CHAPTER 7

High Resolution Agriculture Land Cover Using Aerial Digital Photography and GIS: A Case Study for Small Island States

Charles Galdies, John C. Betts, Antonella Vassallo and Anton Micallef

Introduction

With the advent of site-specific crop management, sustainability and profitability, land farming now requires information and technology-based management system to identify, analyse and manage spatial and temporal resource variability. This approach is being made increasingly possible by recent innovation in information technologies such as mobile devices, geographic information systems, positioning technologies (such as Geographical Position system), and Earth Observations. Such innovation now offers a holistic approach to micro-manage agricultural resources. (Robert et al., 1994).

Basic mapping and farm-level record keeping is one of the first precision agriculture practices that must be implemented in a typical productive agriculture operation (Stombaugh et al., 2001). Typical tasks include mapping of variations that occur in large-scale field features such as vegetation stress, crop rotation, inventorying, irrigation, soil drainage and erosion, pest control, etc. The search for a low cost methodology that takes into account the growth of information technology in data capture and surveying, data processing, database creation and geographic information systems becomes mandatory in order to respond to such needs.

The study constitutes, for the first time in Malta, the collection of high precision farming statistics that makes use of an inexpensive system for aerial mapping that requires minimal ground truthing. The effectiveness of such a method for small areas was later demonstrated by Galdies and Borg (2006) related to coastal and beach management in the Maltese islands. In the current case, digital aerial remote sensing enabled the accurate mapping of agricultural variables, and coupled with ground survey data, resulted in the production of precise, high resolution agricultural crop-cover maps. Additional information can be further derived from this data that can be used for the optimisation of micro agriculture practices.

Methodology

Flight planning, aircraft and remote sensing equipment

Two sets each made up of three consecutive flight plans were conducted for data collection requirements. The Maltese islands were thus divided into three geographical sections (1) Gozo and Comino, (2) Malta west of Ghallies rock, and (3) Malta east of Ghallies rock.

For logistic purposes, the flights were planned as a series of lines running North-South across the islands. The set of images giving full coverage had the strictest requirements; the other image set was designed around the requirements for this set. For full stereophoto coverage of the islands one set of flights had to be carried out at 4500 feet altitude. A side overlap of 30% between one line of images and the next was required, as well as a 70% forward overlap, between one image and the next, to ensure sufficient image overlap for photogrammetric purposes.

The aircraft selected for the missions was a Tecnam P-92J single engine high wing monoplane. This aircraft was not specifically designed for such surveying work, however it was easily adapted in line with engineering safety standards. In this case, two holes of diameter 70mm were cut in the floorplates, and two corresponding holes in the outer skin. A purpose-built camera mount was fitted to the aircraft floor positioning the camera lenses in line with the holes.

Figure 1: The Tecnam single engine high wing monoplane used for the flight survey

Two Kodak digital cameras (DCS460/660), each with 3060 x 2036 CCD arrays, were used to acquire the aerial photographs. Each was fitted with a filter eliminating near infrared light, permitting visible light only to be registered by the CCDs. Each camera was attached to an intervalometer which triggered the shutter at regular intervals to record the required images. Flying at around 90 knots at 4500 feet, and taking pictures every 10 seconds provided a horizontal pixel resolution of approximately 50 cm. The number of flight lines required were 27 for Gozo and Comino and 22 each for the east and west halves of Malta.

To obtain higher resolution imagery suited for crop identification, one of the cameras was fitted with a zoom lens set to f56 mm (compared to f28 mm for the standard camera set). This provided a pixel resolution of approximately 25 cm, although full lateral coverage was not obtained. In order to improve cover at this resolution, a second set of flights was flown following the pattern of the first but at 2000 feet altitude This meant that by using images taken with the camera with the standard f28 mm lens at the lower altitude and images taken with the camera with the zoom lens at high altitude and combining the two sets, close to full coverage would be obtained at this resolution. To fully utilize the available resources, the second camera was also installed, complete with zoom lens, for the second set of flights. The resulting pictures provide high resolution (12-15 cm) snapshots of locations which assist the identification of vegetation.

During flight, a total of 6078 aerial photos were recorded on memory cards. Following each flight, the image data was transferred to data storage hard drives on computers for archiving and analysis.

Land cover classification

Due to the enhanced crop detail visible from the photographic set acquired, the standard CORINE classification was expanded by an additional 2 levels (i.e. CORINE level IV and V). These additional levels group all other additional features related to permanent/temporary crops by exact type as well as information on type of fruit and forest trees which were now possible by the methodology used in this survey.

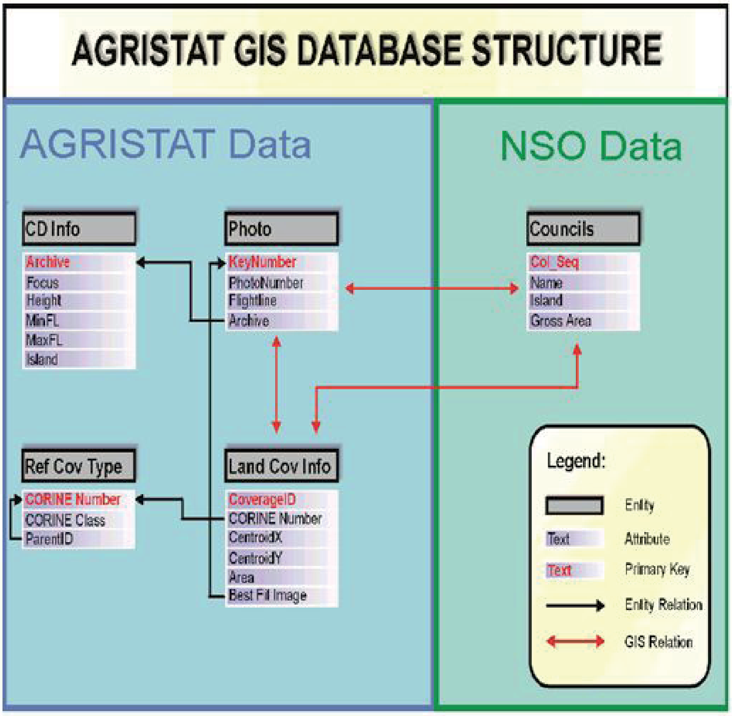
Ground truthing

Around 2000 hectares were surveyed for permanent and temporary crops and related artificial crop cover (mulches, greenhouses, plastic covers etc). Using 1:2500 maps, different types of agriculture land cover, including irrigated and dry land, were surveyed during and after the aerial survey was being carried out. Due to the accuracy of the 1:2500 paper maps, individual fields were recognised and all relevant details, including information obtained directly from farmers were noted. All the geographic information was archived and divided into two separate sets: (1) used for photo-interpretation and classification, and (2) reserved for the accuracy assessment of the final thematic map using an error matrix based type of assessment.

GIS database structure

A fully inter-related database structure was created capable of making use of all spatial data available (Figure 2). The database addressed the archiving and spatial documentation of all imagery collected for the survey. At the same time, data interpretation in the form of classified GIS vectorized information was organised in a way as to provide relational and geographical links between different CORINE classification levels.

Figure 2: Relational spatial (GIS) database structure for AGRISTAT.



Using the structured query language (SQL), the following information was extracted from the spatial database:

- The total number of field crop parcels (in general or by type) by local council;
- The serial photo numbers, together with their centroid spatial coverage, archive name on which particular parcels can be found;
- Analysis of the total area of land covered by a particular crop type (in general or by local council);

- Statistical analysis of land coverage by local council;
- Complete CORINE description of any CORINE code;
- Location of all parcels covered by a particular crop type (e.g. potatoes, lettuce, carrots, etc.) in a defined (local council or other) area;
- Grouping the parcels by vegetation type/land area/local council.

Interpretation and classification of crops from aerial imagery

A set of aerial imagery covering a range of agricultural land type and usage were selected as calibration sources to aid in the photo-interpretation (Figure 3).

This calibration, which was based on the previously conducted ground surveys, consisted of a digital collection of annotated parcels illustrative of the features and conditions to be identified. This was instrumental for the proper interpretation of parcels in successive photographs, which depended on the similarity of such classified parcels containing particular recognition elements. These elements include shape, size, pattern, shadow, tone or colour, texture, association and site (Lilesand & Kiefer, 1994).

Figure 3: An example of a classified 0.25m pixel resolution photograph of an intensively cultivated land area situated within the Pwales valley (St Paul's Bay local council) (af: abandoned parcel of agricultural land; beans: broad beans).

In addition to classified aerial photographs a set of ground photographs were simultaneously used by the data entry operators to assist them to relate the above-mentioned photo-interpretation criteria with those as seen from the ground.

Apart from tone and texture, methods of cultivation and harvesting techniques were additional helpful elements used for photo-interpretation and CLC classification. This was particularly true for crop types such as fodder, potatoes, onions/garlic and marrow.

Digitisation of parcels

The precise location of all field parcels was identified from a national digitised base map (1:2500 scale). Acquisition of the relevant photography was done by overlaying the spatial photo archive layer on top of the base map. Having located the exact position of the parcel on both base map and photograph, parcels were vectorised and classified according to the CORINE scheme (both attribute feature- and colour- code), taking into account the proportional size of the crop cover over its collocated digitised base map. A final geographical atlas (available from the National Statistics Office – NSO) showing agricultural CLC map at Level III and V for each local council area was produced as one of the output of this project (Appendix II).

Accuracy assessment

The most common form of expressing classification accuracy is the error matrix (also referred to as confusion matrix or contingency table). Error matrices compare, on a class-by-class basis, the relationship between known reference data (ground truth) and the corresponding results of the classification procedure (vectorized crop coverage), recognised at the same location. The overall accuracy is the sum of the major diagonal (i.e. the correctly classified parcels) divided by the total number of parcels in the error matrix. This value is the most commonly reported accuracy assessment statistic. The following accuracy indicators were also estimated according to Foody (2002): Producer's accuracy and User's Accuracy.

Ensuring objectivity and consistency during accuracy assessment

To maintain objectivity of the accuracy assessment, the following conditions were followed:

1. Data were collected consistently from designated survey sites;
2. A simple quality control procedure was developed and implemented for all steps of data collection;
3. Adequate training on crop identification was given to farm surveyors prior to site visits;
4. Reference data were kept independent and separate of the training data used to

calibrate and classify a number of photos as described above;

5. Reference data were not reviewed until it was time to perform the assessment i.e. after the classified thematic map was produced following the interpretation of aerial photos and subsequent digitisation on GIS.

Results

Figure 4 shows a land cover map giving agricultural land cover detail for the local Council of Fontana, situated on the island of Gozo. Fontana is such a small locality that a reduced, yet perfectly legible map can be reproduced for the purpose of this paper. Grouping of parcel types at this level was done by aggregating the much more detailed information present at CLC level V to produce the statistical table 1 giving the area coverage in hectares by crop type (both temporary and permanent crops) as well as additional features such as artificial crop cover.

This was done for the entire agricultural area of the Maltese islands excluding urban, industrial areas and natural environments, arranged by local council in the form of a GIS atlas. Semi-natural and natural forests were also identified and included in the vectorization process.

Note: In Figure 4, the class “Natural vegetation” refers to land principally occupied by agriculture with significant areas of natural vegetation (CLC Class 2.4.3.).

Figure 4: Thematic classified agricultural land cover map for the Local Council of Fontana

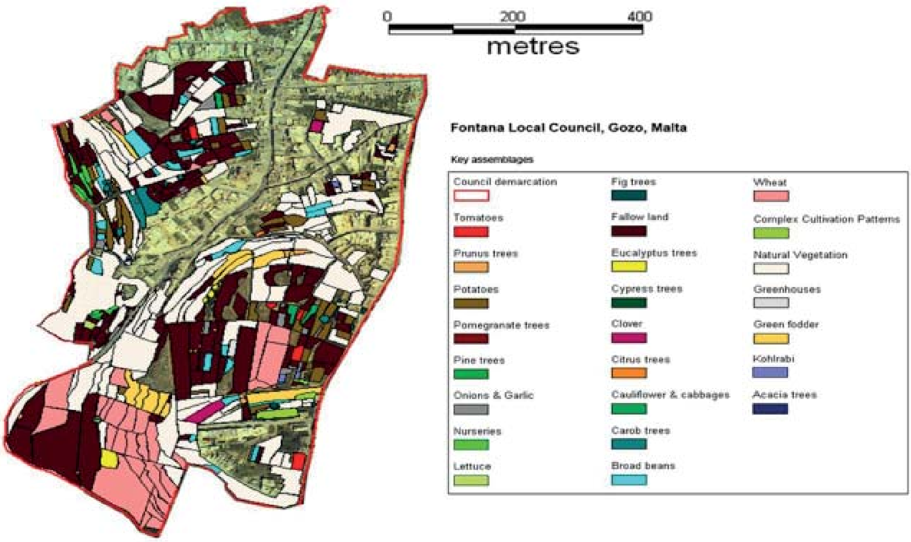


Table 1: Total number of hectares for the local council of Fontana according to the CLC level III; * Complex Cultivation Patterns; **Land principally Occupied by Agriculture (lpoba); Significant Areas of Natural Vegetation

FONTANA, Gozo	Hectares
CORINE LEVEL III - LAND TYPE IN HECTARES	
2.1.1. NON-IRRIGATED ARABLE LAND	9.15
2.1.2. IRRIGATED LAND	1.95
2.2.1. VINEYARDS	0.18
2.2.2. FRUIT TREES	0.83
2.2.3. OLIVE TREES	0.04
2.3.1. PASTURES	4.96
2.4.2. CCP*	0.18
2.4.3. LPOBA**	11.87
2.4.4. AGRO-FORESTRY AREAS	0.00
3.1.2. CONIFEROUS TREES	0.01
3.2.3. SCLEROPHYLLOUS VEGETATION	1.27
Total Area Analysed/Council (Hectares)	30.44
Total Council Area (Hectares)	47.37

Table 2: Total number of hectares for the local council of Fontana according to the new CLC level V; * Complex Cultivation Patterns; **Land Principally Occupied by Agriculture (LPOBA); Significant Areas of Natural Vegetation

FONTANA, Gozo	Hectares
CORINE LEVEL V - CROP TYPE IN HECTARES	
2.1.1.1.1.ONIONS GARLIC	0.30
2.1.1.2.1. BROAD BEANS	0.85
2.1.1.3. PLOUGHED FALLOW LAND	8.00
2.1.2.1.1. POTATOES	1.34
2.1.2.1.2. CARROTS	0.00
2.1.2.2. FRESH VEGETABLES	0.00
2.1.2.2.1. LETTUCE	0.02
2.1.2.2.3. TOMATOES	0.19
2.1.2.2.4. CAULIFLOWER/CABBAGES	0.12
2.1.2.2.7. KOHLRABI	0.04
2.1.2.3. NURSERIES	0.18
2.1.2.4.1. GREENHOUSES	0.04
2.2.1.1.1. VINEYARDS	0.18
2.2.2.1.1. STONE FRUIT TREES (PRUNUS spp.)	0.56
2.2.2.1.2. POMEGRANATE TREES	0.01
2.2.2.1.3. FIG TREES	0.22
2.2.2.1.4. CITRUS spp.	0.03
2.2.3.1.1. OLIVE TREES	0.04
2.3.1.1. GREEN FODDER	1.04
2.3.1.1.1. CLOVER	0.19
2.3.1.1.2. WHEAT	3.73
2.4.2. CCP*	0.18
2.4.3. LPOBA**	11.87
3.1.2.1.1. PINE TREES	0.01
3.2.3.1.1. EUCALYPTUS TREES	0.33
3.2.3.2.1. ACACIA TREES	0.02
3.2.3.2.2. CAROB TREES	0.92
Total Area Analysed/Council (Hectares)	30.41
Total Area of Council (Hectares)	47.37

Accuracy assessment

i. Error matrix assessment

To assess the accuracy of the classified thematic map, an error-matrix based assessment was applied. The error matrix for the CORINE levels III and V were produced by comparing collocated agriculture land parcels identified and interpreted both ground survey versus those classified by the final land cover map.

Table 3 shows the number and type of Level III “reference” parcels that were identified and recorded during the ground survey. A total of 1115 field parcels were used to generate the error matrix of the agricultural land (Table 3).

Table 3: Number of reference data (in terms of number of distinct parcels according to CORINE level III) at the various sampling areas. See table A1 for reference to the CORINE codes)

Level III

	2.1.1	2.1.2	2.2.1	2.2.2	2.2.3	2.3.1	2.4.2	2.4.3	2.4.4	3.1.2	3.2.3
Luqa	5	4	-	-	-	5	-		-	-	6
Gudja	12	5	1	1	-	27	-	5	-	-	5
Gudja	2	6		1	-	11	-	1	-	-	1
Zebbiegh	24	11	11	5	-	9	-	10	-	-	2
Dwejra	5	14	3	1	-	6	-	7	-	-	2
Naxxar	68	71	18	31	-	50	-	52	2	1	71
Fiddien	53	7	25	7	-	15	-	29	1	-	5
Mellieha	76	120	18	66	-	6	1	32	-	-	15
Pwales	57	47	1	14	1	17	-	24	2	-	5
	302	285	77	126	1	146	1	160	5	1	112

Table 4: Error matrix for CORINE classification at Level III between Reference data and Classified data (see table A1 for reference to the CORINE codes)

Level III					Classified Data							
Reference	2.1.1	2.1.2	2.2.1	2.2.2	2.2.3	2.3.1	2.4.2	2.4.3	2.4.4	3.1.2	3.2.3	
2.1.1	270	14	4	-	-	6	-	1	-	-	-	295
2.1.2	23	269	1		-	10	-	4	-	-	-	307
2.2.1	5	-	69	2	-	-	-	-	-	-	-	76
2.2.2	-	-	2	124	-	-	-	-	-	-	-	126
2.2.3	-	-	-	-	1	-	-	-	-	-	-	1
2.3.1	3	-	1	-	-	124	-	8	-	-	-	136
2.4.2	-	-	-	-	-	-	1	-	-	-	-	1
2.4.3	1	2	-	-	-	6	-	147	-	-	-	156
2.4.4	-	-		-	-	-	-	-	5	-	-	5
3.1.2	-	-		-	-	-	-	-	-	1	-	1
3.2.3	-	-		-	-	-	-	-	-	-	112	112
Total	302	285	77	126	1	146	1	160	5	1	112	

The User's and Producer's accuracy for the relevant CORINE Level III classes are shown in table 5.

Table 5: User's and Producer's classification accuracies for CORINE Level III land cover classes (see table A1 for reference to the CORINE codes)

Level III class	User's accuracy (%)	Producer's accuracy (%)
2.1.1	89.4	91.5
2.1.2	94.4	87.6
2.2.1	89.6	90.8
2.2.2	98.4	98.4
2.2.3	100	100
2.3.1	84.9	91.2
2.4.2	100	100
2.4.3	91.9	94.2
2.4.4	100	100
3.1.2	100	100
3.2.3	100	100

The absolute accuracy at CORINE Level III is calculated to be (1123/1216*100) = 92.35%. The User's and Producer's accuracy at CLC Level V are shown in Table 6.

Table 6: User's and Producer's accuracies for CORINE Level V land cover classes (see table A1 for reference to the CORINE codes).

CLC Level V class	User's accuracy (%)	Producer's accuracy (%)
2.1.1.1.1.	90.0	75.0
2.1.1.2.1.	81.3	65.0
2.1.1.2.2.	n/a	n/a
2.1.2.1.1.	88.0	95.0
2.1.2.1.2.	77.8	70.0
2.1.2.2.1.	100	33.3
2.1.2.2.2.	92.9	72.2
2.1.2.2.3.	96.4	81.8
2.1.2.2.4.	72.5	96.7
2.1.2.2.5.	100.0	50.0
2.1.2.2.6.	100.0	66.7
2.1.2.2.7.	50.0	60.0
2.1.2.2.8.	71.4	100.0
2.1.2.2.9.	n/a	n/a
2.1.2.4.1.	100.0	100.0
2.1.2.4.2.	100.0	88.6
2.1.2.4.3.	100.0	100.0
2.2.1.1.1.	93.5	97.3
2.2.2.1.1.	100.0	96.6
2.2.2.1.2.	100	100.0
2.2.2.1.3.	100.0	100.0
2.2.2.1.4.	75.0	100.0
2.2.2.1.5.	n/a	n/a
2.2.2.1.6.	66.7	100.0
2.2.3.1.1.	100.0	100.0
2.3.1.1.1.	66.7	100.0
2.3.1.1.2.	100.0	85.3
2.3.1.1.3.	42.9	100.0
2.3.1.1.4.	75.0	75.0

In a similar way, the absolute accuracy at CORINE Level V was calculated to be 89.0%.

ii. Ground-truth validation

An additional ground truthing exercise to assess the accuracy of permanent crops, such as vines and citrus trees, was also carried out. A total of 12.68 hectares of land containing vines in Gozo (specifically, in Għajnsielem, Nadur and Żebbug) were selected from the land cover map and validated on site. Table 7 shows the percentage of mapped area analysed that matched with collocated fields containing vines.

Similarly, another ground truthing (i.e. independent verification) survey was conducted, this time covering a total of 20.75 hectares in the primary viticulture locality of Mġarr, Malta. The survey resulted in a percentage accuracy of 97.5% of the total viticulture area analysed. It is interesting to note that out of the non-matched area of 0.52 hectares, 0.38 hectares were found to be covered by small fruit trees of the prunus type. The remaining unmatched fields consisted of ploughed fallow land. The total area surveyed amount to almost 13% of the total area of the locality of Mġarr, Malta.

It is observed that the majority of the mismatched land parcels pertained to those having very small vine stalks, situated in dry fields lacking irrigation. For this reason, it is doubtful whether these crops are productive at all. Their very small size has constituted a limiting factor for the present remote sensing technique to detect the smallest of features.

Table 7: Percentage match of congruence between mapped and collocated (surveyed) vineyard in various localities.

Locality	Total mapped area verified (in hectares)	Matched area (in hectares)	Non-matched area (in hectares)	Percentage hit
Għajnsielem	3.67	3.27	0.30 (a)	97.7%
Żebbug, Gozo	3.34	2.93	0.41	87.7%
Nadur	5.67	4.76	0.91	84.0%
Mġarr, Malta	20.75	20.23	0.52	97.5%

(a) - of which 0.30 hectares contained vines that have been uprooted after the aerial survey was conducted (as confirmed by farmers tilling the land).

In addition to vines, another 3 hectares of land containing citrus trees were verified against the land cover map pertaining to this crop type situated in Nadur area (≈100 citrus orchard situated along San Blas road). Verification resulted in 100% matching.

Discussion

Sample design for ground surveys

The ground survey exercise was designed to collect the main distribution and types of samples from the designated areas. The selection of an effective sample design to collect valid reference data was one of the most important components that supported the validity of the accuracy assessment. The extent of area coverage during the ground survey was however, limited by its cost.

Because accuracy assessment assumes that the information displayed in the error matrix is a true representation of the map being assessed, an improperly gathered sample will produce meaningless results. Congalton and Green (1999) argue that a balance between what is statistically sound and what is practically attainable must be found. In their experience, a general guideline seems to collect a minimum of 50 samples for each category in the error matrix. This can be one of the main reasons why the error matrix and final accuracy assessment of the land cover map pertaining to the CORINE Level III is much more robust and reliable than the Level V. It has to be kept in mind that the collection of data at each sample point can be very expensive, requiring that sample size be kept to a minimum to be affordable.

The number of samples for each category can however be adjusted based on the relative importance of that category within the objectives of the mapping or by the inherent variability within each of the categories. The relatively extensive ground survey over irrigated arable land, such as Pwales valley, Burmarrad, Mġarr and Mellieħa areas, reaching a total of 119.18 hectares or 91% of the total ground area covered, emphasizes this point. This was done in order to expand the CORINE classification table with two additional levels giving higher detail than provided by similar national surveys carried out elsewhere.

Ground truth data was collected within a matter of days before collection of the aerial photos. Since the accuracy assessment reference data was collected at the beginning of the project before the land cover map was generated, it was not possible to stratify the data according to the final map category. It was also not possible to have a collection of each map category that is proportional to total area allocation of each sample since the total area of each map class was still unknown at that time. This limitation can now be re-considered for future, similar aerial remote sensing projects.

Accuracy of ground surveys

A certain degree of variability of detailed estimates of vegetation cover was evident but only to a minor extent which cannot be precisely measured. It should be noted that the mapped estimates using aerial photos were much richer in detail than the data collected from the ground. Using ground estimates as reference data for aerial cover estimates can sometimes be rather a challenging task. This is due to a number of reasons, mainly originating from the laborious procedure to try to (1) identify exactly the parcel of land from the ground, (2) include all the detail in the space available on the survey sheet, and (3) to respect proportionality of fragmented coverage of different crop types in the same land parcel. In addition, the rugged landscape and boundary walls, did not always offer full visibility of the content of these parcels.

Success of image coverage

Due to common technical problems (such as civilian air-traffic) and weather conditions (such as strong winds) during the sequence of flight navigation, the airphoto coverage resulted in a 97.4% of the total area cover of the Maltese islands. Fortunately the remaining uncovered area included urban, industrial and environmental areas that did not fall within the requirements of the Project, including the small island of Filfla.

Airphoto interpretation

Coloured RGB airphotos mode present some difficulties when used to interpret crop cover without any additional spectral information such as in the near-infrared and infrared region. This was particularly true for the identification of a restricted range of crops such as kohlrabi and cabbages. While these two crop types are easily distinguishable from the ground, photo-interpreters were faced with two crop types that had to be differentiated on the basis of only their variation in colour. Their cultivation patterns and crop size are similar at maturation at the time of the flight survey. The resulting inaccuracy is reflected in the Producer's accuracy for this crop type (60%). On the other hand, cauliflower (which as a CLC class comprises also cabbages) was easily identified from their bluish-green tone seen in aerial photos. This is reflected by the high Producer's accuracy (96.7%).

Another low accuracy estimate was that for lettuce crops (33.3%). Mainly due to irrigation purposes, this crop type was found planted in small land parcels arranged in narrow rows (circa 2.5 x 40 m) adjacent to other different crops, and therefore difficult to identify correctly. On the other hand, recognition of this crop type was made much easier when sufficiently larger areas of field parcels containing lettuce were available. This gave the photo-interpreters enough recognition elements to confidently classify this crop type. This was also true for some other crop categories such as broccoli, beetroot and to a much lesser extent celery, which due their small size were also difficult to interpret from even the best quality aerial photos available.

The characterisation of the main variety of fruit trees at CORINE Level V using the present remote sensing technique proved to be quite sufficient from an interpretation point of view. Unfortunately however, few samples were collected during the ground survey to allow a realistic accuracy assessment of the final cover at Level V. The discrimination between *citrus* and *prunus* species proved to be easy from aerial photos. The discrimination between pyrus and prunus species was more challenging however, since the elements that characterise these two crop types at the time of the flight survey were not so much different. Fortunately, when the aerial flights were conducted, *prunus* trees appeared greener than pyrus trees, and this was evidenced by ground truthing. The grouping together of these fruit trees at CORINE Level III presents therefore a higher confidence in the overall accuracy (98%).

Another tree type that was very difficult to identify from aerial photos was pomegranate, the reason being that these tend to be found adjacent to boundary walls and sheltered by other tree types. They show no spatial, systematic arrangement whatsoever that could have assisted their identification. Their inclusion in the CORINE table was solely due to their presence from ground surveys.

One interesting class of tree included in the CORINE Level V list is small fruit trees (CLC class 2.2.2.1.6.). The digital photographic systems used in this study was able to capture new orchards showing typical plantations of small trees but providing no additional information on their type due to their small size. The association of these parcels of land with adjacent ones containing mature fruit trees suggest that these were also fruit trees. However, there is always a probability that this mapped category can be contaminated by other small trees having similar plantation patterns but are not fruit trees, such as trees of the sclerophyllous type.

The classification of parcels containing olive trees was based on the identification of a homogenous plantation of olive trees. Therefore, this category does not exclude the presence of olive trees admixed with other vegetation of coniferous or sclerophyllous type. This is particularly true for areas such as is-Simar, Mizieb and l-Ahrax tal-Mellieha areas, where the predominant vegetation type consists of sclerophyllous or coniferous type. Within these coverages, solitary olive trees are also found distributed but were difficult to identify and digitise.

No major problems were encountered in the classification of LPOBA (Land Principally Occupied By Agriculture, with significant areas of natural vegetation). This category is easily discriminated from cultivated parcels of land. However, when such parcels are ‘cleaned’ from vegetation as a preparation for the spring-summer crops, they can be misinterpreted as harvested fodder and could therefore have been classified as such. This would of course lead to a biased result in favour of a larger overall coverage by fodder. It is very difficult to assess this quantitatively unless a specific ground survey is designed to address this problem.

Crop maturation and harvesting

An intimate knowledge of the progressive development of each crop was essential for reliable identification on aerial photos. The reliability of crop identifications on single-date photography was improved by scheduling the remote sensing survey during April when the most important crops are distinctly separable. If the aerial survey was further delayed then there was the chance of missing the inclusion of important crops in the final land cover map because of harvesting.

In fact, due to unfavourable weather conditions, the aerial survey was conducted at a time when harvesting of important crops was already started. This included fodder and potatoes. Fortunately, their characteristic recognition elements were still traceable. This was assisted by including these features in the interpretation keys. In the case of fodder however, discrimination of the main types proved to be an impossible task from harvested parcels. Instead these were simply given a level III category – green fodder (CLC class 2.3.1.1.). It has to be noted that parcels containing homogenous coverage of mature green fodder were also identified in extended areas such as clay slopes, which may not have been sown deliberately.

Quality control

The engagement of a team of airphoto interpreters, each with his/her own ability to interpret aerial photos may have affected the quality of the final interpretation. To minimise this, a final quality control was made by the leading photo-interpreter by a final "screening" of 90% of the entre thematic map, prior to the accuracy assessment. This ensured further harmonisation of the final product as well as removing biases.

Conclusion

The AGRISTAT Project successfully demonstrated the effective use of CCD-array, digital cameras and their combination with GIS environments for precision agriculture mapping for small island states. This facility allows direct integration of external digital datasets, retains data integrity and enables unlimited recall for subsequent analysis. In-house data processing and management by local personnel led to a reduction in the overall cost of a fully comprehensive, one time agriculture survey with exceptional precision. Compared to surveys utilizing orbiting multispectral sensors, such as fused products from LANDSAT and SPOT (Galdies, 1998), this technique is ideally suited for small islands states where large scale thematic mapping is a national requirement.

For an enhanced mapping accuracy, it is recommended that an additional full set of colour infrared aerial photos should be acquired as to provide additional recognition elements (Avery & Berlin, 1992). One such element is the variable moisture content of crops as a discriminatory element between different crop types.

It is hoped that this case study can be used as a demonstration for future updating and augmenting of existing data, as well as in the recording of agricultural information (such as seasonal crop rotation).

Acknowledgements

We would like to acknowledge the assistance of the National Statistics Office, and of Dr Alex Koh, from Bath Spa University, for their strong support and cooperation in the execution of AGRISTAT Project.

References

Avery, T.E. and Berlin, G.L. (1992) *Fundamentals of Remote Sensing and airphoto interpretation*, fifth edition In T.E. Avery and G.L. Berlin (Eds.), Prentice Hall.

Congalton, R.G. & Green K. (1999). *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. In R. G. Congalton & K. Green (Eds.), Lewis Publishers.

Foody G.M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80, 185– 201.

Galdies C., (1998). *Data Fusion of SPOT PAN and LANDSAT TM for land use classification of small Mediterranean islands. Satellite-based observation: a tool for the study of the Mediterranean Basin*, CNES, Tunisia, 23-27 November 1998.

Galdies, C., & Borg, J.A. (2006). Aerial remote sensing and spatial analysis of marine benthic habitats in St. George's Bay (Malta). In A.Micallef, A. Vassallo & M. Cassar (Eds.), *Proceedings of the Second International Conference on the Management of Coastal Recreational Resources - Beaches, Yacht Marinas and Coastal Ecotourism*, 25th - 27th October 2006, Gozo, Malta, pp 81 - 87; Euro-Mediterranean Centre on Insular Coastal Dynamics, Foundation for International Studies, Valletta: Malta.

Graham & Koh A. (2002). *Digital Aerial Survey: Theory and Practice.* ISBN 1-870325-98-2.

Lilesand T.M. & Kiefer R. W. (1994). *Remote Sensing and Image Interpretation* third edition. In T.M. Lilesand & R.W. Kiefer (Eds.), John Wiley & Sons, Inc.

Robert, P.C., Rust R.H., and Larson W.E.. (1994). In P.C. Robert et al. (Ed.), Site-specific management for agricultural systems. *American Society of Agronomy*, Madison, WI.

Stombaugh, T.S., Mueller, T.G. Shearer, S.A. Dillon, C.R. and Henson. G.T. (2001). *Guidelines for Adopting Precision Agriculture Practices,* Publ. No: PA-2. Lexington, Kentucky. University of Kentucky Cooperative Extension Service.

APPENDIX I

Table A1. Classification table used for Project AGRISTAT and based on the CORINE Classification

	LEVEL 1		LEVEL 2		LEVEL 3		LEVEL 4		LEVEL 5
2	AGRICULTURAL AREAS	2.1.	ARABLE LAND	2.1.1.	NON-IRRIGATED ARABLE LAND	2.1.1.1.	ROOT CROPS	2.1.1.1.1.	ONION/GARLIC
						2.1.1.2	DRY PULSES	2.1.1.2.1.	BROAD BEANS
								2.1.1.2.2.	PEAS
						2.1.1.3.	PLOUGHED FALLOWLAND		
				2.1.2.	IRRIGATED LAND	2.1.2.1.	ROOT CROPS	2.1.2.1.1.	POTATOES
								2.1.2.1.2.	CARROTS
						2.1.2.2.	FRESH VEGETABLES	2.1.2.2.1.	LETTUCE
								2.1.2.2.2.	GLOBE ARTICHOKES
								2.1.2.2.3.	TOMATOES
								2.1.2.2.4.	CAULIFLOWER/CABBAGES
								2.1.2.2.5.	CELERY
								2.1.2.2.6.	BEETROOT
								2.1.2.2.7.	KOHLRABI
								2.1.2.2.8.	MARROW
								2.1.2.2.9.	BROCCOLI
						2.1.2.3.	NURSERIES		
						2.1.2.4.	CROPS UNDER ARTIFICIAL COVER	2.1.2.4.1.	GREENHOUSES
								2.1.2.4.2.	CLOCHES
								2.1.2.4.3.	CROP COVERS
						2.1.2.5.	FLORICULTURE		
		2.2.	PERMANENT CROPS	2.2.1	VINEYARDS			2.2.1.1.1.	VITIS spp.
				2.2.2.	FRUIT TREES			2.2.2.1.1.	*PRUNUS AMYGDALUS* and its varieties
								2.2.2.1.2.	POMEGRENATES
								2.2.2.1.3.	FIGS
								2.2.2.1.4.	*CITRUS* and its varieties
								2.2.2.1.5.	*PYRUS COMMUNIS CULTIVARS*
								2.2.2.1.6.	SMALL FRUIT TRESS
				2.2.3.	OLIVE TREES			2.2.3.1.1.	OLEA spp.
		2.3.	PASTURES	2.3.1.	PASTURES	2.3.1.1.	GREEN FODDER	2.3.1.1.1.	CLOVER
								2.3.1.1.2.	WHEAT
								2.3.1.1.3	BARLEY
								2.3.1.1.4.	VETCHES
		2.4.	HETEROGENEOUS AREAS	2.4.1.	ANNUAL CROPS ASSOCIATED WITH PERMANENT CROPS				
				2.4.2.	COMPLEX CULTIVATION PATTERNS				
				2.4.3.	LAND PRINCIPALLY OCCUPIED BY AGRICULTURE, WITH SIGNIFICANT AREAS OF NATURAL VEGETATION				
				2.4.4.	AGRO-FORESTRY AREAS				
3	FORESTS AND SEMI-NATURAL AREAS	3.1.	FORESTS	3.1.1.	BROAD-LEAVED FOREST				
				3.1.2.	CONIFEROUS	3.1.2.1.	PINECEAE	3.1.2.1.1.	PINE
						3.1.2.2.	CUPRESSACEAE	3.1.2.2.1.	CYPRESS
		3.2.	SHRUB AND/OR HERBACEOUS VEGETATION ASSOCIATION	3.2.3.	SCLEROPHYLLUS	3.2.3.1.	MYRTACEAE	3.2.3.1.1.	EUCALYPTUS
						3.2.3.2.	FABACEAE	3.2.3.2.1.	ACACIA
								3.2.3.2.2	CAROB

APPENDIX 2

The Agristat Land-Cover Nomenclature

The AGRISTAT land cover nomenclature consists of five levels according to the CORINE standard classification method. The first three levels are identical to CORINE specified nomenclature, whereas the remaining successive levels (levels IV to V) have been added subject to the following criteria:

- Additional items included all the land covered by the corresponding level III items.
- Newly created items are not related to more than one three-figure level III class.
- Positive identification from the high-resolution aerial photos at a pixel resolution of not greater than 12-15cm.

These additional layers are important in that they group all other additional features related to permanent/temporary crop type as well as information on type of trees.

CORINE Level III Class Definitions

Non-irrigated arable land (2.1.1.): Cereals, legumes, fodder crops, root crops and fallow land. According to the CORINE technical guidelines, ploughed land with no productive vegetal cover on the date of data acquisition belongs to this category.

Irrigated land (2.1.2.): According to CORINE technical guidelines, this class contains crops irrigated permanently and periodically, using a permanent infrastructure (irrigation channels, drainage network). Most of these crops cannot be cultivated without an artificial water supply.

Vineyards (2.2.1.): Areas planted with vines. Vineyards present a uniformly linear pattern on aerial photographs and are easily identifiable. Since grape cultivation requires a specific amount of spacing between individual rows, vineyards are not likely to be confused with different row crops of similar height and texture.

Fruit trees (2.2.2.): Parcels planted with fruit trees: single or mixed fruit species, fruit trees associated with permanently grassed surfaces.

As a rule orchards are characterised by uniformly spaced rows of trees that give the appearance of a grid pattern. Orchards planted on level terrain (as are citrus orchards) are usually laid out in squares so that the same spacing exists between rows as between individual trees in the same row. On rolling to hilly terrain, tree rows may follow old cultivation terraces or land contours (as in peach and apple orchards).

For most orchards, the key identification characteristics were row spacing, crown size and crown shape (often visible in shadow patterns on large scale photographs). Whether the plants are deciduous or evergreen was also of assistance.

This classification code is especially used when orchards having a dense mixture of fruit trees are identified and interpreted from aerial photos. Typical mixtures include pear, peaches and oranges. The range of different fruit tree type identifiable by the aerial digital photographic system (ADPS) used for AGRISTAT system are included in Level V.

Fruit trees that have been recently planted and which cannot be characterised due to their small size are included in Level V as small fruit trees (2.2.2.1.6). Their small size and constant pattern as seen from aerial photos is easily recognisable by the ADPS.

Olive trees (2.2.3.): Homogenous areas planted with olive trees. Olive trees can also be found admixed within areas predominantly occupied by coniferous and sclerophyllous vegetation.

The classification of parcels containing olive trees was based on the identification of a homogenous plantation of olive trees. Therefore, this category does not exclude the presence of other olive trees admixed with other vegetation predominantly consisting of coniferous or sclerophyllous type. Within these coverages, solitary olive trees are difficult to discriminate from aerial photos.

Pastures (2.3.1.): Areas showing dense grass cover, of floral composition, dominated by graminaceae, not under a rotation system. Mainly for grazing, but the fodder may be harvested mechanically.

The aerial survey was conducted at a time when fodder started to be harvested. The discrimination of the fodder types from recently harvested fodder fields was impossible. Instead harvested parcels were given a level III category – green fodder (2.3.1.1.). It has to be noted that parcels containing homogenous coverage of mature green fodder were also identified in extended areas such as clay slopes, which may not have been sown deliberately.

Relevant heterogeneous agricultural areas include:

Complex cultivation patterns (2.4.2.): Juxtaposition of small parcels of diverse annual crops, pastures and/or permanent crops.

Such parcels were difficult to segment and characterise using the aerial remote sensing technique, but their occurrence was moderately rare.

Land principally occupied by agriculture, with significant areas of natural vegetation (2.4.3.): Areas principally occupied by agriculture, interspersed with significant natural areas.

These parcels may, to a minor extent, include wild crops such as mixed type of fodder (often found on clay slopes) admixed with wild vegetation. They are easily discriminated from cultivated parcels of land. However, when such parcels are 'cleaned' from vegetation as a preparation for the spring-summer crops, the resulting pattern from aerial photos can be misinterpreted as not-so-recent harvested fodder and could therefore have been classified as such. It is very difficult to assess this bias quantitatively unless a specific ground survey is designed to address this problem.

Agro-forestry areas (2.4.4.): Annual crops or grazing land under the wooded cover of forestry species.

For the present classification, this class includes forest trees, mainly related to coniferous, that are planted to serve a number of purposes, including shelter against wind and as field borders.

Relevant forests and semi-natural areas include:

Coniferous (3.1.2.): Vegetation formation composed principally of trees, including shrub and bushes, where coniferous species predominate. May include olive trees admixed or scattered within coniferous vegetation.

Shrub and/or herbaceous vegetation associations:

Sclerophyllous (3.2.3.): bushy sclerophyllous vegetation. Comprises a dense vegetation association composed of numerous shrubs associated with siliceous soils in the Mediterranean environment. May include olive trees admixed or scattered within sclerophyllous vegetation.

This class may also contain olive trees admixed with the main varieties of sclerophyllous vegetation.

CORINE Level IV Class Definitions

The following description provides definitions of additional agriculture land cover classes.

Root crops (2.1.1.1.): Any crop cultivated in non-irrigated arable land whose edible portion is taken from under the ground. The range identifiable by the ADPS system are included in Level V.

Pulses (2.1.1.2.): Annual leguminous crops yielding from one to 12 grains or seeds of variable size, shape and colour within a pod. They are used for both food and feed. The range identifiable by the ADPS system are included in Level V.

Ploughed fallow land (2.1.1.3.): Land that has been cultivated and left to rest without a crop for an extended period of time in order to accumulate soil moisture. Easily recognisable by the ADPS system.

Root crops (2.1.2.1.): Any crop cultivated in irrigated arable land whose edible portion is taken from under the ground. The range identifiable by the ADPS system are included in Level V.

Fresh vegetables (2.1.2.2.): Any group of crops cultivated in irrigated arable land that need warm weather to germinate and actively grow. The range identifiable by the ADPS system are included in Level V. However, in some cases local farming practices tend to cultivate small areas with different types of vegetables sown very close together in such a way that their discrimination from aerial photos is not possible.

Nurseries (2.1.2.3.): Any group of small crops that have recently germinated and to be sown accordingly. No further discrimination between crop types under this class is possible by the ADPS system.

Crops under artificial cover (2.1.2.4.): This relates to those crops which require an artificial cover for faster maturation. The range identifiable by the ADPS system are included in Level V.

Floriculture (2.1.2.5.): The cultivation of flowers, especially to be cut and sold, including flowering plants and foliage plants, cut flowers, greens, bedding plants (annual and perennial). Often found in restricted commercial sites with permanent cover.

Green fodder (2.3.1.1.): Arable land used to cultivate animal feed for the purpose to feed local livestock. The range of fodder type identifiable by the ADPS system are included in Level V. Parcels of land highly suggestive of harvested fodder are given this classification code.

Pinaceae (3.1.2.1.): Trees forming part of the family of Pinaceae; pine family; Type: Gymnosperm family; Part of Coniferalis

Cupressaceae (3.1.2.2.): Trees forming part of the family Cupressaceae; Genus Cupressus; Type of gymnosperm family; Part of Cupressaceae

Myrtaceae (3.2.3.1.): Evergreen trees, up to 50 feet tall, very fast growing. Typical example is eucalyptus.

Fabaceae (3.2.3.2.): Trees forming part of the family Fabaceae; Plants belonging to the Leguminosae (now Fabaceae) family. Fruits are simple, dry, dehiscent which splits along two seams edible legumes.

Due to the enhanced resolution that is offered by the ADPS, an additional two CORINE columns were added. The final, fifth column consists of the individual crop type as differentiated by the ADPS according to their corresponding level III class.

THE ATLAS

The final Atlas (available from the National Statistics Office – NSO) consists of a set of full-colour agriculture land cover maps accompanied by tables containing related land cover statistics. This data is organised according to the geographical classification for the Republic of Malta as based on the Nomenclature Des Unités Territoriales Statistiques (Nuts), as follows:

MT011	**SOUTHERN HARBOUR DISTRICT**
MT012	**NORTHERN HARBOUR DISTRICT**
MT013	**SOUTH EASTERN DISTRICT**
MT014	**WESTERN DISTRICT**
MT015	**NORTHERN DISTRICT**
MT026	**GOZO AND COMINO**

Land cover maps of localities having no agricultural land cover data have been omitted.