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AGRICULTURAL APPLICATIONS OF ERTS-1 DATA

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INTRODUCTION

Considering the present needs for regional, national, and worldwide inventory and evalution data, coupled with the particular capabilities of the ERTS system, agricultural applications appear to be especially promising as an area in which important benefits might be realized from the use of such technology. In the United States, the Department of Agriculture presently conducts an enumerative program in which virtually all agricultural land is inventoried annually. In addition numerous other federal, state and local agencies conduct extensive crop inventories, land use surveys, and soils mapping projects of varying magnitude. On a worldwide basis it would seem that the principal obstacles to providing enough food for all persons are those of allocation and distribution. What is needed is knowledge as to where and how much food is now being produced, and how crop production is changing with time.

Up to the present time agricultural inventories have required a tremendous effort on the part of on-the-ground enumerators, and have presented a formidable data compilation task. However, a satellite sensing system, with which large areas of land can be surveyed in their entirety on one image, and which can provide uniform worldwide coverage with a relatively small number of images offers great promise as a data collection tool for alleviating these problems. Furthermore, the dynamic nature of agriculture requires not a single evaluation in most cases, but rather a continual updating of conditions. In fact, it has been shown that desired information about agricultural crops can often be obtained only by capitalizing on a knowledge of the patterns of change of particular crop types of conditions. Again, this suggests that a satellite sensing system such as ERTS, which makes possible regular, frequent observations of each spot on the earth's surface, can provide a service which would be totally infeasible using conventional techniques.

Based on these facts, plus the encouraging results achieved using both high altitude aircraft and spacecraft imagery for crop inventory experiments over the past several years, the Forestry Remote Sensing Laboratory at the University of California has undertaken the experiment described in this paper. The experiment is designed to evaluate the feasibility of using satellite data regionally to provide needed agricultural information on an operational basis. The experiment is being performed in Maricopa County, Arizona and San Joaquin County, California in cooperation with a number of state and federal agencies.

In an effort to accurately determine the degree of detail which can be extracted from ERTS-1 data, and the optimum use of "subsampling" in the form of aerial photography and ground truth data for various agricultural-related tasks, the investigation is being carried out in a step-wise fashion beginning with gross land use mapping, and progressing to very detailed crop inventories. In all cases, emphasis is being placed on obtaining a quantitative expression of the accuracy of estimates obtained by the use of remote sensing for the county as a whole, and where possible, a comparison of these results with those obtained using conventional techniques. Investigations entail the use of both human interpreters and automatic classification and data handling techniques, and an evaluation of the optimum mix of human and machine techniques for each analysis problem. In each case, an attempt is made to ensure that the types of information compiled (e.g., maps, tabular data, crop acreages, etc.) conform to actual requirements or desires as expressed by those persons currently involved in resource evaluations and planning in the test site.

In the area of agricultural land stratification, initial stratifications have been performed in the San Joaquin area on ERTS-1 imagery which was obtained on July 26, 1972. Plans call for similar stratifications on later dates of imagery, and for comparisons of delineations made at different dates and seasonal states. Preliminary analyses of the stratifications to ascertain the extent to which they do provide meaningful crop type and condition information already have been carried out. Finally, a study is under way to analyze the usefulness of stratification information in improving crop classification accuracy using automated techniques.

Crop classification and inventory studies are progressing concurrently with the stratification investigation, as it seems likely that any operational inventory procedures will be heavily dependent on an initial stratification of agriculture on ERTS or other small scale imagery. At the present time an automatic "CALSCAN" classification has been completed for a single stratum using ERTS data acquired in July, 1972. Subsequent work will include an extension of these techniques to the entire San Joaquin test site, and the use of multidate imagery for crop classification. Little crop inventory work using human interpreters has been done to date due to the dependence of the interpreter on the selection of optimum dates of imagery for specific crop categories. This factor seems to be more critical in the case of human interpreters than with automatic classification. Therefore most non-automated crop inventory work will be done next spring. In the meantime, however, studies are under way to ascertain optimum methods for point sampling in the interpretation process on ERTS imagery of large areas for crop inventory purposes. This work is based on the assumption that if crop inventory techniques using ERTS and other remote sensing data are ever to be adopted on an operational basis, efficient statistical sampling methods must be developed concurrent with the actual interpretation methods in order to adequately demonstrate the practicality of using space-acquired data.

Agricultural land use change detection studies are being conducted primarily in the Maricopa County test site, where MAPIT techniques will be used to analyze both long-term and short-term additions to and deletions of agricultural land using both Apollo 9 and earlier conventional aerial photographs as well as the ERTS imagery as data inputs.

Finally, efforts to develop a computer storage and compilation capability for the handling of the large amounts of ground data gathered in the two test sites is progressing well, and it is planned that this work should be completed soon.

RESULTS

a. Agricultural Land Use Stratification

In an attempt to evaluate the usefulness of ERTS imagery for the production of land use stratifications as a preliminary step in the crop inventory process, all land within San Joaquin County was delineated into broad land use and crop category classes based on their appearance on the ERTS-1 color composite image. The stratification of the agricultural land use categories proved to be a relatively simple task, taking each of three interpreters approximately 30 minutes to complete. The three interpretations were quite similar, requiring only minor revisions to produce a "consensus" stratification. A total of 13 different agricultural strata were recognized, differing both in general field size and relative proportions of crop types and degree of irrigation. Upon comparing these interpretations, it was concluded that nearly all boundaries were truly representative of differing cropping practices. In a number of cases, the stratifications agreed almost exactly with soil type boundaries as drawn by earlier soils surveys, and in many cases probably represent a refinement of those earlier boundaries drawn "in the field".

Certainly a much more detailed and up-to-date stratification was produced from the ERTS image than is currently used by the Statistical Reporting Service of the USDA for their inventory work. The obvious questions arise, however, as to: (1) whether the strata as drawn on the image are meaningful in terms of actual land use conditions, and (2) whether such a detailed delineation could enable the SRS to more efficiently and accurately estimate the parameters of interest on a statewide basis.

The capability has been developed to digitize stratification boundaries as drawn by the interpreters and to store these data for future retrieval. The resulting data bank can then be used to accomplish the following:

1. Provide area information for individual strata from an analysis of the digitized boundary coordinates.
2. Monitor the degree to which strata boundaries change as delineated on imagery acquired at different times throughout the year.
3. Compare stratification boundaries with data from other sources.

In order to quantitatively evaluate the correlation between land use/

crop type as delineated on ERTS-1 imagery and actual ground conditions, a sampling system using transects flown by a light aircraft was developed. As the transects are flown, an observer records the land use/crop type that appears below the aircraft at 10 second intervals. Six such sample transects, with about 130 observations per line, were flown over the San Joaquin test site, and a statistical analysis performed to test the relationship between the proportion of each land use/crop type appearing in each stratum. It was concluded that the delineations as drawn by the interpreters were indeed meaningful on a quantitative basis. Furthermore, the method of data collection proved to be quite efficient, and will be utilized for future aspects of this study.

b. Monitoring Agricultural Land Use Change

The use of satellite imagery in monitoring the shift of land use in agricultural areas has been investigated using coverage of the Maricopa County test site acquired both from Apollo 9 and from ERTS-1.

An ERTS-1 color composite of the area taken on August 23, 1972 was interpreted and delineations were made of the agricultural, wildland and urban areas. These delineations were transferred onto acetate material which was directly overlaid on the Apollo 9 enlargement such that shifts in land use could be quickly identified. Since the prime interest in this study was to monitor land use shifts, either to or from agricultural use, only changes involving agricultural usage were quantified. With the use of a dot grid the acreages of land shifts were calculated.

For the Salt River Valley region of the county there were no apparent significant shifts of wildlands into agriculture during the period in question. All of the agricultural land shifts were to urban uses of various kinds, mostly urban residential usage. The total agricultural acreage shift into urban usage was computed to be approximately 28,160 acres, indicating an average annual shift of approximately 9,400 acres of agricultural land converted to urban use each year. In a recently published report of the Economic Research Service, it was estimated that for the period from 1949 to 1964, Maricopa County had an average annual shift of all land into the urban category of 9,010 acres. Eighty percent of this figure was agricultural land being urbanized, and thus the average annual shift of agricultural land to urban usage for the period of their study was 3,208 acres per year. Thus it can be seen that the rate of urbanization of agricultural land in Maricopa County has tripled in recent years.

c. Crop Identification and Inventory -- Manual Interpretation

In a study designed to evaluate the potential for manually identifying crop types on the ERTS-1 imagery, a survey of safflower fields in a portion of the San Joaquin County, California test site was carried out using human photo interpreters. Approximately sixty fields were interpreted, of which thirty were safflower as ascertained by ground surveys. In a selected portion of the test area the interpreter was asked to delineate all safflower fields, thus necessitating not only an identification of the crop, but a determination of the field boundaries as well. Safflower was chosen as the subject crop for this test because it was the only crop that was passing through an "optimum" phenological stage for discrimination on the single date for which ERTS-1 data were available.

The identification test produced an 83 percent correct identification, while in the area where both detection and delineation were required, the results were as follows:

$$\% \text{ Correct} = \frac{\text{\# of fields correctly delineated as safflower}}{\text{total \# of safflower fields in the test area}} \times 100 = 79\%$$

$$\% \text{ Commission Error} = \frac{\text{\# of fields incorrectly delineated as safflower}}{\text{total \# of safflower fields in the test area}} \times 100 = 4.6\%$$

Considering the fact that in this initial test the interpreters were unable to exploit the advantage of sequential coverage which ERTS-1 will provide, and that perhaps more nearly "optimum" dates for crop discrimination can be found at other times of the year, these results were quite encouraging. Certainly they show that an interpreter can detect and delineate individual fields on the imagery. It was the general consensus of persons interpreting the ERTS-1 color composite that ground resolution for non-linear objects of medium contrast was on the order of 250 to 350 feet, and that it was possible to observe generally reliable signatures for fields down to 20 acres in size on the color composite.

d. Crop Identification and Inventory -- Automated Interpretation

During the initial phase of the study, considerable effort has been directed toward: (1) The creation of a computer system and programs which will accept the varied inputs derived from the ERTS-1 images, tapes, supporting training and ground data (and also the subsequent data produced in the steps leading to an operational output), and which will provide output in a format that is both efficient for the operator and useful for the consumer. (2) The implementation of techniques for utilization of ground data, spectral information and imagery stratification to facilitate classification of ERTS-1 data into useful information.

Four major classes of computer programs have been assembled for use on the Forestry Remote Sensing Laboratory computer and the associated large scale computers: (1) Digital image handling and display, (2) Statistical spatial and spectral pattern recognition, (3) General statistical, and (4) Multilevel data bank. These programs are being used to process the data obtained from ERTS-1 aircraft, and ground data collections. Their use allows the selection and reformatting of areas of the state that are being analyzed intensively for correlation with ground data, mapping of features of interest based on their spatial and spectral characteristics, selection of optimum dates and spectral band(s) for classification, and comparison with existing data, both mapped and point. They are also being used to compare manually mapped boundaries and computer generated boundaries with ground data. The FRSL system has been applied to the problem of crop classification in San Joaquin County with very good results.

The first quantitative evaluation of the CALSCAN process for classifying ERTS-1 data was performed using black-and-white MSS bulk transparencies acquired of the San Joaquin test site on July 26, 1972.

Of the forty-eight ground data cells in San Joaquin County, eleven cells in the field crop strata (as delineated by photo interpreters in the stratification study described previously) were selected for intensive analysis.

Each cell was scanned on each of the four MSS transparencies to a common scale and registration such that each data point represented a 250 x 250 foot spot on the ground. To accomplish this, the map coordinates of the cells were entered in a program that computed the translation, rotation, and scale change necessary to place the map coordinates over the MSS images. This transformed coordinate information was then used by the scanner program to locate and scan the cells. Twenty-seven representative training areas were selected from the data to train the classification algorithm on the ten land use categories considered.

After the point-by-point classification was completed, each point was reclassified by an algorithm that considers the classification assigned to neighboring points. This technique improved the point-by-point classification between ten and thirty percent, depending on the homogeneity of the field. A field map of the ground truth was then laid over the final automatic classification results. Each field was then assigned by an interpreter to the class that had the maximum data point count within the field on the overlaid map.

A total of 201 fields were classified in the test area, with an overall correct identification of eighty-four percent. Again, these results are based on a field-by-field rather than a point-by-point identification, and are the result of an analysis of data from all four MSS bands. Use of the scanned photo data and pre-mapped field boundaries allowed classification down to a twenty-acre field size.

The classification of a large agricultural block on the west side of the San Joaquin County test site was next undertaken (1) as the natural subsequent step in an effort to show the capability of an automated data processing approach in producing accurate and timely agricultural inventories of larger areas and (2) as the next step in the automated analysis of human stratification of agricultural areas and of the relation of these strata to further automatic classification.

The area classified comprises approximately 340 square miles or 220,000 acres, and, at the time of image acquisition, contained primarily field crops of which asparagus, corn, alfalfa and sugar beets comprised the majority. The study was accomplished by training on 1,340 acres, and testing on 11,000 acres. The total area of the inventory was 219,872 acres.

Ten agricultural categories which comprised the majority of crops in the test area were included in twenty-five training fields. After training of the statistical models, each point in the area was classified using an algorithm that computes a likelihood factor that the point is statistically similar to each training model and then assigns to the point the name of the category for which its factor is the highest. The area was then run through "reclassification" as described earlier. Quantitative evaluations were made of the point-by-point results in the training areas by a routine in the CALSCAN program and of the field-by-field results in the test cells by manually overlaying field maps and assigning to each field the crop indicated by a majority of its points.

The point-by-point evaluation of the training fields showed a class average of 87.8 percent correct for the "classified" results and 96.1 percent after "reclassification". Overall, 88.3 percent of the fields in the test areas were correctly identified, some of which were smaller than ten acres in size. The major crops in the test area were asparagus and corn which scored 89.4 and 92.2 percent correct, respectively.

With the results from the test area as an indicator of the accuracy obtained, the classification of the entire test area was undertaken. The results of the total area classification in terms of acreage and percentage of crop type are shown in Table 1. The data presented there are essentially a quantitative description of the study area. The table lists the number of elements or points classified by CALSCAN as each crop type in the (1) "classified", (2) "reclassified", and (3) "reclassified with weights" versions of the display routine. Also shown are acreages and the percent of the total area occupied by each crop type, according to the "classified" results. In addition, the number of points, corresponding acreages and percent of total area or areas extracted on which the test fields were scored are listed. Comparison of the "% of total" columns shows that the ground data cells are quite representative of the area as a whole.

CONCLUSIONS

Certainly the results described here demonstrate the potential usefulness of data acquired from satellites such as ERTS-1 for agricultural applications. Particularly when the ability of the human interpreter to delineate meaningful land use strata is combined with the demonstrated ability of computerized systems to produce fast and accurate crop classifications, a potentially powerful tool is provided for the collection of agricultural information on a regional basis.

TABLE 1
POINT-BY-POINT RESULTS OF CLASSIFICATION OF ERTS-1 TAPE DATA
SAN JOAQUIN COUNTY, CALIFORNIA

CROP TYPE	STUDY AREA					TEST EXTRACTIONS		
	CLASSIFIED POINTS	RECLASSIFIED POINTS	RECLASSIFIED W/WEIGHTS	ACRES	% OF TOTAL	CLASSIFIED POINTS	ACRES	% OF TOTAL
ASPARAGUS	56,371	56,833	57,857	62,070	28.23	17,446	19,190	33.21
HARVESTED	32,103	31,282	30,416	35,377	16.09	5,159	5,675	9.83
CORN	26,662	31,320	31,290	29,375	13.36	8,720	9,592	16.60
SUGARBEET	15,646	14,689	15,046	17,238	7.84	4,309	4,740	8.20
SAFFLOWER	11,089	9,127	9,513	12,225	5.56	2,945	3,240	5.61
WATER	10,189	12,188	10,189	11,235	5.11	2,404	2,644	4.58
POTATO	5,749	3,022	3,137	6,332	2.88	1,866	2,053	3.55
BARE SOIL	1,450	973	1,450	1,583	.72	647	712	1.23
TOMATO	30,409	29,584	30,059	33,487	15.23	7,019	7,721	13.37
ALFALFA	9,932	10,582	10,643	10,950	4.98	1,994	2,193	3.80
TOTALS	199,600	199,600	199,600	219,872	100.00	52,509	57,760	99.98