JOHN R. JENSEN, PH.D.
University of Georgia
Athens, GA 30602
JOHN E. ESTES, Ph.D.
LARRY R. TINNEY
University of California
Santa Barbara, CA 93106

High-Altitude versus Landsat Imagery for Digital Crop Identification

Because of vignetting in the high-altitude photography, Landsat data proved to be superior for digital crop identification.

ABSTRACT: *Multidate crop identification using microdensitometer scanned color infrared high-altitude photography (original scale 1:120 000) and Landsat digital data was conducted for a 140 km² study area in Kern County, California. The purpose of this analysis was not to achieve maximum crop identification accuracy* per se, *but to comparatively evaluate the utility of the two image formats for digital crop identification. Preliminary results indicate that the Landsat digital approach is superior to analysis of digitized high-altitude photography. Vignetting in the high-altitude photography dataset caused serious signature extension problems.*

INTRODUCTION

THE NEED for accurate crop identification and acreage estimation at the local, regional, state, and national levels is well documented (G. E. Space Division, 1974; National Academy of Sciences, 1977).[1] At the national and international level, the Large Area Crop Inventory Experiment (LACIE) is being conducted to inventory wheat production in the United States and selected foreign countries.[2] At the micro-scale, basic research continues to evaluate system configurations and interpretation methods, especially as they relate to identifying multiple crop types for local and regional data requirements. One such topic is the usefulness of digitizing high-altitude or satellite photography for machine assisted crop identification.

Early work by Anuta and MacDonald (1971) evaluated the effectiveness of digitized Apollo 9 multiband and multiemulsion photography and concluded that "precise breakdowns of crop types is difficult from three-band satellite photography, and in some cases impossible."[3] When using digitized S190A Skylab photography, Colwell and Benson (1975) experienced varied crop identification accuracies ranging from poor (50 percent) to acceptable (85 percent) depending upon the individual date analyzed. A more comprehensive study by Silva (1976) evaluated the utility of using digitized Skylab S190A photography, S192 multispectral scanner data, and Landsat digital data for level two land-use mapping. Unfortunately, no crop type classification was performed. The study concluded that the overall performances of the Skylab and Landsat multispectral scanner data sets were superior to those of the digitized S190A data sets.

Initial crop identification research using digitized high-altitude aircraft multiband and multiemulsion photography (1:120 000) reported encouraging accuracies (Hoffer *et al.*, 1972). The authors stated that digitized

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"color infrared film is an effective three-band multispectral sensor and offers the efficiency of requiring only a single film frame rather than three, as is the case in the black-and-white (digitized) multiband photography."[4] However, in still other work by Hoffer (1972) and Coggeshall and Hoffer (1973) with digitized aircraft photography, there was difficulty in spectrally separating and identifying individual crop types.

Based on the conflicting research efforts, the question arose as to the degree of spectral differentiation possible between crop types and other cover types using digitized color infrared high-altitude photography versus aircraft multispectral scanner data. A study by Coggeshall *et al.* (1974) found that crop types are particularly difficult to separate from forest cover using digitized photography, whereas good separation was obtained with aircraft multispectral scanner data.[5] Such comparisons relied on aircraft multispectral scanners which obtained high spectral resolution data (often 12 channels) at relatively high spatial resolution due to the low flying altitudes. Also, these studies usually involved only a single date of imagery.

With the realization of the Landsat multispectral scanning systems (MSS), a logical question was whether the increased atmospheric column and reduced spectral and spatial resolution would still provide digital crop classification superior to analysis of digitized high-altitude photography. Awareness of improvements in image processing of photographic data suggested that its potential for providing accurate results was by no means documented, especially since multiple date analyses incorporating the important temporal (phenological) dimension had not been performed. To investigate these questions, a comparative experiment was conducted for an 140 km^2 study area in Kern County, California to evaluate the multidate crop identification performance of Landsat digital data versus digitized high-altitude (1:120 000) color infrared photography.[6]

Method

Since a paired evaluation was desired, it was necessary to constrain the choice of Landsat digital data to only those dates closest in temporal proximity to high-altitude photography available during a growing season. High-altitude U-2 photography was obtained by NASA Ames personnel using an RC-10 camera with a 6 in. (153.2 mm) lens, wratten 12 and antivignetting filtration (1.4), and Aerochrome Infrared 2443 film. The dates of imagery used in the analyses are shown below.

High-Altitude Photography	Landsat Data
* 27 Nov 73	* 4 Nov 73
* 4 Apr 74	* 15 Apr 74
* 15 Aug 74	* 19 Aug 74
* 6 Dec 74	* 5 Dec 74

Each original color infrared transparency was subjected to a color separation procedure yielding three black-and-white transparencies, each representing one of the photograph's three emulsion layers. The color separated images were digitized by using a scanning microdensitometer at a 50 μm aperture producing 12 channels in computer compatible tape format.[7] These 12 channels were then geometrically rectified by VICAR[8]

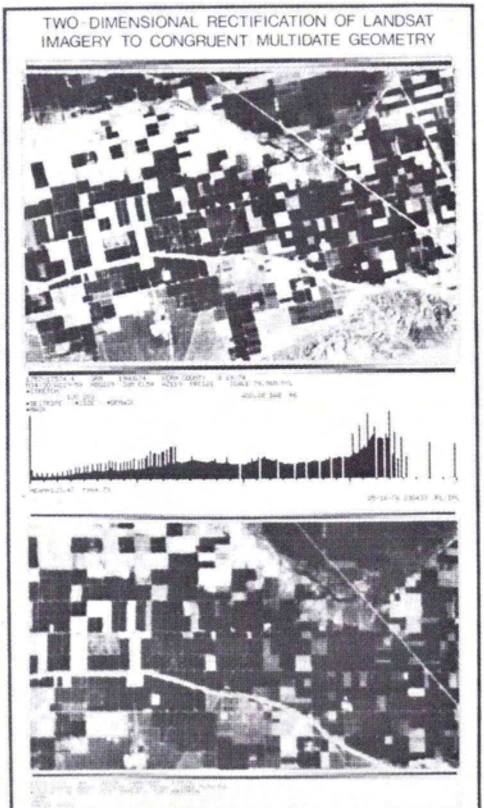


Fig. 1. Top: Original unrectified channel of the 19 Aug 74 LANDSAT image. Bottom: Geometrically rectified channel. Each of the 16 Landsat and 12 high-altitude channels was rectified to similar two-dimensional geometry.

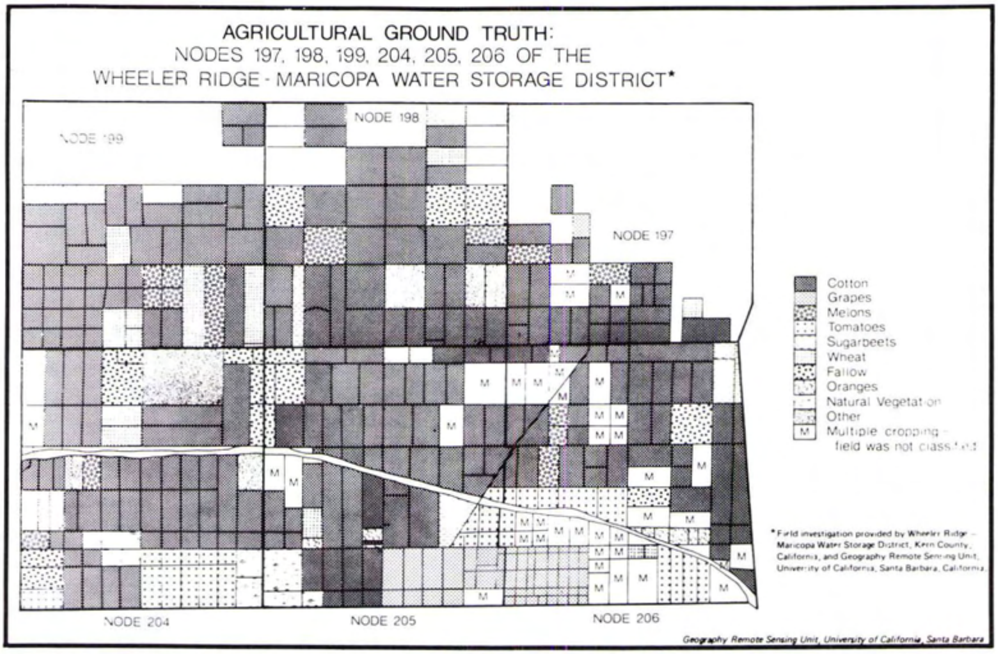


FIG. 2. Agricultural ground truth was provided by the Wheeler Ridge-Maricopa Water Storage District. These data in conjunction with acreage tabulations were used to assess digital classification accuracies. Nodes 197, 205, and 206 comprised the primary test region while nodes 198, 199, and 204 represented the secondary test region furthest away from the training fields.

software using map tie points. The 16 Landsat channels were then rectified to the high-altitude data set. In this manner, the entire 28 channel data set was brought into multiple date geometric congruency (Figure 1). Additional preprocessing such as contrast stretching, histogram equalization, and special antivignetting filtering was applied to certain channels.

The Wheeler Ridge-Maricopa Water Storage District and Kern County Water Agency provided ground truth information for the training and test areas (Figure 2). These included crop type and acreage statistics for each field within individual polygons (each 9 mi^2) of a regional hydrologic model used by the Kern County Water Agency and to which many agencies supply spatially accurate data. A ± 5 percent error in the ground truth statistics was assumed (Estes *et al.*, 1977).

The test area was divided into primary and secondary regions which were, respectively, adjacent to and distant from the training region. Training field selection was based on manual stratification of the Wheeler Ridge area into homogeneous regions. The majority of training fields was chosen from one essentially homogeneous area lying east and south of the test regions, in order to compare signature extension performances. Because all channels were in common register, it was necessary to select training fields only once for the entire 28 channel data set (Figure 3). Training class separability statistics were used to identify optimum combinations of Landsat or high-altitude channels taken 1, 2, 3, and 4 at a time for the 16 and 12 channel data sets respectively. These optimum channels were then used as input data for the VICAR per field and per pixel maximum likelihood classification algorithms.[9]

RESULTS

The high-altitude per field crop identification accuracy was poor in the primary test area (Figure 4) and deteriorated rapidly for fields in the secondary test area. Overall, classification accuracies dropped from 53 to 43 percent (Tables 1 and 2) mainly due to the increased misclassification of cotton as grapes or melons. Comparison of Figures 2 and 4 reveals that this misclassification increased as the classification progressed away from the training area into the secondary test site.

Two potential limitations appear to be associated with the use of a digitized high-altitude photography data base; namely, the

FIG. 3. Several of the training fields scribed onto a single band of Landsat imagery.

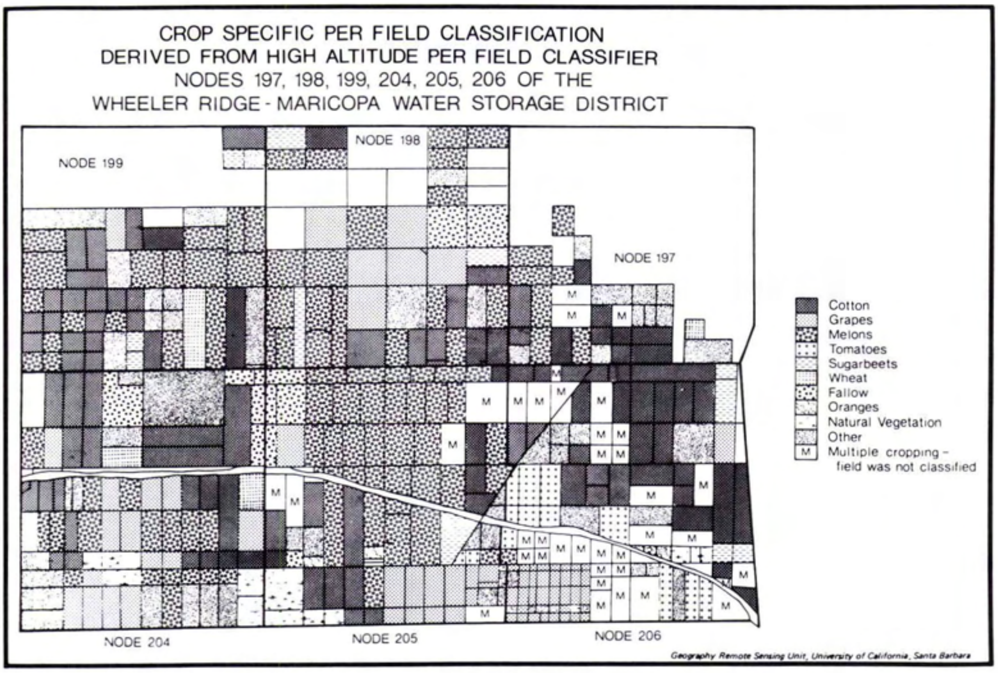


FIG. 4. High-altitude digital crop classification of the 1974 growing season. Comparison of this classification with the ground truth in Figure 2 reveals that cotton is consistently misclassified as melons and grapes as the classification progresses away from the training area.

TABLE 1. DIGITAL ACREAGE WEIGHTED HIGH-ALTITUDE MULTIDATE-MULTIBAND CROP CLASSIFICATION NODES 197, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

	Remote Sensing Classification											
	% Accuracy	Cotton	Grapes	Melons	Tomatoes	Sugar-beets	Wheat	Fallow	Oranges	Natural Vegeta-tion	Other	District Ground Truth Total
Cotton	45	3235	200	2935	145	80		40			595	7230
Grapes	87		1010							10	140	1160
Melons	24			80	100						160	340
Tomatoes	53			72	372						260	704
Sugar-beets	89			35		295						330
Wheat	26						40				115	155
Fallow	52							260			240	500
Oranges	46								90		105	195
Natural Vegeta-tion	100									280		280
Other	69			80		80	15	120			650	945
Total	53	3235	1210	3202	617	455	55	420	90	290	2265	11839

existence of vignetting (if any), and directional reflectance effects. An assumption often made in quantitative analyses of aerial photography is that illumination is uniform across the entire photograph (i.e., no vignetting or other lens distortions cause uneven illumination on the film plane). It is possible to acquire high-altitude photography without vignetting. However, even metric cameras such as the RC-10 equipped with anti-vignetting filtration occasionally produce vignetting.[10] Also, the risk of vignetting increases when multiple date overflights are required since near identical principle points centered on the study area are difficult to obtain. If vignetting is present, this may result in two agronomically identical fields of cotton, for example, having different density values if one field is located near the principle point of the photograph and the other near the edge.

Vignetting was present in the color infrared photography data set despite precautionary measures. Frankly, the authors believe it would be a rare occurrence to obtain a four-date data set without any vignetting. If the data are transformed into a digital format as described in this paper, mathematical functions can be applied to correct for some of the vignetting effects. To this end, certain channels were preprocessed prior to classification.[11] However, even after filtering techniques were applied, obvious changes in density indicative of vignetting were still present on certain channels of the high-altitude photography (Figure 5a), reducing overall classification accuracy.

An inherent, fundamental limitation when using a photographic data base are the directional reflectance effects. A Landsat image covers about ±5.78° whereas the camera's 6 in. focal length, 9 in. format image sweeps approximately ±37° from the nominal vertical. The spectral properties of a highly textured surface such as vegetation may change significantly over such angles, again creating signature extension problems within the photographic data set. The Landsat image does not encounter such difficulties because of its near orthogonal field of view (Colvocoresses, 1976).

The Landsat classification accuracy actually increased from 78 to 86 percent as it progressed from the primary to the secondary test site (compare Tables 3 and 4).[12] Comparison

TABLE 2. DIGITAL ACREAGE WEIGHTED HIGH-ALTITUDE MULTIDATE-MULTIBAND CROP CLASSIFICATION NODES 198, 199, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

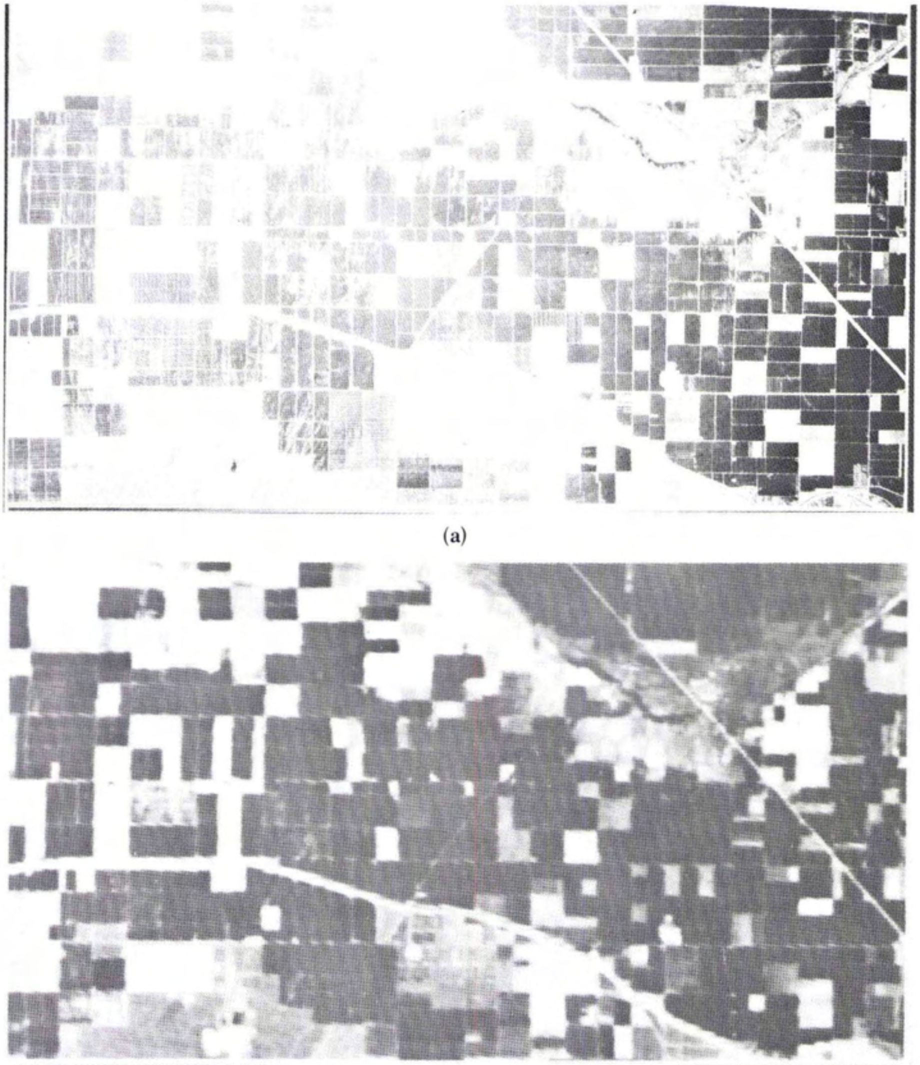
		Remote Sensing Classification										
	% Accuracy	Cotton	Grapes	Melons	Tomatoes	Sugar-beets	Wheat	Fallow	Oranges	Natural Vegeta-tion	Other	District Ground Truth Total
Cotton	38	3325	2050	3260		40					120	8795
Grapes	0										15	15
Melons	56			380		80					220	680
Tomatoes	0			240							440	680
Sugar-beets	40			360		240						600
Wheat	13					80	80				470	630
Fallow	100							600				600
Oranges	0										45	45
Natural Vegeta-tion	100									320		320
Other	78		140	80							780	1000
Total	43	3325	2190	4320	0	440	80	600	0	320	2090	13365

of both per field (Figure 6) and per pixel classification maps (Plate 1) with the agricultural ground truth verifies that the Landsat classification did not experience serious signature extension problems. Note that cotton, the single most important crop in the region, is consistently classified correctly throughout the two test sites.

This increased classification accuracy is believed to be due to the nature of Landsat's multispectral scanning system. The Landsat scanner is an object plane scanner wherein scanning is performed before the optical elements of the system. Each pixel is treated identically by the optics. Therefore, it is fundamentally impossible for a Landsat image to have vignetting effects. With no vignetting present and a small 5.78° field-of-view resulting in limited directional reflection effects, it seems logical that Landsat should provide a more suitable data set for crop identification. For example, comparison of high-altitude and Landsat channels in similar wavelength regions (Figure 5a and 5b) demonstrates that the signature of cotton remains relatively constant across the scene in the Landsat image while there are significant changes in density due to vignetting and/or directional reflection effects in the high-altitude image. An analysis of per field statistics for selected training and test fields of both the high-altitude and Landsat data sets substantiated this assumption. Histograms for cotton, melons, and grapes showed that the spectral characteristics of these categories were barely separable in the primary test region for the photographic data set. In the secondary test region, there was no spectral difference between the categories, their histograms being superimposed. In contrast, similar histograms of the same fields in the Landsat data set showed that a distinct separation could be obtained in both the primary and secondary test sites.

SUMMARY

This research evaluated the effectiveness of using digitized high-altitude photography and Landsat digital data for multidate crop identification. Because the goal was of a compartive nature, only those dates of Landsat data close to the high-altitude photography were used. In the authors' opinion, more optimally selected Landsat dates would have further improved classification performance. Crop classification using digital



(a)

(b)

FIG. 5. (a): Green band of the 15 Aug 74 high-altitude dataset representing wavelengths from 0.5-0.6 μm. (b): Band 4 (0.5-0.6 μm) of the 19 Aug 74 Landsat image. Vignetting present in the high-altitude photography caused signature extension problems as the crop classification progressed from the southeast to northwest.

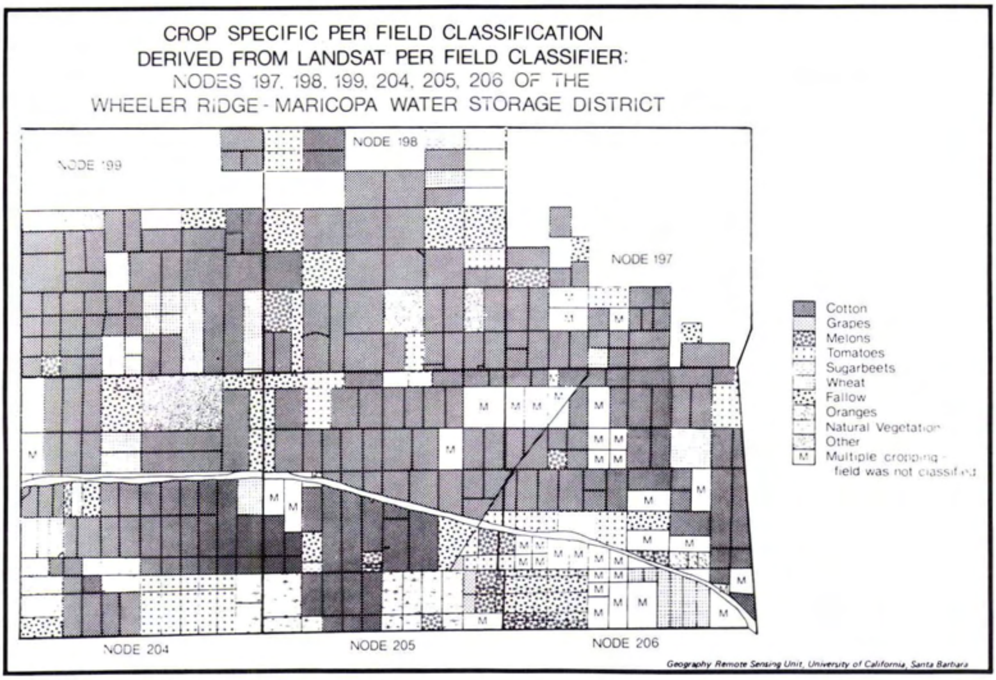


FIG. 6. Per field Landsat digital crop classification of the 1974 growing season in the Wheeler Ridge-Maricopa Water Storage District, Kern County, California.

TABLE 3. DIGITAL ACREAGE WEIGHTED LANDSAT MULTIDATE-MULTIBAND CROP CLASSIFICATION NODES 197, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

		Remote Sensing Classification										District Ground Truth
	% Accuracy	Cotton	Grapes	Melons	Tomatoes	Sugar-beets	Wheat	Fallow	Oranges	Natural Vegeta-tion	Other	Total
Cotton	97	7020		10	180		20					7230
Grapes	5		55	190				445		470		1160
Melons	35	140		120	80							340
Tomatoes	48		24	75	330	90	185					704
Sugar-beets	11	60			80	35		155				330
Wheat	42						65	90				155
Fallow	76	40						380	80			500
Oranges	51			65		30			100			195
Natural Vegeta-tion	100									280		280
Other	90	80						12			853	945
Total	78	7340	79	460	670	155	270	1082	180	750	853	11839

TABLE 4. DIGITAL ACREAGE WEIGHTED LANDSAT MULTIDATE-MULTIBAND CROP CLASSIFICATION NODES 198, 199, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

	Remote Sensing Classification											District Ground Truth
	% Accuracy	Cotton	Grapes	Melons	Tomatoes	Sugar-beets	Wheat	Fallow	Oranges	Natural Vegeta-tion	Other	Total
Cotton	97	8495		140	80			80				8795
Grapes	0			15								15
Melons	0	160			80		220	220				680
Tomatoes	88				600			80				680
Sugar-beets	27				160	160	180	100				600
Wheat	100						630					630
Fallow	100							600				600
Oranges	0										45	45
Natural Vegeta-tion	100									320		320
Other	70	80					60	160			700	1000
Total	86	8735	0	155	920	160	1090	1240	0	320	745	13365

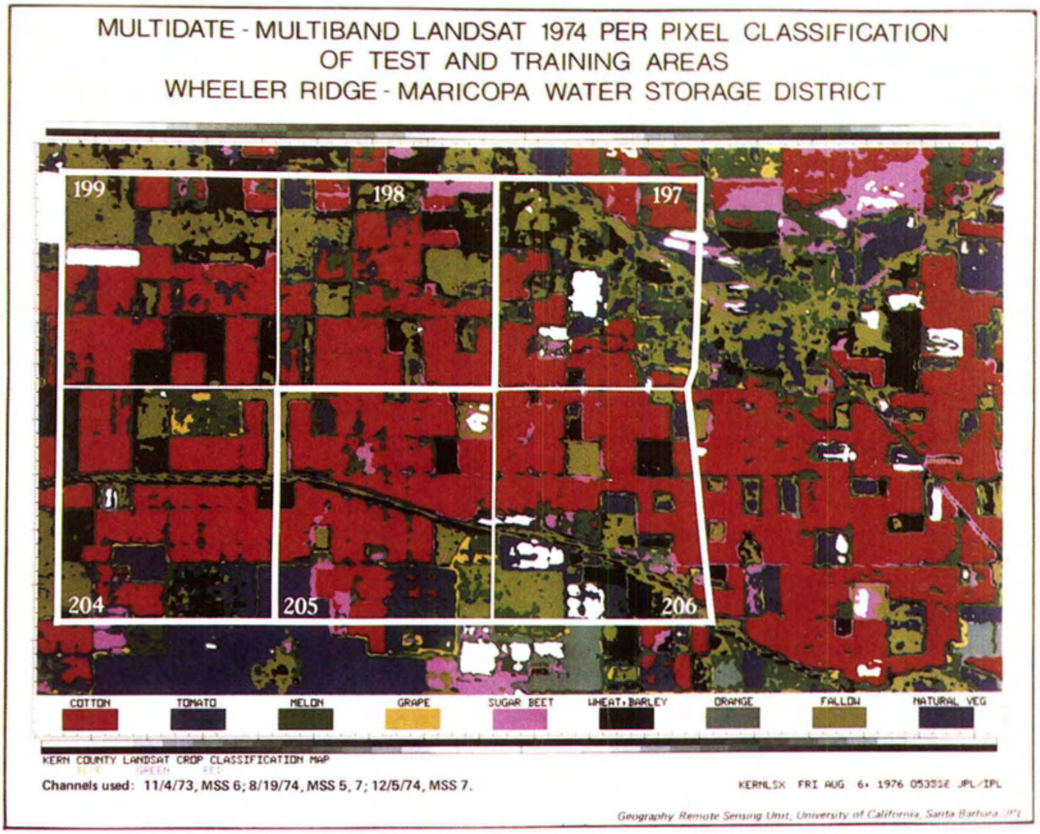


PLATE 1. Landsat per pixel classification map of the training and test (197, 198, 199, 204, 205, 206) areas in the Wheeler Ridge-Maricopa Water Storage Districts in Kern County California.

Landsat data, nevertheless, proved superior to analysis of digitized high-altitude photography. This is primarily attributed to signature extension problems associated with vignetting present in the high-altitude photography. Consequently, if high-altitude photography is considered for digital multidate crop identification, any image with serious vignetting should be carefully preprocessed or deleted from the study. A more logical alternative is to use a satellite system such as Landsat to provide data in a digital format already conducive to multidate crop identification.

Footnotes

[1] The TERSSE study conducted by General Electric for the National Aeronautics and Space Administration identified crop identification and yield estimation as high priority research areas for the 1980-2000 time frame. The National Academy of Sciences came to similar conclusions concerning the need for crop acreage and yield estimation statistics for the developing world.

[2] The National Aeronautics and Space Administration (NASA), the U.S. Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration (NOAA) are currently engaged in a major study to determine the degree of accuracy in crop identification, acreage, and yield prediction that can be achieved by Landsat remote sensing. LACIE began by monitoring wheat plantings, yields, and crop conditions in the Great Plains area, checked against ground truth and conventional data collection carried out by USDA personnel. If the results are satisfactory in the United States, the experiment will continue in respect to wheat in other countries and then may be extended to other major crops such as rice and soybeans.

[3] The recognition accuracy was very high for soils, salt flats, and water, but individual crops were difficult to recognize. Barley was most easily recognized (75 percent test accuracy) with sugar beets and alfalfa seriously cross-classified.

[4] The classification accuracies for corn, soybeans, pasture, and trees were consistently over 90 percent, except for a single 85 percent classification of soybeans using the digitized multiemulsion color infrared photography. Overall correct classification for digitized 70 mm multiband black-and-white photography was 95.5 percent.

[5] Results for six classes (deciduous, conifer, water, forage, corn, and soybean) were 47.5 percent correct identification for the digitized color infrared photography as compared to 80.5 percent for the corresponding three channels of multispectral scanner data produced by the 12 channel Environmental Research Institute of Michigan (ERIM) aircraft system.

[6] Preliminary results of this research were reported in *Comparison of Photointerpretation and Machine-Assisted Interpretation of Digital Scanner Imagery*, NASA, Task No. 177-11-51, July, 1977.

[7] The filters used in the color separation process corresponded as close as possible to the sensitometric characteristics of the three color emulsion layers; however, precise spectral interpretation of the density characteristics was not attempted. The image processing was done at the California Institute of Technology Image Processing Laboratory, Jet Propulsion Laboratory.

[8] VICARS is an acronym for Video Communication and Retrieval System developed at JPL.

[9] This algorithm is based upon an equally weighted maximum likelihood decision rule which treats each pixel independently and assigns a pixel having pattern measurements or features (d) to that category (c) whose samples are most probable to have given rise to pattern or feature vector (d), that is, such that the conditional probability of (c) given (d), P (c/d), is highest. Normal or "gaussain" distributions are assumed to exist.

[10] Personal communication with Bob Ekstrand, NASA Ames Research Center U-2 Photography Unit, Mountain View, California.

[11] Photographs exhibiting vignetting were processed using "Stretch", a VICAR program which changes the pixel by pixel intensity of an image by generating a transfer function on the domain of intensity values. There were seven types of transfer functions available with the most successful being the cube root function for the Kern County data set. Cube root caused the input data to be evaluated by a modified cube root function such that if input = 0, then output = 0, and if input = 255, output = 255. The actual function is output = ((input/255)**33)*255.

[12] Actually, the results in both the primary and secondary test areas would be very similar if not for numerous small grape fields in the primary test regions which were smaller than the spatial resolution of Landsat.

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