification. The extra spectral information provided by a middle-infrared waveband (as in Landsat TM) enhances crop discrimination compared to data confined to visible and near-infrared wavebands (e.g. SPOT HRV), Buttner & Csillag, 1989, Gallego *et al.*, 1993.

Satellites that can acquire data at frequent intervals (such as SPOT with its option for off-nadir viewing) have an important operational advantage for obtaining satellite imagery at preferred dates within the growing season (Guerif *et al.*, 1992, Jewell, 1989). Seasonal timing is important as the imagery needs to show the maximum spectral divergence for the range of crop types; with different crops being at different stages of growth, late spring to mid-summer is best for single season imagery. The summer date of 15 July for these images of Eastern England seemed suitable, although early harvesting of some crops had just started (barley, beans) and this gave rise to some misclassification. It is mainly the spectral variation within the summer imagery that allows individual crops to be distinguished; many examples in the scientific literature show that appropriate single season imagery is sufficient for good crop identification for known arable land but there is a risk of confusion between crops and non-arable cover types if only single season data are used. Multi-temporal composite imagery provides additional data for classification - a winter / summer combination is an operational option, as for the LCMGB where the inclusion of winter data allowed summer arable crops to be distinguished from other cover types such as grassland where there is vegetation cover at all seasons (Fuller *et al.*, 1994b). However, combining many images from within a wide temporal range (but within a single growing season) is probably not feasible for extensive mapping exercises using optical satellite data.

Operational programmes of crop measurement, that provide agricultural statistics for extensive geographical areas using remote sensing, tend to be carried out within statistically selected sample areas only, as even satellite images are of limited size compared to countries and regions. And there are considerable difficulties in obtaining data for specific dates, encompassing widespread areas. Cloud cover poses the major problem for optical satellite imagery. Radar images (SAR) are obtainable regardless of cloud cover but, at present, such data are used in operational programmes only in a supplementary capacity. Crop area estimates are usually made with a regression estimator that combines sample ground data with satellite data and may be combined with the use of confusion matrices (Gonzalez-Alonso & Cuevas, 1993). Successful examples of general crop mapping in operational use are provided by the MARS project in Europe and the agricultural monitoring for MAFF in the UK.

Because of spectral variation and overlap within and between vegetated surfaces, the ability to map the entire range of crops with total accuracy is unlikely to be achieved by remote sensing alone. Basic crop classification relies on spectral differences between different crops and many crops are extremely similar in this respect. Moreover, a widespread crop such as winter wheat will be present in a landscape in many different stages of growth (and hence spectral identity) due to a range of sowing times, soils, weather conditions, etc. and some of these spectral profiles will match those of other less abundant crops. However, satellite-based remote sensing is the only technique that enables general crop mapping to be conducted with reasonably high levels of accuracy for the more common crops over extensive areas and at a spatial resolution that shows a field-by-field scale of pattern.

Classification of arable crops by land parcels rather than by pixels gives a better correspondence with ground data. General landcover mapping for agricultural purposes would be greatly improved by integrating remotely sensed data with other datasets within a GIS. This is exemplified by techniques being developed by ITE in the CLEVER-Mapping project in which remotely sensed data are classified within polygons, the polygons being derived from imported vector data or generated within the imagery (Smith *et al.*, 1997a & b).

6. Conclusions

- Crop mapping by satellite remote sensing at field-by-field scale (based on 25 m pixels) over an extensive area of Eastern England has been demonstrated.

- Landcover input data for nitrate modelling have been produced.

- The satellite-derived crop data produced by reallocating LCMGB subclasses corresponded with digitised ground-based data by c. 70-75% when assessed on a per pixel basis, and by c. 80% per parcel (i.e. essentially per-field).

- Lack of correspondence between the two datasets was due to lack of spectral distinction between some cover types and to the different nature of the two datasets.

- The most extensive crop, wheat, tended to be over-estimated, sugar beet and potato showed high levels of correspondence between satellite and ground-based data and other crops showed lesser levels of correspondence.

- New, crop-specific classifications produced results that were only slightly improved from those obtained by reprocessing the original LCMGB data.

- Summer/winter composite satellite imagery is useful in separating arable from non-arable cover types and the seasonal timing of the summer data is critical to the success of distinguishing individual crops.

- Remote sensing, using optical satellite data, may need supplementary information to consistently map the entire range of crops, with a high level of accuracy. This is especially true when, as here, the images are not specifically chosen to complete this task.

- Despite difficulties, remote sensing is the only technique for crop mapping that realistically enables general crop mapping to be conducted on a field-by-field basis, over extensive areas.

- Relatively high levels of accuracy can be obtained by careful seasonal timing of image acquisition and improved data processing such as classification per parcel.

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Table 1. Extent of coverage of arable land analysed in comparison between the Land Cover Map of Great Britain (LCMGB) subclasses and known crops growing in summer 1989.

Location - geographical areas of sample sites	No. of pixels	ha		No. of parcels
Landsat scene - East Anglia North				
March, Morley, Terrington	13541	846		84
Wells, Welney, Wolferton				87
Total	**13541**	**846**		**171**
Landsat scene - East Anglia South				
Huntingdon	13699	856	)	
Ramsey	6264	392	)	
March	9553	597	)	
Cambridge	9072	567	)	
Rothamsted	2661	166	)	270
Ickleton, Stretchworth, Swavesey, Welney, Woodwalton				250
Total	**41249**	**2578**		**520**

Table 2. Example of a correspondence matrix for a cross-comparison of known crops and the full range of LCMGB subclasses for a single site. Arable subclasses shown as **bold**.

LCMGB subclass	CROP TYPES OS RAPE	WHEAT	BARLEY	POTATOES	SUG BEET	BEANS 1	BEANS 2	LINSEED	TOTALS
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	4	0	0	0	2	0	0	6
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	8	0	0	0	2	87	0	97
7	7	155	40	12	0	3	680	5	902
8	0	2	0	0	0	20	0	0	22
9	0	4	0	7	0	0	0	0	11
10	1	3	29	0	0	0	0	0	33
11	0	0	0	0	0	0	0	0	0
12	0	106	2	20	19	0	4	0	151
13	0	8	1	0	0	0	0	0	9
14	0	0	0	0	0	0	0	0	0
15	**0**	**0**	**0**	**216**	**0**	**0**	**0**	**0**	**216**
16	**0**	**0**	**0**	**0**	**250**	**0**	**0**	**0**	**250**
17	**21**	**11**	**550**	**0**	**0**	**0**	**0**	**0**	**582**
18	**7**	**1276**	**15**	**0**	**1**	**0**	**199**	**0**	**1498**
19	**374**	**43**	**81**	**0**	**0**	**0**	**0**	**0**	**498**
20	**2**	**249**	**204**	**0**	**0**	**1**	**0**	**0**	**456**
21	**0**	**99**	**0**	**0**	**104**	**221**	**8**	**103**	**535**
22	**0**	**2623**	**0**	**0**	**0**	**5**	**0**	**0**	**2628**
23	**0**	**2241**	**0**	**6**	**288**	**77**	**5**	**287**	**2904**
24	0	0	0	0	0	0	0	0	0
25	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
26	**292**	**706**	**0**	**0**	**4**	**1**	**15**	**0**	**1018**
27	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
28	**0**	**7**	**0**	**10**	**216**	**586**	**9**	**0**	**828**
29	0	0	0	0	0	0	109	0	109
30	0	0	0	0	0	0	0	0	0
31	**2**	**149**	**3**	**102**	**46**	**17**	**276**	**12**	**607**
32	5	44	2	0	0	2	8	0	61
33	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0
35	0	25	0	0	1	0	23	0	49
36	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0
38	0	3	0	2	0	3	0	0	8
39	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0
41	0	1	0	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0
45	**1**	**99**	**0**	**6**	**14**	**19**	**3**	**1**	**143**
46	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0
54	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
55	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
56	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
57	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
58	0	3	1	0	0	0	70	0	74
Totals	712	7872	928	381	943	959	1496	408	13699

Table 3. Allocation of individual LCMGB subclasses to known crops based on pixel-by-pixel comparisons of satellite and ground-based datasets.This shows the crop class that has the maximum number of pixels of each LCMGB arable subclass

LCMGB Subclasses		Individual sites/areas:		
EAST ANGLIA NORTH	All data	March	Morley	Terrington
20	WHEAT	WH	BL	WH
22	WHEAT	WH	WH	WH
23	WHEAT	WH	PE	WH
26	WHEAT	WH	LN	SB
27	WHEAT	WH	LN	WH
29	WHEAT	WH	LN	WH
48	WHEAT	WH	BL	SB
18	BARLEY	PE	BL	WH
19	BARLEY	WH	BL	WH
17	PEAS	PE	BL	OR
30	PEAS	PE	BN	WH
15	POTATO	PO	no data	PE
38	POTATO	PO	PE	WH
16	SUGAR BEET	SB	SB	WH
21	SUGAR BEET	SB	LN	WH
28	SUGAR BEET	SB	SB	WH

Key:

WHEAT	WH
BARLEY	BL
OILSEED RAPE	OR
LINSEED	LN
PEAS	PE
BEANS	BN
POTATO	PO
SUGAR BEET	SB

EAST ANGLIA SOUTH	All data	Huntingdon	Ramsey	March	Cambridge	Rothamsted
18	WHEAT	WH	WH	PE	BL	BL
20	WHEAT	WH	WH	WH	WH	WH
22	WHEAT	WH	WH	WH	WH	WH
23	WHEAT	WH	WH	WH	WH	WH
25	WHEAT	no data	no data	no data	WH	no data
26	WHEAT	WH	WH	WH	OR	OR
27	WHEAT	WH	no data	WH	no data	WH
31	WHEAT	BN	WH	PE	WH	WH
45	WHEAT	WH	WH	WH	WH	WH
17	BARLEY	BL	BL	no data	WH	BL
19	OILSEED RAPE	OR	OR	no data	OR	OR
28	BEANS	BN	WH	WH	BN	WH
15	POTATO	PO	PO	PO	PO	PO
16	SUGAR BEET	SB	SB	SB	SB	no data

Table 4. Pixel-by-pixel comparison of test sites in East Anglia North, using reallocation of original LCMGB subclasses. (Values are pixels per thousand.)

Satellite data / Ground data	WHEAT	BARLEY	OS RAPE	BEANS	PEAS	POTATO	S BEET	OTHER CROPS	TOTALS
WHEAT	381	31	4	1	12	11	27	6	475
BARLEY	10	18	2	1	6		2		39
OS RAPE									
BEANS									
PEAS	7	6	5	1	53	3	3		78
POTATO	5				6	81	2		93
S BEET	33	1		7	4	9	213	9	276
[Unalloc.arable]									
Urban/suburban	13	1			3	2	1		20
Agricultural grass	5	6	1	1	1	1	2	1	16
Others	2						1		3
TOTALS	456	65	12	10	85	107	249	16	1000

Total number of pixels	13541
Overall correspondence:	
Number of pixels	10108
% correspondence	74.6

Table 5. Pixel-by-pixel comparison of test sites East Anglia South, using reallocation of original LCMGB subclasses. (Values are pixels per thousand.)

Satellite data / Ground data	WHEAT	BARLEY	OS RAPE	BEANS	POTATO	S BEET	OTHER CROPS	TOTALS
WHEAT	499	21	13	28	17	29	43	650
BARLEY	1	16	1					19
OS RAPE	6	3	27					36
BEANS	4			26	1	7		38
POTATO	1				48	5		53
S BEET	1				3	95		99
[Unalloc.arable]								
Urban/suburban	17	11	5	24	1		1	58
Agricultural grass	11	6	2		6	4		29
Others	7	1	2	1	2	1	1	16
TOTALS	547	59	49	80	78	142	45	1000

Total number of pixels	41249
Overall correspondence:	
Number of pixels	29349
% correspondence	71.2

Table 6. Parcel-by-parcel comparison of test sites in East Anglia North, using reallocation of original LCMGB subclasses as used in pixel-by-pixel analysis (Values are numbers of parcels.)

Satellite data / Ground data	WHEAT	BARLEY	OS RAPE	BEANS	PEAS	POTATO	S BEET	OTHER CROPS	TOTALS
WHEAT	78	8	1		2	1	2	1	93
BARLEY	5	7	1				1		14
OS RAPE									0
BEANS									0
PEAS		2	1		3	1			7
POTATO	1				1	16			18
S BEET	5			3		2	26	3	39
[Unalloc.arable]									0
Urban/suburban									0
Agricultural grass									0
Others									0
TOTALS	89	17	3	3	6	20	29	4	171

Total number of parcels	171
Overall correspondence:	
Number of parcels	130
% correspondence	76.0

Table 7. Parcel-by-parcel comparison of test sites in East Anglia South, using reallocation of original LCMGB subclasses as used in pixel-by-pixel analysis (Values are numbers of parcels.)

Satellite data / Ground data	WHEAT	BARLEY	OS RAPE	BEANS	POTATO	S BEET	OTHER CROPS	TOTALS
WHEAT	296	34	3	9	1	1	19	363
BARLEY	3	17		1				21
OS RAPE	1	2	12					15
BEANS				27	2			29
POTATO					47	2		49
S BEET						55		55
[Unalloc.arable]								0
Urban/suburban	1	12		6			1	20
Agricultural grass	1	1					2	4
Others								0
TOTALS	302	66	15	43	50	58	22	556

Total number of parcels	556
Overall correspondence:	
Number of parcels	454
% correspondence	81.7

Table 8. Subclass allocations for pixel-by-pixel and parcel-by-parcel comparisons and summaries of % correspondence.

EAST ANGLIA NORTH LCMGB Subclasses	A Allocation of subclasses based on pixel-by-pixel comparison	B Allocation of subclasses based on parcel-by-parcel comparison
20	WHEAT	WHEAT
21	SUGAR BEET	WHEAT
22	WHEAT	WHEAT
23	WHEAT	WHEAT
26	WHEAT	WHEAT *
27	WHEAT	WHEAT
29	WHEAT	WHEAT *
48	WHEAT	WHEAT
18	BARLEY	WHEAT
19	BARLEY	BARLEY
17	PEAS	BARLEY
30	PEAS	PEAS
15	POTATO	POTATO
38	POTATO	WHEAT
16	SUGAR BEET	SUGAR BEET
28	SUGAR BEET	SUGAR BEET
25	Unallocated arable	Unallocated arable
40	Unallocated arable	Unallocated arable
44	Unallocated arable	Unallocated arable
46	Unallocated arable	Unallocated arable
53	Unallocated arable	Unallocated arable
54	Unallocated arable	Unallocated arable

* no data - retain px/px alloc.

(See text for explanation of unallocated subclasses)

% correspondence for East Anglia North:

Pixel-by-pixel comparison with (A) allocation of subclasses	74.6
Parcel-by-parcel comparison with (A) allocation of subclasses	76.0
Parcel-by-parcel comparison with (B) allocation of subclasses	78.4

EAST ANGLIA SOUTH LCMGB Subclasses	A Allocation of subclasses based on pixel-by-pixel comparison	B Allocation of subclasses based on parcel-by-parcel comparison
18	WHEAT	BARLEY
20	WHEAT	WHEAT
21	WHEAT	WHEAT
22	WHEAT	WHEAT
23	WHEAT	WHEAT
25	WHEAT	WHEAT *
26	WHEAT	WHEAT
27	WHEAT	WHEAT
31	WHEAT	WHEAT
45	WHEAT	WHEAT
17	BARLEY	BARLEY
19	OILSEED RAPE	OILSEED RAPE
28	BEANS	BEANS
15	POTATO	POTATO
16	SUGAR BEET	SUGAR BEET
54	Unallocated arable	Unallocated arable
55	Unallocated arable	Unallocated arable
56	Unallocated arable	Unallocated arable
57	Unallocated arable	Unallocated arable

% correspondence for East Anglia South:

Pixel-by-pixel comparison with (A) allocation of subclasses	71.2
Parcel-by-parcel comparison with (A) allocation of subclasses	81.7
Parcel-by-parcel comparison with (B) allocation of subclasses	83.5
Pixel/pixel comparison after **reclassification** based on ground data	71.5
Pixel/pixel comparison after **reclassification** based on ground data if two unallocated arable subclasses are included with wheat	74.0

Table 9. Pixel-by-pixel comparison of test sites in East Anglia South, following reclassification based on known ground data. (Values are pixels per thousand.)

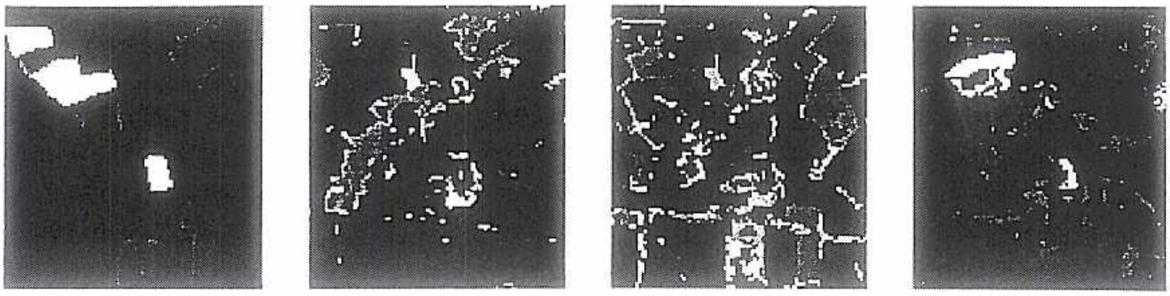
Satellite data / Ground data	WHEAT	BARLEY	OS RAPE	BEANS	POTATO	S BEET	OTHER CROPS	TOTALS
WHEAT	458	4	5	5	4	11	25	512
BARLEY	2	27	1	3				32
OS RAPE	1	2	32					35
BEANS	10			33	1	5	3	54
POTATO	2			1	56	7	1	67
S BEET	1				3	108	1	114
Unalloc.arable	25	1		5	1	2	1	36
Urban/suburban	24	14	5	29	2	1	3	79
Agricultural grass	13	8	2		7	5	6	41
Others	11	3	4	3	3	2	4	30
TOTALS	547	59	49	80	78	142	45	1000

Total number of pixels	41249
Overall correspondence:	
Number of pixels	29499
% correspondence	71.5
% correspondence if unalloc. arable included with wheat	74.0

Table 10. Pixel-by-pixel comparison of 4 NSA test sites in the Midlands using reallocation of original LCMGB subclasses - and excluding 50 m buffer zone at field boundaries.
(Values are pixels per thousand)

Satellite data / Ground data	WHEAT	BARLEY	OS RAPE	PEAS	POTATO	S BEET	TOTALS
WHEAT	**558**	46	7	15		1	627
BARLEY	22	**90**	6			2	120
OS RAPE	2	33	**107**	11			153
PEAS							
POTATO							
S BEET							
Agricultural grass	38	50	8		2	2	100
Others							
TOTALS	620	219	128	26	2	5	1000

Total number of pixels	8670
Overall correspondence:	
Number of pixels	6547
% correspondence	75.5



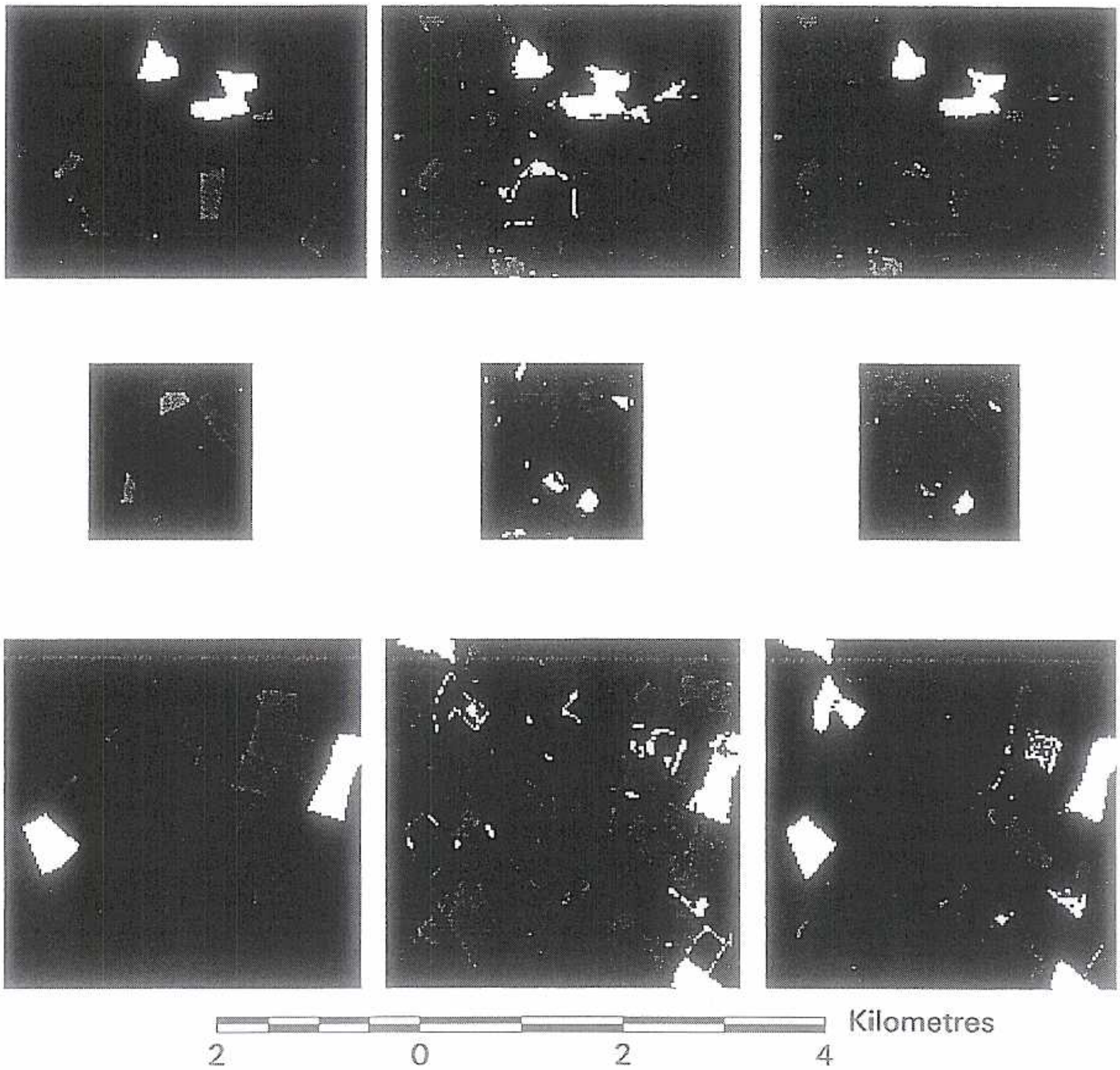


Figure 1. (TOP ROW - From left to right):

a) Digitised crop map for ADAS, Boxworth for 1989.
b) Extract of Land Cover Map of Great Britain covering ADAS, Boxworth.
c) LCMGB showing underlying subclasses.
d) Crop map compiled from reallocated LCMGB subclasses.

Figure 2. (ROWS 2-4) Examples of crop mapping for three sites in Cambridgeshire.
Left. Digitised crop maps compiled from 1989 ground-based data.
Centre. Crop maps compiled from reallocated subclasses of the satellite-based LCMGB.
Right. Crop maps derived from reclassification of satellite imagery using new training data.
See Figure 3 for Keys.

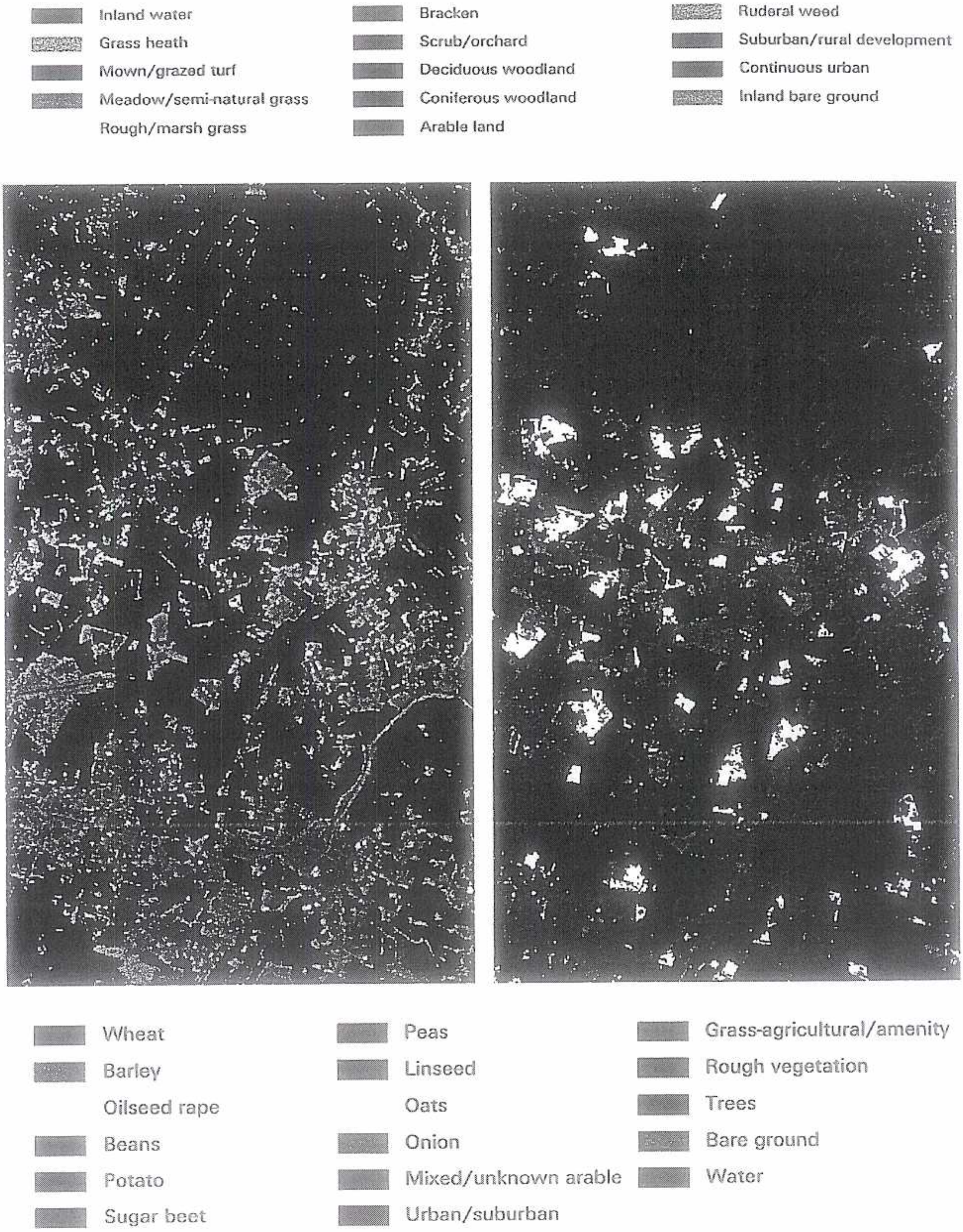


Figure 3. An extensive area of Cambridgeshire (left) mapped by the LCMGB and (right) with crop mapping from reallocated subclasses. The new crop classification displays a clear distinction between the fenland at the top of the map where many fields grow sugar beet and potatoes and the more typical arable fields elsewhere dominated by wheat. Key for LCMGB classes shown above and for new crop classification below.

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