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16. Abstract

Differences among the responses of the six individual sensors per channel were studied for water in the 5/27/73 scene. In band 6 every sensor was statistically different from the others; band 5, with only one sensor different, had the best uniformity among sensors. The Kubelka-Munk model, a regression model, and a combination of these models were used to extract plant, soil, and shadow reflectance components of vegetated surfaces. The combination model was superior to the others; it explained 86% of the variation in band 5 reflectance of corn and sorghum, and 90% of the variation in band 6 reflectance of cotton. A fractional shadow term substantially increased the proportion of the digital count sum of squares explained when plant parameters alone explained 85% or less of the variation. Overall recognition of 94 agricultural fields using simultaneously acquired aircraft and spacecraft MSS data was 61.8 and 62.8%, respectively; recognition of vegetable fields larger than 10 acres and taller than 25 cm, rose to 88.9 and 100% for aircraft and spacecraft, respectively. Agriculture and rangeland, were well discriminated for the entire county but level II categories vegetables, citrus, and idle cropland, except for citrus, were not.

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43

CONTENTS

Page

TYPE II REPORT

Contents

INTRODUCTION

The work planned under this contract had three stated objectives:

1. To compare experimental results using ERTS-1 data with predictions of analytical models for interaction of light with vegetation.

2. To determine the seasonal changes of the various crops and soils in Hidalgo County, Texas and discriminate them by means of reflectance measured from ERTS-1.

3. To gain experience developing an operational system of satellite data analysis tailored to the needs of the U.S. Department of Agriculture.

The objectives can be logically grouped into substudies in the following categories:

1. Crop vigor and potential crop yield

    a. Relation to leaf area index (LAI) and to MSS signal strength

    b. Iron deficiency detection

    c. Crop vigor categories within crops and their relation to yield.

2. Crop discrimination

    a. Cotton versus sorghum

    b. Among vegetables

    c. Optimum time of year to discriminate citrus

    d. Dominant rangeland plants

    e. Rangeland condition

3. Soil

    a. Bare versus cropped land

    b. Major soil types

    c. Spectral contrast between freshly irrigated and nonirrigated soil

    d. Spectrum of saline soil and distribution of salt-affected soil.

The crop vigor and potential crop yield studies are based on laboratory and aircraft experience that resulted in an understanding of the interaction of light with vegetation and the subsequent definition of most useful wavelengths for indicating physiological stress and for discriminating among crop genera. Analytical models were also produced relating reflectance to crop vigor and leaf area index.

The second and third groups of studies are based on computer identification procedures. Procedures developed using film optical densities and aircraft scanner data are being refined and applied to ERTS-1 data.

GROUND DATA COLLECTION

Hidalgo County, Texas has been chosen as the base area from which data are collected and analyzed. The complete county was chosen as the base unit because this is the governmental unit by which agricultural census data are collected and summarized, and is the unit by which crop allotment and acreage restrictions are most commonly administered.

Because of the need for extensive ground truth representative of the county to use as a basis for comparing the reliability and accuracy of the ERTS-1 data interpretations, statisticians of the Statistical Reporting Service, USDA, were asked to design a sound sampling procedure for the county that would allow a valid summary of data for the county from the sample. Hidalgo County contains three major agricultural areas which may be designated as Northern, Central, and Southern. The Northern region is mainly pasture and rangeland with a little irrigated farming located around local water supplies. The Central region is practically all under irrigation. The cultivated land is generally broken into small fields, of typically medium-textured terrace soils devoted to mixed field and vegetable row-crops, citrus, and miscellaneous farm enterprises. The Southern region of Hidalgo County is generally fine-textured soil that is used extensively for winter vegetable production. The majority of land in the Southern region is irrigated. Urban and other non-agricultural areas are found mainly in the Central region. The urban areas are not included in the survey.

The sampling procedure used was to divide the county into approximately 160-acre segments and assign each segment a number. By the random start and increment method, four interpenetrating samples of 43 segments each were selected. These were distributed through all three regions. Four more interpenetrating samples were selected, but only the segments located in the Southern region were designated sampling sites. These 25 additional segments in the Southern region were chosen because of the concentration of winter vegetables in the Southern region when few crops are growing in the other regions. A total of 197 sampling segments was chosen from the 3,927 segments listed for the county. The sampling area is thus approximately 4% of the total area.

Each of the 197 segments was located on a base aerial map of the county and assigned a unique number designation. Each field in each segment is being ground-truthed and each is numbered. Fields are, by definition, plots of land devoted to the same crop or use. The number of fields fluctuates slightly. The total number of fields being ground-truthed each satellite pass is approximately 1,400.

After each sample segment has been visited, the field information is coded by the technician in charge of ground-truthing and recorded on 80-column computer punch cards. The data on the computer cards are later edited and stored on magnetic tape for use in the analysis of the satellite data. A print-out of these tapes is given to the ground truth personnel. The magnetic tapes and computer cards are stored in separate buildings to minimize the chances of data loss.

Considerable information of agricultural importance can be extracted from these ground truth data; however, the main reason for collecting such a complete set of records is their use as an independent data set to judge the reliability and accuracy of the county-wide interpretation of ERTS-1 data. Such data also provide the training fields used in computerized recognition algorithms. The various steps in processing computer compatible (CCT) ERTS-1 tapes at Weslaco are described in Appendix C of the Type II report for the period December 19, 1972, to June 19, 1973.

RESULTS

MSS Individual Sensor Response Variability

A phenomenon called "banding" is observed in some Earth Technology Satellite One (ERTS-1) Multispectral Scanner (MSS) imagery if one or more of the six sensors within a specific channel yields a signal sufficiently higher or lower, on the average, than the other sensors in that channel. The consequence is "bands" at regular intervals in the imagery. So the question arises; do the six sensors within each channel really respond alike?

The MSS of the ERTS-1 uses six sensors per channel to measure reflected radiance from scenes on the earth in each of four channels. These four channels (six sensors per channel) are sensitive over the wavelength intervals (WLI) 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, and 0.8 to 1.1 µm. Since the MSS of the ERTS-1 senses the earth at a six scan line per sweep rate, each individual sensor forms a separate image scan line.

A uniform earth target, the Gulf of Mexico (May 27, 1973), was selected as the MSS data source for a statistical experiment that was designed to test the null hypothesis (H_o) of no difference among the six sensors within each channel using a simple randomized block analysis of variance (ANOV). The experiment was replicated seven times (six sensors x four channels equals 24 total sensors per sweep (replication) of the ERTS-1 MSS with 25 pixels sampled per sweep). The 25 pixels per sweep were averaged within each sensor, channel, and replication to obtain the basic data for the experiment (Table 1).

The ANOV was run separately for each channel to avoid unwanted interaction from natural differences among the four ERTS-1 channels (Table 2). The F-Test among sensors was highly significant (at the 0.01 probability level) for all four channels. The replications were not significant in any of the four channels (at the 0.01 probability level); as was expected, since the uniform Gulf of Mexico water should cause a uniform response for each replication. Channels 4 and 5 had considerably lower Found F's than did channel 6 or 7, which may indicate that the calibration and/or the digitizing process for channels 6 and 7 are more critical than for channels 4 or 5.

A Duncan's multiple range test was used to statistically rank the six sensor means within each ERTS-1 MSS channel (Table 3). Within ERTS-1 channel 4, sensor 5 has a significantly different mean than all other sensor means in that channel. Possibly this sensor is responsible for the "banding effect" for channel 4. Similarly, since sensor 5 in channel 5 (a different detector than sensor 5 of channel 4) is significantly different from all other sensors in that channel, it is possibly responsible for the "banding effect" in channel 5. Sensor 1 in channel 6 and sensors 1 and 6 in channel 7 may also cause "banding effects."

The six sensors of channel 5 exhibited the least statistical variability indicating that channel 5 may be better than the other channels on the basis of uniform response among sensors. On that basis, channel 6 appears to be the worst channel, because every mean is statistically different from every other sensor mean.

The implications of this finding impact heavily on the results obtained in applying the data for discriminating among crops and differentiating among soils and soil conditions. It is evident that the non-uniformity in response of the six sensors per channel introduces variability in the spectral signature among individual pixels in the data. Consequently, the spectral differences have to be larger between any two categories to distinguish between them than if the sensor responses were the same. Subtle differences such as between soil types become indistinguishable.

All the MSS data from a scene could be preprocessed, as the Canadians are doing to establish the mean for the whole scene for each sensor. Then the response of each sensor can be adjusted on a pixel by pixel basis to the mean response of all sensors or to one sensor in the mid-range of responses encountered. This procedure should improve overall recognition accuracy some, perhaps up to 10%. The disadvantage is that it adds a preprocessing step to the analysis procedures. If adjustments are incorrectly made, the data could be degraded rather than improved.

TABLE 1 TEST PLOT DATA FROM A PORTION OF THE GULF OF MEXICO FOR ERTS-1 OVERPASS ON MAY 27,1973 (SCENE ID 1308-16323). THE TEST PLOT WAS REPLICATED (MSS SWEEPS) SEVEN TIMES FOR EACH MSS SENSOR AND CHANNEL.

ERTS-1 MSS CHANNELS	ERTS-1 MSS SENSORS	REPLICATION (MSS SWEEPS) 1	2	3	4	5	6	7
4	1	36.0	36.9	35.8	36.3	36.1	36.8	37.0
	2	36.0	36.8	35.9	36.3	36.1	36.9	36.0
	3	36.1	36.0	35.0	35.8	36.2	36.1	35.9
	4	35.6	35.4	35.7	35.6	35.7	35.7	35.7
	5	34.9	34.6	34.8	34.6	34.8	34.6	35.0
	6	35.3	36.0	36.2	35.9	36.0	36.2	36.1
5	1	24.8	24.9	24.8	24.9	25.0	25.0	25.0
	2	25.3	24.5	25.4	25.6	24.8	24.7	24.9
	3	25.0	25.0	25.0	25.0	25.3	25.1	25.0
	4	25.0	24.5	24.5	24.7	24.8	24.5	24.6
	5	26.3	26.3	26.1	25.3	25.8	25.4	25.5
	6	24.3	24.2	24.4	24.2	24.2	25.5	25.5
6	1	15.7	15.5	15.8	16.1	16.3	16.4	16.6
	2	17.0	17.3	17.3	17.3	17.4	17.4	17.4
	3	18.2	18.0	18.0	18.5	18.3	18.0	18.3
	4	15.9	17.1	16.8	17.5	17.8	16.8	17.0
	5	18.3	18.1	18.2	18.1	18.4	18.3	18.3
	6	18.8	18.6	19.0	18.7	18.8	18.7	18.9
7	1	5.4	5.4	5.2	5.4	5.5	5.5	5.3
	2	6.0	6.0	6.0	6.0	6.0	6.0	5.9
	3	5.7	5.6	5.6	5.4	5.7	5.7	5.6
	4	5.9	6.0	6.0	6.0	6.1	6.0	6.2
	5	5.9	6.1	6.0	6.0	5.9	6.0	6.0
	6	5.5	5.4	5.5	5.5	5.3	5.4	5.5

TABLE 2 TEST OF THE NULL HYPOTHESIS OF NO SIGNIFICANT DIFFERENCE AMONG SENSOR MEANS USING VARIANCE ANAYLSIS. TEST PLOT IS FROM A PORTION OF GULF OF MEXICO FOR ERTS-1 OVERPASS ON MAY 27, 1973 (SCENE ID 1308-16323). THE PLOT WAS REPLICATED 7 TIMES AND A TEST MADE FOR EACH OF THE FOUR ERTS MSS CHANNELS.

EXPERIMENTAL SOURCE OF VARIATION	DEGREES OF FREEDOM	ERTS-1 CHANNEL 4 FOUND F	ERTS-1 CHANNEL 5 FOUND F	ERTS-1 CHANNEL 6 FOUND F	ERTS-1 CHANNEL 7 FOUND F
SENSOR(S)	5	20.1**	9.1**	88.7**	93.1**
REPLICATION(R)	6	1.4	0.3	2.7	0.3
ERROR(SXR)	30	-	-	-	-
TOTAL	41	-	-	-	-

** STATISTICALLY SIGNIFICANT AT THE 0.01 PROBABILITY LEVEL.

TABLE 3 COMPARISION AMONG SENSOR MEANS USING DUNCAN'S MULTIPLE-RANGE TEST. MEANS ARE FROM A TEST PLOT TAKEN FROM A PORTION OF THE GULF OF MEXICO ON THE MAY 27, 1973 ERTS-1 OVERPASS. THE TEST CONTAINED SEVEN REPLICATES AND ANALYSIS OF VARIANCE TEST HYPOTHESIS OF NO DIFFERENCE AMONG SENSOR MEANS (FOR THE 4 ERTS-1 MSS CHANNELS) WAS SIGNIFICANT AT THE 0.01 PROBABILITY LEVEL.

ERTS CHANNEL 4			ERTS CHANNEL 5			ERTS CHANNEL 6			ERTS CHANNEL 7		
SENSOR NUMBER	SENSOR MEAN	TEST	SENSOR NUMBER	SENSOR MEAN	TEST	SENSOR NUMBER	SENSOR MEAN	TEST	SENSOR NUMBER	SENSOR MEAN	TEST
1	36.4	A	5*	25.8	A	6	18.8	A	4	6.0	A
2	36.3	A	3	25.1	B	5	18.2	B	5	5.9	A
3	35.9	B	2	25.0	B	3	18.2	B	2	5.9	A
6	35.8	B	1	24.9	B	2	17.3	C	3	5.6	B
4	35.6	B	4	24.7	B	4	16.9	D	6	5.4	C
5*	34.7	C	6	24.6	B	1*	16.0	E	1	5.4	C

* THESE SENSORS PROBABLY CAUSE THE "BANDING" EFFECTS SEEN IN ERTS-1 MSS IMAGERY.

Plant Canopy Models

Multispectral scanner (MSS) data from Earth Resource Technology Satellite One (ERTS-1) and the measured geometry of sun and plant canopies were used to extract plant, soil, and shadow reflectance components of vegetated surfaces using three plant canopy models (Kubelka-Munk (KM), a regression model, and a combination of the Kubelka-Munk and regression models[a/]).

The ERTS-1 MSS data used were the average digital data for 3 corn, 10 grain sorghum, and 10 cotton fields in the scene of the May 27, 1973, satellite overpass. Ground truth, consisting of fractional crop cover, fractional shadow cover (determined from sun elevation, sun azimuth, row azimuth, plant height, and row width), and leaf area index (LAI - ratio of total leaf area of plants to ground area occupied by plants), were also obtained at the time of the satellite overpass.

In the reflective infrared portion of the spectrum (bands 6 and 7), the Kubelka-Munk (K-M) model yielded high reflectance values for the mature corn and sorghum and low values for the immature cotton that had low LAI and ground cover. The K-M theory explained up to 84% of the variation in the band 6 and 7 composite reflectance of cotton.

The regression model did not express crop and soil reflectances well; it explained up to 69% of the variation in the observed reflectance in the visible (band 5) for corn and sorghum, but a maximum of only 56% in the reflective infrared (band 6) for cotton.

Combination of the Kubelka-Munk and regression models integrated the best features of each model. The combined model yielded a higher correlation, in general, between the composite canopy reflectance and ground truth than the first two models. It explained 86% of the variation in the visible light reflectance (band 5) of corn and sorghum and 90% of the variation in reflective infrared (band 6) for cotton. The infinite plant canopy and soil reflectances determined from the combined model were reasonable for both the corn and sorghum, and the cotton data. Shadow reflectance values were more reasonable for cotton that was young and had exposed interrow soil than for corn and sorghum. Corn and sorghum averaged 72% ground cover with leaves touching between rows making the contribution of shadows to the reflectance more difficult to estimate for these two crops than for cotton that averaged only 30% ground cover.

[a/] These models are developed in more detail in a manuscript in preparation.

Shadow Contribution to MSS Digital Counts

In addition to the plant parameters leaf area index (LAI), plant population, plant cover, and plant height, the shadows cast by plants should influence the MSS digital counts. A model has been developed that uses sun azimuth and elevation, row direction (angle), and plant height to estimate the amount of interrow area viewed by the sensor that would be shaded by row crop plants.

Fractional shadow is defined in terms of plant and sun geometry by

$$fs = \frac{PH \cdot SIN/\theta-\phi/}{RW \cdot TAN\ (\alpha)}$$

wherein PH is plant height, θ is sun azimuth east of true north, ϕ is row azimuth east of true north, RW is row spacing, and α is sun altitude above the local horizon. A detailed derivation is given in a manuscript in preparation.

Multiple regression equations have been developed relating the MSS digital counts (DC) for the May 27, 1973 (scene ID 1308-16323) overpass to LAI, plant population (POP), plant cover (PC), plant height (PH), and shadow (S). The proportion of the MSS DC sum of squares explained by the plant parameters alone and by the plant parameters plus the shadow term are as follows:

Crop	Band	Plant parameters alone	Plant parameters plus shadow	Plant parameters, except LAI, plus shadow	Plant parameters, except POP, plus shadow
Cotton	4	0.899	0.952	0.818	0.935
	5	.853	.854	.754	.805
	6	.934	.951	.922	.942
	7	.959	.962	.949	.893
Sorghum and Corn	4	.590	.795	.731	.762
	5	.653	.804	.826	.799
	6	.873	.890	.780	.828
	7	.782	.921	.753	.912

The R^2 values show that when plant parameters alone explained a low proportion of the variation, addition of a shadow term resulted in a very substantial improvement in the R^2 values.

When the LAI term was deleted, and the shadow term retained with the other 3 plant parameters (third column of R^2 values from left), less of the variation in DC for cotton was explained than by the plant parameters alone. For corn and sorghum, the R^2 were larger in the visible (bands 4 and 5) when a shadow term was added and LAI was deleted, but were lower in the infrared (bands 6 and 7). Thus the shadow term helps most to explain the visible band response of corn and sorghum.

When the plant parameters, except POP, plus the shadow parameter were used to predict the DC (fourth column of R^2 values), the R^2 values were higher in 6 of 8 instances than when LAI was the deleted plant parameter. Plant population did account for more of the variation in the digital counts than LAI in band 7 for cotton and band 5 for corn and sorghum.

Since the simple correlation between LAI and POP for corn and sorghum was highly significant (r = 0.829), it was hoped that the time consuming task of LAI determination could be replaced with the population information that is easier to acquire. Although not as powerful as LAI in explaining ERTS MSS responses, plant population is a useful parameter and one that will undoubtedly have to be relied on in practice.

Acreage Estimate for 16 Vegetables

Ground surveys have been made from the fall of 1972 through the spring of 1974 on approximately 1400 fields in Hidalgo County, Texas, to obtain ground truth identity of individual training and test fields, and to obtain acreage estimates to compare the computer classifications on a county-wide basis with. The replicated sample permitted calculation of county acreage estimates and standard errors of the mean for 16 vegetable crops.

Acreage estimates not previously available are listed in Table 4 for 7 crops (bean, beet, mustard greens, turnip, parsley, southern peas, and squash) along with comparative acreages for 9 others (broccoli, cabbage, carrot, cantaloupe, cucumber, lettuce, onion, green pepper, and tomato) that are estimated by the Texas Crop and Livestock Reporting Service (TCLRS). The ground survey consistently overestimated the acreage of onion and tomato compared with the TCLRS estimates, and the ground survey inadequately sampled the melon and potato areas of the northern and western part of the county; however, it appears to yield representative estimates for about 15 vegetable crops.

By studying the dates on which the maximum acreages of the crops occurred, it was determined that a ground survey in April for the warm season crops, and one in December for the fall planted crops would represent the annual land uses satisfactorily, with minor exceptions.

On the visits to the fields of the ground survey, observations were also made of plant height, percent ground cover and phenological stage of crop development. These data provide the necessary information for developing crop calendars for the vegetable and field crops of the county.

Table 4. Comparison of Texas Crops and Livestock Reporting Service (TCLRS) and ARS ground survey estimates of vegetable acreages in Hidalgo County in 1972 and 1973, and ground survey estimates of spring planted vegetables in 1974.

CROP	1972 (Spring & Fall) TCLRS estimates	1972 (Fall, only) Ground survey	1973 Spring & Fall TCLRS estimates	1973 Spring & Fall Ground survey	1974 (Spring, only) Ground survey
	(Acres)	(Acres$\pm s_{\bar{x}}$)	(Acres)	(Acres$\pm s_{\bar{x}}$)	(Acres$\pm s_{\bar{x}}$)
Bean	--	2401±1589	--	1706±792	445±445
Beet	--	1399±791	--	945±570	Fall planted
Broccoli	1600	2555±1100	1100	1091±763	" "
Cabbage	9300	9698±2387	10700	13768±3513	" "
Carrot	11800	10546±3112	11200	10890±2260	" "
Cantaloupe	5400	796±796	5400	4581±1438	7645±1333
Cucumber	2800	992±651	2300	4346±3514	429±429
Lettuce	2300	3916±1425	1900	3145±1538	Fall planted
Mustard Greens	--	1864±862	--	540±399	" "
Turnip	--	1348±857	--	840±533	" "
Onion	10200	17667±3535	10600	13540±3422	" "
Parsley	--	187±187	--	861±487	" "
Peas	--		--	4869±2203	
Squash	--	441±441	--	706±448	0
Green Pepper	3200	1850±1116	2700	2716±1078	2118±880
Tomato[1]	4200	4756±2354	2400	5025±1500	3178±1015

Simultaneously Acquired Aircraft and ERTS-1 MSS Data Comparison

A paper entitled "Land use classification and ground truth correlations from simultaneously acquired aircraft and ERTS-1 MSS data" was prepared by A. J. Richardson, et al., and presented at the 9th International Remote Sensing of the Environment Symposium. The abstract follows; the full text is presented as Appendix A of this report.

Multispectral scanner (MSS) data simultaneously collected by the NASA 24-channel MSS (flown at 10,000 feet, 3.048 km) and by Earth Resource Technology Satellite (ERTS-1) on January 21, 1973 were used to compare crop recognition results and acreage estimates.

Optimum channel selection programs selected aircraft channels 3, 5, and 8 (0.466-0.495 μm, 0.588-0.643 μm, and 0.770-0.810 μm, respectively) and spacecraft channels 4, 5, and 7 (0.5-0.6 μ, 0.6-0.7 μ, 0.8-1.1 μ, respectively) as the best channels for distinguishing among five training categories: Carrot, cabbage, onion, broccoli, and mixed shrubs. Actual test field recognition results were based on vegetable, rangeland, bare soil, and water categories. Correlations among aircraft, spacecraft, and ground truth (plant cover, maturity, height, and condition) data indicated that aircraft and spacecraft MSS data agreed more closely than either data source agreed with ground truth data. Aircraft MSS data were related slightly better than spacecraft MSS data to ground truth data. On a per field basis, overall recognition performance using data for 94 agricultural test fields, was low for both aircraft and spacecraft data (61.8 and 62.8%, respectively). When classifications were limited to vegetable fields larger than 10 acres and with taller than 25 centimeter plants, recognition results for vegetables improved to 88.9 and 100.0% for aircraft and spacecraft, respectively. Thus, the main difficulty in recognizing vegetable fields was that fields with little vegetative cover and short plants were misclassified as bare soil, the category they most spectrally resembled.

Both spacecraft and aircraft acreage estimates for one aircraft flight line (61.6 square kilometers) and 94 test fields, indicated that spacecraft agricultural surveys are as reliable as aircraft agricultural surveys, although aircraft and spacecraft MSS data acreage estimates did not agree closely with ground truth acreage.

January 21, 1973 Analysis Summary

Extensive analysis has been made of Hidalgo County, Texas, land uses from the ERTS-1 MSS digital data for the January 21, 1973, overpass. The abstract of the report in draft form of those studies follows:

Supervised and unsupervised methods were successfully used to identify and select training categories to be used in automatic land use mapping of agricultural classes in Hidalgo County. Divergence channel selection programs identified ERTS-1 MSS channels 4, 5, and 7 (0.5 to 0.6 nm, 0.6 to 0.7 nm, and 0.8 to 1.1 nm, respectively) as the best three channels for distinguishing among five training categories (vegetable, citrus, mixed shrubs, and two idle cropland types, the McAllen and the Harlingen soil associations).

Recognition accuracies for 1,290 fields, on a per pixel basis, for agriculture (74.6%) and rangeland (74.9%) (level I categories) were higher than the per field results for agriculture (65.9%) and rangeland (60.7%) because recognition errors due to small fields affected the per field results more adversely than the per pixel results. Investigations of the effects of field stratification by size, plant cover, and plant height showed that fields greater than 15 acres in size could be distinguished from each other, and that fields with greater than 25% plant cover and/or plants 30 cm or taller were correctly identified as vegetable fields. When 502 fields meeting these three criteria were classified, the overall level I category recognition results, on a per field basis, improved from 64.5 to 84.3%.

Attempts to further improve recognition results were made by stratifying the county into northern, central, and southern regions. Overall level I category recognition results (83.8%) on a per field basis using regionalized training fields, were not significantly different from the previous results (84.3%) using the general training fields.

The criteria that improved classification results improved the actual (statistical estimate based on ground truthing 4% of the land area of the test county) to computer acreage estimate comparisons for vegetable, citrus, and idle cropland (level II categories). These criteria did not improve agriculture and rangeland comparisons significantly. There was no statistically significant difference (0.01 probability level) in the entire county actual to computer acreage estimate comparisons for agriculture and rangeland categories (486,860 to 454,048 acres and 453,346 to 470,112 acres, respectively). There were significant differences (0.01 probability level) for all level II category actual to computer acreage estimate comparisons, except citrus (89,215 to 80,729 acres).

PROGRAM FOR THE REMAINING CONTRACT PERIOD

Activities for the remaining contract period will include:

1. Continue land use, crop discrimination, acreage estimate, data quality and other analyses for May 27, 1973 scene (spring-summer season) similar to those already completed for the January 21, 1973 scene (fall-winter growing season). Compare acreages with those determined from the ground truth statistical estimate for the county.

2. Formulate a handbook of recommendations for an operational data analysis system useful to agriculture based on ERTS-1 experience.

3. Follow through on investigation such as those reported on herein and prepare manuscripts for publication. These studies include also analysis of the rangeland resources of the county, including their extent, vegetation composition, and the discriminability and mappability of major range sites; the relations among the MSS digital counts and various ground truths to identify the most meaningful ground truths in terms of the ERTS-1 MSS signals; and, examination of analytical models for predicting leaf area index (LAI) or vegetation density, and for estimating vegetation, soil, and shadow components of reflectance from vegetated fields.

4. Prepare final report(s).

CONCLUSIONS

See title page abstract, Appendix A, and individual results section contributions.

RECOMMENDATIONS

We would appreciate being restored to the distribution list for the standard U S Data Catalog.

Evidently, NASA should give continuing attention to the performance of the 6 individual sensors per band.

APPENDIX A

LAND USE CLASSIFICATION AND GROUND TRUTH CORRELATIONS FROM SIMULTANEOUSLY ACQUIRED AIRCRAFT AND ERTS-1 MSS DATA

A. J. Richardson, M. R. Gautreaux, R. J. Torline,

and C. L. Wiegand

1. INTRODUCTION

Agricultural land use inventories using spacecraft MSS signals are useful if they can identify crops and estimate acreages as reliably as aircraft MSS data (Fu, Landgrebe, and Philips, 1969; Duda and Hart, 1973). If MSS crop recognition and acreage estimate data are not spectrally distinctive, then land use data will not be accurate enough for routine use (Anderson, Hardy, and Roach, 1972). For this study, simultaneously collected aircraft and spacecraft (ERTS-1) MSS data permitted a comparison of the land use classification results (Ellefsen, Swain, and Wray, 1973; Carneggie and Degloria, 1972).

Objectives were to: (1) Determine the optimum MSS channels[1] for both aircraft and spacecraft data for agricultural land use discrimination, (2) determine the correlation among aircraft, spacecraft, and ground truth data for a common set of agricultural test fields, (3) compare the recognition performance of aircraft and spacecraft MSS data for a common set of agricultural test fields, (4) estimate acreages within each classification category for both aircraft and spacecraft MSS data in an area covered by one aircraft computer compatible tape (CCT), and (5) determine the spectral signature of various crop, soil, and water scenes at one date (1/21/73) for both aircraft and spacecraft MSS data.

2. EXPERIMENTAL PROCEDURE

The NASA 24-channel multispectral scanner (MSS) on board the NASA NC130B aircraft (flown at 10,000 feet, 3.05 km, altitude) and by Earth Resource Technology Satellite (ERTS-1, that orbits at 886 km) on January 21, 1973, simultaneously collected data in an area (southern portion of Hidalgo County, Texas) where detailed ground truth data were also available. All four of the spacecraft channels and 10 of 24 aircraft channels were used for this study. All aircraft and spacecraft MSS resolution elements were collected from an aircraft flight line covering 94 agricultural fields. These fields were 15 of 197 sample segments that comprise the total statistical sample for ERTS-1 crop, soil, and water reflectance studies conducted by the USDA in Hidalgo County.

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[1] The term "channel" is used for both aircraft and spacecraft MSS data, although the term "band" is used for spacecraft MSS data in the NASA ERTS-1 Data Handbook.

These 94 fields consisted of carrot, onion, cabbage, broccoli, sorghum (young), cotton (young), sugarcane (young), mixed shrubs, and bare soil. The Rio Grande River was also present in the study area. Not enough vegetable fields with detailed ground truth data were available for studying the capability of distinguishing individual vegetable species. Therefore, for this study only four classes were considered: Vegetables, rangeland, bare soil, and water. Of the 94 fields, seven consisting of carrot (1), cabbage (1), onion (1), broccoli (1), mixed shrubs (1), bare soil (2), and a sample of the Rio Grande River were used to train the maximum likelihood classifier (Fu et al., 1969; Duda and Hart, 1973). Which optimum channels to use in the classifier were selected using the five vegetal training fields (carrot, onion, cabbage, broccoli, and mixed shrubs), and a channel optimizing program (Jones, 1973), based on a divergence algorithm. Four fields (carrots, cabbage, onion, and broccoli) were combined into one vegetable category for classifying the 94 test fields. The one mixed shrub field represented immature crops and mixed shrubs, as a general rangeland category. Bare soil and water areas were classified with the 94 test fields, even though they were not used to evaluate the optimum channels. The accuracy of both MSS classification test data was determined using all 94 fields, on per pixel and per field bases (Anuta et al., 1971; Bauer and Cipra, 1973). Recognition maps of the area, covered by one aircraft computer-compatible tape (CCT), were made using aircraft and spacecraft MSS data by displaying the classification on a cathode-ray-tube (CRT) type digital display (Dicomed Model 36).[2] The recognition maps were computer generated, in five gray levels on the CRT, that corresponded to vegetables, rangeland, bare soil, water, and threshold (defined as any field not classified as one of training categories).

Acreage estimates, based on the 94 test field classification using both MSS data, were compared with the actual acreage determined from ground measurement for three categories (vegetables, rangeland, and bare soil). Acreage estimates based on classification of the area covered by one aircraft CCT using both MSS data, were compared with the actual acreage within the three categories (vegetables, rangeland, and bare soil) determined from planimeter measurements of aerial photographs.

The MSS digital counts within each of the 94 fields were averaged for each of the 10 aircraft channels, and for each of the four spacecraft channels. These averages were used with multiple regression analysis to study the relation among aircraft, spacecraft, and ground truth data.

[2] Dicomed Corporation, Minneapolis, MN. Trade names are included for information only and do not constitute endorsement by the U.S. Department of Agriculture.

3. EXPERIMENTAL RESULTS

Optimum MSS Channels for Land Use Discrimination from both Aircraft and Spacecraft

Using the training data for the five vegetation categories (carrot, cabbage, onion, broccoli, and mixed shrubs), a channel optimizing program (Jones, 1973) ranked the aircraft and the spacecraft MSS channels in order of discrimination ability (Table I). Expected recognition results, based on the training data, using the optimum channels were determined. The actual recognition results were determined, using all 94 fields in the study area for testing. For the aircraft data, channel 3 gave the highest cumulative overall recognition results (71.4%), and for the spacecraft data, channel 7 gave the highest cumulative recognition results (87.9%). For the aircraft data the overall expected recognition results reached the point of diminishing returns (94.1%) for the best three channels (3, 8, and 5; 0.466-0.495 μm, 0.770-0.810 μm, and 0.588-0.643 μm). For the spacecraft data, the best channels (4, 7, 5; 0.5-0.6 μm, 0.8-1.1 μm, and 0.6-0.7 μm) gave 95.3% overall correct recognition. The ERTS-1 MSS data of band 6 contained zero digital counts every sixth scan line and did not give a true evaluation of the usefulness of this channel.

Correlation Among Spacecraft, Aircraft, and Ground Truth Variables

For this study, aircraft and spacecraft data were correlated since one of the stated objectives was to compare spacecraft and aircraft land-use inventories. If the aircraft and spacecraft data do not respond alike for the same agricultural scene, then land use surveys from these two sources will not be equivalent.

Spacecraft channel (SCC) 4 (0.5-0.6 μm) correlated highest (0.528**) with aircraft channel (ACC) 13 (2.3-2.43 μm) and second highest (0.477**) with ACC 5 (0.588-0.643 μm)(Table II). That SCC 4 correlates with ACC 5 is explainable, since they cover similar spectral intervals. The correlation of SCC 4 with ACC 13 is not so easily explained because they cover different spectral intervals. The correlation coefficients between SCC 5 (0.6-0.7 μm) and ACC 5 and 13 are 0.517** and 0.643**, respectively. The reason for the high correlation between SCC 5 and ACC 13 is not apparent, since they cover different spectral intervals. Generally, the correlation between SCC 6 and all ACC was lower than for the other SCC, as indicated by its multiple correlation coefficient of 0.653**; every sixth scan line had zero digital counts for SCC 6, so that a true measure of the correlation coefficient was not obtained. Aircraft channels 8 and 9 (0.770-0.880 μm) had the highest correlations (0.704** and 0.695**, respectively) with SCC 7 (0.8-1.1 μm); they cover similar spectral intervals. These correlations indicate that the ACC and SCC respond alike in the visible and reflective infrared spectral regions, and that land use surveys from ACC and SCC should be equivalent.

The aircraft channels (3, 4, 5, and 6) in the visible spectrum (0.466-0.690 μm) correlated positively with SCC 4 and 5, also in the visible spectrum (Table II). These aircraft channels were inversely related to reflective infrared SCC 6 and 7, as shown by the negative simple correlation coefficients. Aircraft channels 7, 8, 9, and 10 in the infrared spectrum (0.720-1.045 μm) were inversely related to SCC 4 and 5 (visible spectrum) and directly related to SCC 6 and 7 (infrared spectrum). Even though ACC 6 and SCC 6 were not up to the general standards of performance of the other ACC and SCC, they did show the same general trends by being positively or negatively corrlated.

Aircraft MSS data correlated highest (Table III) with crop cover plus weed cover (PWC), as shown by the multiple correlation coefficient (0.802**). The other ground truth parameters had lower multiple correlation coefficients as follows: Plant condition (PC) (0.707**), plant maturity (PM) (0.663**), and plant height (PH) (0.533**).[3] Aircraft channels 3, 4, 5, and 6 (0.466-0.690 μm) (visible spectrum) are inversely related to PWC, but in the infrared spectrum (0.720-1.045 μm) ACC 7, 8, 9, and 10 are directly related to PWC (Table III). This relation was also noted with the Bendix 8-channel scanner data (Richardson, Wiegand, and Torline, 1972).

Spacecraft MSS digital counts were significantly correlated with PWC (Table IV), as shown by the multiple correlation coefficient (0.656**). Spacecraft channels 4 and 5 (0.5-0.7 μm) (visible spectrum) were inversely related to PWC in the same manner as ACC 3, 4, 5, and 6. The infrared SCC 6 and 7 (0.7-1.1 μm) were directly related to PWC as were ACC 7, 8, 9, and 10.

Canonical correlation coefficient (IBM Scientific Subroutine Package, 1968; Veldman, 1969) showed that aircraft and spacecraft MSS data (Table II) for the same fields were correlated significantly (0.954**). Aircraft MSS data had a higher canonical correlation (0.804**, Table III) with ground truth variables than spacecraft MSS data (0.698**, Table IV), indicating that aircraft data were slightly better related to ground truth than were the spacecraft data. Ground resolution may have affected the spacecraft correlations with ground truth more adversely than it did the aircraft data. Close attention was given to boundary identification for spacecraft data but for fields that are only 1 to 5 pixels in size (Appendix Table II) boundary identification was subjective.

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[3] Ground truth parameters are defined in Appendix Table I.

In general, the simple, multiple, and canonical correlations of ACC to SCC were higher than either correlation was to ground truth data, indicating that predictions of ground truth from aircraft or spacecraft would have the same reliability.

Recognition Performance of Aircraft and Spacecraft MSS Data

The recognition results for all 94 test fields were not high for either aircraft or spacecraft MSS data, but the correspondence in the recognition results demonstrated that aircraft and spacecraft sensors responded similarly. The 94 fields studied totaled 2,244 acres (908.1 hectares), and consisted of 177,414 aircraft pixels (0.0127 acres/pixel, 0.00514 hectares/pixel), and 1,942 spacecraft pixels (1.155 acres/pixel, 0.467 hectares/pixel). On a per pixel basis, recognition results for vegetables were 40.6 and 40.4% correct for aircraft and spacecraft data, respectively (Table V). Recognition results for bare soil were 77.9 and 77.0% correct for aircraft and spacecraft data, respectively. Recognition results for the one category of immature crop and mixed shrub (rangeland, Fig. 1) was 53.5 and 28.8% for aircraft and spacecraft, respectively. The difference in recognition result was expected because of the great variability within this category (rangeland) that consisted of young crops with low percent ground cover, low density mixed shrubs, and a few weedy fallow fields. Overall recognition results were 64.6 and 59.6% for aircraft and spacecraft, respectively, on a per pixel basis.

The per field recognition results (Table VI) indicated that the aircraft and spacecraft MSS data are more closely associated than the per pixel recognition results (Table V). The vegetable fields were discriminated almost exactly the same (50.0% recognition for aircraft and spacecraft data); the number of vegetable fields classified into each category was 14, 4, and 10 (vegetables, immature crops and mixed shrubs, and bare soil, respectively) for the aircraft data, and 14, 5, and 9 for the spacecraft data, respectively (Table VI). The discrimination results for aircraft and spacecraft field classifications did not correspond as closely for the other two categories (immature crops and mixed shrubs, and bare soil), but the overall recognition results did at 61.8 and 62.8%, respectively (per field basis).

Even though recognition results for all 28 vegetable test fields were low (Table VI), most of the error in this category was due to low crop cover, low plant height, and small field size. When vegetable fields were limited to fields larger than 10 acres, plants 25 centimeters high, and 50 percent crop cover, recognition results were 88.9 and 100.0%, respectively (Table VII) for aircraft and spacecraft MSS data (on a per field basis). Although the small number of fields (8) makes these statistics weak, they indicate that vegetable fields generally are identified reliably by both aircraft and spacecraft. These statistics are too weak to determine reliably whether individual vegetal species can be discriminated using ERTS-1 spacecraft data, as has been shown by other investigators (Bauer and Cipra, 1973). Spacecraft data can be as reliable as the aircraft data mentioned by other investigators (Bauer and Cipra, 1973).

The recognition maps (Fig. 1) of aircraft and spacecraft MSS data, over an area covered by one aircraft CCT, give further evidence of the close correspondence between the aircraft and spacecraft recognition results. Apparently, both aircraft and spacecraft are in close agreement for vegetation identification for the whole flight line (Fig. 1). The aircraft identified as bare soil some areas around the Rio Grande that the spacecraft identified as vegetation. Probably the spacecraft data are correct because the aircraft data were not corrected for scan angle effects (Malila, 1968) since it misclassified part of the river closest to the southern edge of the imagery as bare soil and distorted the southern side of the aircraft flight line which seems to have more rangeland than the northern side. Scan angle effects were also very apparent in images provided by NASA for the various channels.

The segment and field boundaries[4] for 36 of the 94 fields used in this study are shown for the aircraft and spacecraft recognition maps in Fig. 1. The segment and field numbers are keyed to the ground truth listed in Appendix Table II. In segment 2086 for the aircraft recognition map, the misclassifications of two onion fields (field numbers 40 and 31; PWC 10 and 15%) as bare soil fields are apparent; the spacecraft recognition map indicates the same error. In segment 1043 for the aircraft recognition map, a bare soil field (field number 32) was misclassified as vegetation; the spacecraft recognition map indicates the same error. Segment 5174 shows that two cabbage fields (field numbers 11 and 30; 7 and 2% crop cover) and three onion fields (field numbers 12, 13, and 14; 22, 4, and 30% crop cover) were misclassified as bare soil according to both aircraft and spacecraft recognition maps. The error of classifying as bare soil a vegetable field with low crop cover is a ground truth spectral representation problem, but the error of identifying bare soil as vegetation is more difficult to explain. Whether the misclassified bare field was recently irrigated or recently tilled is unknown, but either irrigation or tillage could change its spectral signature, compared with the training signature, and result in misclassification. These results provide evidence for agreement between spectrally similar aircraft and spacecraft recognition results and disagreement among spectral categories (MSS data) and ground truth categories.

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[4] Segment and field boundaries are defined in Appendix Table I.

Although the effect of field size (Appendix Table II) on recognition results for these data is not known, it probably affects the spacecraft more than aircraft because of resolution differences. One spacecraft pixel is equal to a 9 by 9 pixel matrix (81 pixels) of the aircraft imagery. Spacecraft correlation results were degraded more than spacecraft recognition results, partly because of the subjectivity in fixing the field boundaries for small fields (1 to 5 pixels in size), and because some pixels used contained spectral information from adjacent fields and boundaries of the intended fields.

Comparison of Land Use Inventories from Aircraft and Spacecraft

The land use acreage estimates for aircraft and spacecraft MSS data in 94 test fields are shownin Table VIII. The actual land use, determined from ground truth listed in Table VIII, are given in percent of the total coverage (2,244 acres) in these 94 fields. The estimated land use, determined from classification of aircraft and spacecraft MSS data(Table V; per pixel basis), are given in percent of total pixels (177,414 and 1,942 pixels for aircraft and spacecraft, respectively) for each land use category in the 94 fields. The estimated land use is reported for correct, omission, commission, and threshold classification of MSS data.

The actual land use in each category (Table VIII) may be compared with the estimated land use in the correct column (Table V) or in the total column (Table V) for each category. The estimated land use for each category, in the correct column, will underestimate the actual land use by approximately the percent correct recognition of the category listed in Table V. For example, the aircraft estimate for vegetables is 39.1% of the actual coverage (10.7/27.4 = 39.1 in Table VIII that compares to 40.6% correct recognition (Table V). The underestimate would be exactly equal, if the proportion of acres in the fields to pixels selected from the fields were the same from field to field. These proportions are not the same because of the difficulty in exactly fixing field boundaries. The final overall correct estimated land use results (Table VIII) are exactly equal to the percent overall correct recognition (Table V) because the acre/pixel ratio was determined on the overall basis. The underestimation error is due to omission and threshold classification and can be determined by equation 5 (Table VIII).

When ground truth is not available, then land use estimates, based on the total percent identified in each category (equation 4 in Table VIII), are compared to the actual land use. Without ground truth, it is not possible to determine the error due to omission and commission classifications.

The land use comparisons, using aircraft or spacecraft MSS data, were not close (Table VIII), for the same reasons that the recognition results (Table V) were not high; ground truth was not spectrally representative of the crop and soil conditions, as measured by aircraft and spacecraft MSS. The agreement between the aircraft and spacecraft land use estimations, based on correct classifications, for vegetation (10.7 and 11.5%, respectively) and bare soil (46.3 and 44.0%, respectively) categories were in good agreement. The rangeland category comparisons (7.6 and 4.1% for aircraft and spacecraft, respectively) were not as good. Agreement between aircraft and spacecraft land use estimations, based on total classification, for vegetables (14.7 and 18.3%, respectively) and bare soil (56.9 and 61.3%, respectively) was close, but not as good as the estimates based on correct classification estimates.

The land use acreage estimates for aircraft and spacecraft MSS data for the coverage contained by one aircraft CCT are shown in Table IX. The actual land use, determined from aerial photographic planimetering of land use categories, is given in percent of total area covered by one aircraft CCT. The estimated land use, determined from classification of aircraft and spacecraft MSS data of the area covered by one aircraft CCT, are given in pixels, acres, and percent of total area for each land use category. Ground truth was not detailed enough to determine correct, omission, and commission classification of MSS data.

In general, spacecraft estimates of land use were better than aircraft estimates for all categories except vegetables (61.1 and 19.5% overestimation error, respectively). None of the land use estimates as compared to actual estimates were very good. The water estimates are probably better than the differences indicate (-57.1 and 57.1% for aircraft and spacecraft, respectively) because of the difficulty in arriving at the actual planimetered value for water from aerial photographs. The largest differences involved the bare soil and rangeland categories. Actually much more bare soil (72.6%) was in the survey area than either the spacecraft or aircraft indicated (39.2 and 34.1%, respectively). The threshold category for aircraft and spacecraft account for some of the error (6.4 and 10.6%, respectively). Actually, much less rangeland (11.6%) was in the survey area than either spacecraft or aircraft indicated (24.8 and 41.7%, respectively). The overestimation of rangeland accounted for the rest of the bare soil underestimation by aircraft and spacecraft MSS data. The poor estimate of land use categories is probably due to lack of spectrally representative ground truth that would allow selection of representative training fields. Table IX indicates that the aircraft and spacecraft estimations are in fairly good agreement, but not in good agreement with ground truth, indicating that the spacecraft land-use estimation reliability is comparable to aircraft estimations.

Spectral Signature of Various Crop, Soil, and Water Categories

Figure 2 is a graph of typical spectral signatures for crop, soil, and water categories using spacecraft and aircraft MSS data. The circles are one standard deviation error bands about each mean for each category. The wavelength intervals for each channel are given in Table I.

For the spacecraft MSS data (Fig. 2), most of the separability among the crop, bare soil, and water categories seemed to be in channel 7 (0.80-1.10 μm). The standard deviations are comparatively small in this channel for each category and the means have good separation. Channel 5 (0.60-0.70 μm) seems to have the second best separability for these three categories. The effects of the zero digital counts in channel 6 (0.70-0.80 μm) are apparent from the relatively large standard deviation for vegetable and bare soil categories. Future studies plan to estimate values for the zero digital counts in channel 6 by considering digital counts before and after the zero digital count. Channel 4 (0.50-0.60 μm) did not seem to separate the three categories as well as 5 and 7; bare soil and water particularly had overlapping standard deviations.

The aircraft MSS data (Fig. 2) had the best discrimination of crop, bare soil, and water in channels 7, 8, 9, and 10 (0.72-1.045 μm), as evidenced by the good separation of means and nonoverlapping standard deviations. Channels 4 and 5 (0.53-0.643 μm) and 12 and 13 (1.533-2.43 μm) had the noisiest channels, as evidenced by the relatively large standard deviations for the water category. Channel 6 (0.65-0.69 μm) was not responding correctly; the average digital count measurement for each of the categories was 54 (21% digital count ratio with 255). The digital count data for ACC 6 could not be recovered. Channel 3 (0.466-0.495 μm) seemed to have the second best separation among the three categories for the aircraft MSS data.

These intuitive observations of the aircraft and spacecraft signatures were not used as a bases for optimum selection of the best channels. These kind of observations provide a graphic check of the optimum channel selection program CHOICE (Jones, 1973).

4. CONCLUSIONS

The three optimal channels for vegetal category discrimination in a set of simultaneously acquired data for 94 fields were 3, 8, and 5 for the 24-channel aircraft and 4, 7, and 5 for ERTS-1. The aircraft and spacecraft MSS data correspond better than the MSS data and ground truth data, as shown by simple, multiple, and canonical correlations. Ground truth data collected in this study do not seem closely associated with the spectral characteristics of the soil and crop categories studied. Aircraft and spacecraft data were essentially similar in their recognition of vegetables, bare soil, and water, based on a common set of 94 fields. Agricultural surveys from spacecraft seem as reliable as surveys from aircraft, although neither aircraft nor spacecraft MSS data survey results compared closely to ground truth data.

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Table I. Cumulative overall percent recognition of aircraft and spacecraft scanner training data for vegetal categories carrot, onion, cabbage, broccoli, and mixed shrubs. Percent recognition is given for best single channel, best two channels, best three channels, and so on. The channel ranking for both spacecraft and aircraft MSS data was tested using both average probability of misclassification and divergence criteria. Wavelengths and channel numbers are given in the lower part of the table for both.

AIRCRAFT MSS DATA		SPACECRAFT MSS DATA	
Optimal channels	Cumulative overall percent recognition	Optimal[1/] channels	Cumulative overall percent recognition
3	71.4	7	87.9
3-8	92.5	4-7	93.3
3-8-5	94.1	4-7-5	95.3
3-8-5-10	94.6	4-7-5-6	-
3-8-5-10-7	95.4		

Channel No.	Wavelength, µm	Channel No.	Wavelength, µm
3	0.466 - 0.495	4	0.5 - 0.6
4	0.53 - 0.58		
5	0.588 - 0.643	5	0.6 - 0.7
6	0.65 - 0.69		
7	0.72 - 0.76	6	0.7 - 0.8
8	0.770 - 0.810		
9	0.82 - 0.88	7	0.8 - 1.1
10	0.981 - 1.045		
12	1.533 - 1.62		
13	2.3 - 2.43		

[a/] Channel 6 not used because of zero values.

Table II. Correlation coefficients, r and R, for aircraft and spacecraft January 21, 1973 data for 94 fields. Ten of the 24-MSS channels of the BENDIX scanner are related to the MSS channels of the ERTS.

		SPACECRAFT CHANNELS			
		4	5	6	7
		---Micrometers---			
Aircraft channels	Wavelength	0.5-0.6	0.6-0.7	0.7-0.8	0.8-1.1
	Micrometers	-----Simple Correlation Coefficients, r-----			
3	0.466-0.495	0.421**	0.451**	-0.221*	-0.436**
4	0.530-0.580	0.399**	0.398**	-0.136	-0.338**
5	0.588-0.643	0.477**	0.517**	-0.246*	-0.493**
6	0.650-0.690	0.046	0.078	-0.072	-0.041
7	0.720-0.760	-0.180	-0.352**	0.465**	0.601**
8	0.770-0.810	-0.263*	-0.444**	0.516**	0.704**
9	0.820-0.880	-0.256*	-0.433**	0.517**	0.695**
10	0.981-1.045	-0.206*	-0.358**	0.470**	0.587**
12	1.53 -1.62	0.361**	0.442**	-0.212*	-0.480**
13	2.3 -2.43	0.528**	0.643**	-0.377**	-0.673**
		----Multiple Correlation Coefficients, R-----			
All aircraft channels		0.762**	0.847**	0.653**	0.927**
		All Spacecraft Channels			
		Canonical Correlation Coefficient			
All aircraft channels		0.954**			

* Significant at the 5% probability level.

** Significant at the 1% probability level.

Table III. Coefficients of correlation of aircraft with ground truth variables for January 21, 1973, ERTS-1 overpass in conjunction with aircraft support Mission 226 for 32 vegetated fields. Ground truth parameters are: crop cover plus weed cover (PWC), plant maturity (PM), plant height (PH), and plant condition (PC).

Aircraft channels	Wavelength	GROUND TRUTH PARAMETERS[a/] PWC %	PM	PH cm	PC
	Micrometers	----Simple Correlation Coefficients, r-----			
3	0.466-0.495	-0.102	0.045	-0.179	0.109
4	0.530-0.580	-0.077	0.080	-0.197	-0.014
5	0.588-0.643	-0.155	0.168	-0.178	0.154
6	0.650-0.690	-0.161	0.120	-0.076	0.236
7	0.720-0.760	0.312	-0.045	-0.139	-0.384*
8	0.770-0.810	0.340	-0.061	-0.127	-0.408*
9	0.820-0.880	0.361*	-0.049	-0.118	-0.398*
10	0.981-1.045	0.398*	-0.020	-0.110	-0.346
12	1.53 -1.62	0.063	0.203	0.034	0.269
13	2.3 -2.43	-0.149	0.212	-0.006	0.441*
		---Multiple Correlation Coefficients, R----			
All aircraft channels		0.802**	0.663**	0.533*	0.707**
		Canonical Correlation Coefficient			
All aircraft channels					0.804**

* Significant at the 5% probability level.

** Significant at the 1% probability level.

a/ See Appendix Table I for ground truth parameter definitions.

Table IV. Coefficients for correlation of spacecraft with ground truth variables for January 21, 1973, ERTS-1 overpass in conjunction with aircraft support Mission 226 for 32 vegetable fields. Ground truth parameters are: crop cover plus weed cover (PWC), plant maturity (PM), plant height (PH), and plant condition (PC).

		GROUND TRUTH VARIABLES[a/]			
Spacecraft channels	Wavelength	PWC %	PM	PH cm	PC
	Micrometers	------Simple Correlation Coefficients------			
4	0.5-0.6	-0.286	0.127	-0.252	0.321
5	0.6-0.7	-0.289	0.164	-0.149	0.482**
6	0.7-0.8	0.446*	0.055	-0.084	-0.257
7	0.8-1.1	0.435*	0.014	-0.035	-0.499**
		-----Multiple Correlation Coefficients-----			
All spacecraft channels		0.656**	0.412	0.362	0.624**
		ALL GROUND TRUTH VARIABLES			
		Canonical Correlation Coefficient			
All spacecraft channels		0.698**			

* Significant at the 5% probability level.

** Significant at the 1% probability level.

a/ See Appendix Table I for ground truth definitions.

Table V. Per pixel classification results for a common set of 94 aircraft and spacecraft test fields using MSS data for January 21, 1973.

Classification category	Total	AIRCRAFT CLASSIFICATION RESULTS				
		Vegetables	Immature crops and mixed shrubs	Bare soil	Threshold*	Percent Recognition
Vegetables	46,427	18,834	12,659	13,526	1,408	40.6
Immature crops and mixed shrubs	25,225	4,725	13,504	5,291	1,705	53.5
Bare soil	105,762	2,422	18,364	82,223	2,753	77.9
Total	177,414	25,981	44,527	101,040	5,866	64.6

Classification category	Total	SPACECRAFT CLASSIFICATION RESULTS				
		Vegetables	Immature crops and mixed shrubs	Bare soil	Threshold*	Percent Recognition
Vegetables	554	223	103	218	10	40.4
Immature crops and mixed shrubs	278	48	80	128	22	28.8
Bare soil	1,110	85	73	855	97	77.0
Total	1.942	356	256	1,201	129	59.6

* Any pixel values not classified as any of the three training categories were placed in an "other" category called "threshold."

Table VI. Classification results for a common set of 94 aircraft test fields using MSS data for January 21, 1973. Results are given on a per field basis using a majority rule classification procedure for each field.

Classification category	Total	AIRCRAFT CLASSIFICATION RESULTS Vegetables	Immature crops and mixed shrubs	Bare soil	Threshold*	Percent Recognition
Vegetables	28	14	4	10	0	50.0
Immature crops and mixed shrubs	19	8	6	4	1	31.6
Bare soil	47	1	8	38	0	80.8
Total	94	23	18	52	1	61.8

Classification category	Total	SPACECRAFT CLASSIFICATION RESULTS Vegetables	Immature crops and mixed shrubs	Bare soil	Threshold*	Percent Recognition
Vegetables	28	14	5	9	0	50.0
Immature crops and mixed shrubs	19	4	4	9	2	21.0
Bare soil	47	2	0	41	4	87.2
Total	94	20	9	59	6	62.8

* Any fields not classified as any of the three training categories were placed in an "other" category called "threshold."

Table VII. Classification results for a common set of vegetable fields using aircraft and spacecraft MSS data (January 21, 1973). Only vegetable fields greater than 10 acres, greater than or equal to 25 centimeters of plant height (PH), and 50 percent plant cover (PWC) were included in these results. Results are given on a per field basis using a majority rule classification procedure for each field. Segment (SEG), field (FLD), and crop codes (CC) definitions are given in appendix.

Vegetable field ground truth						Fields classified as indicated	
SEG	FLD	CC	PWC	PH	ACRES	AIRCRAFT	SPACECRAFT
			%	cm			
3125	32	10	90	60	11.27	Vegetable	Vegetable
5178	10	20	75	30	19.23	Vegetable	Vegetable
5178	20	20	80	35	37.77	Vegetable	Vegetable
3125	31	20	70	30	11.99	Vegetable	Vegetable
1043	22	20	60	25	29.21	Rangeland	Vegetable
6181	22	30	50	30	18.15	Vegetable	Vegetable
7190	21	30	50	30	10.87	Vegetable	Vegetable
6184	42	30	85	30	14.14	Vegetable	Vegetable
Percent Recognition						88.9	100.0

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Table IX. Comparison of land use inventory results for aircraft and spacecraft MSS data over an area contained on one aircraft CCT (approximately half of the total coverage) for M226, January 21, 1973. The total acres for aircraft and spacecraft are different because spacecraft and aircraft coverage are not exactly matched. An estimate of the actual percent coverage of each category was determined from aerial photography. The percent difference between the actual aircraft and spacecraft percent coverage is listed to indicate the estimated land use inventory error. If the difference is an overestimation, the sign is positive, and if the difference is an underestimation, the sign is negative.

Classi-fication category	Actual percent coverage*	LAND USE INVENTORY RESULTS FOR ONE AIRCRAFT CCT COVERAGE							
		Aircraft				Spacecraft			
		Pixel	Acres	Percent	Difference	Pixel	Acres	Percent	Difference
				%	%			%	%
Vegetables	14.4	206,503	2,623	17.2	19.5	3,232	3,133	23.2	61.1
Bare soil	72.6	409,681	5,196	34.1	-53.1	5,459	6,305	39.2	-46.0
Rangeland	11.6	499,681	6,346	41.7	259.0	3,451	3,986	24.8	114.0
Water	1.4	7,795	99	0.6	-57.1	301	348	2.2	57.1
Threshold	----	76,179	967	6.4	----	1,473	1,701	10.6	----
Total	100.0	1,199,272	15,231	100.0	----	13,916	16,073	100.0	----

* Observed ground truth makes no provisions for estimating size of water bodies or areas that would likely be classified as threshold (pixels not classified as any of the four training categories).

FIGURE LEGENDS

Fig. 1. Recognition maps of an area covered by one aircraft computer compatible tape using aircraft and spacecraft multispectral scanner data collected on January 21, 1973. Four categories are shown (vegetation, rangeland, bare soil, and water) using the indicated intensity levels. The boundaries of five experimental segments containing 36 fields are shown. The segment and field numbers reference ground truth information given in the appendix.

Fig. 2. Spectral signature of vegetation (---), bare soil (— —), and water (——) categories using aircraft and spacecraft multispectral scanner data collected on January 21, 1973. Circles are used to indicate one standard deviation error bands for the spacecraft signatures. Spacecraft signatures are in radiance measurements ($\mu w/cm^2$-SR-μ). The aircraft signatures are digital counts relative to the maximum digital measurement (255). Aircraft channel 6 had a constant reading of 21% digital count ratio with 255 and a very small standard deviation for all three categories.

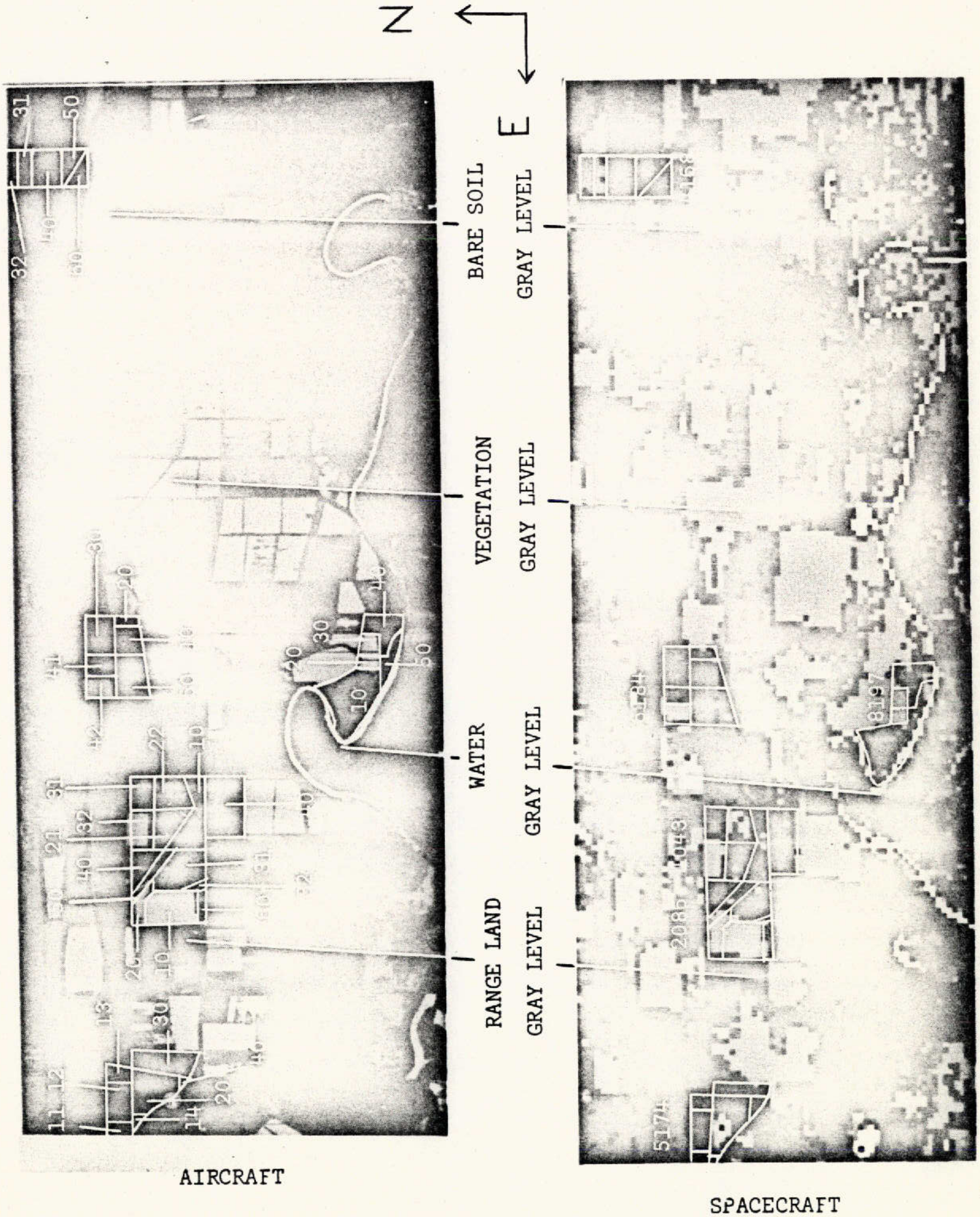
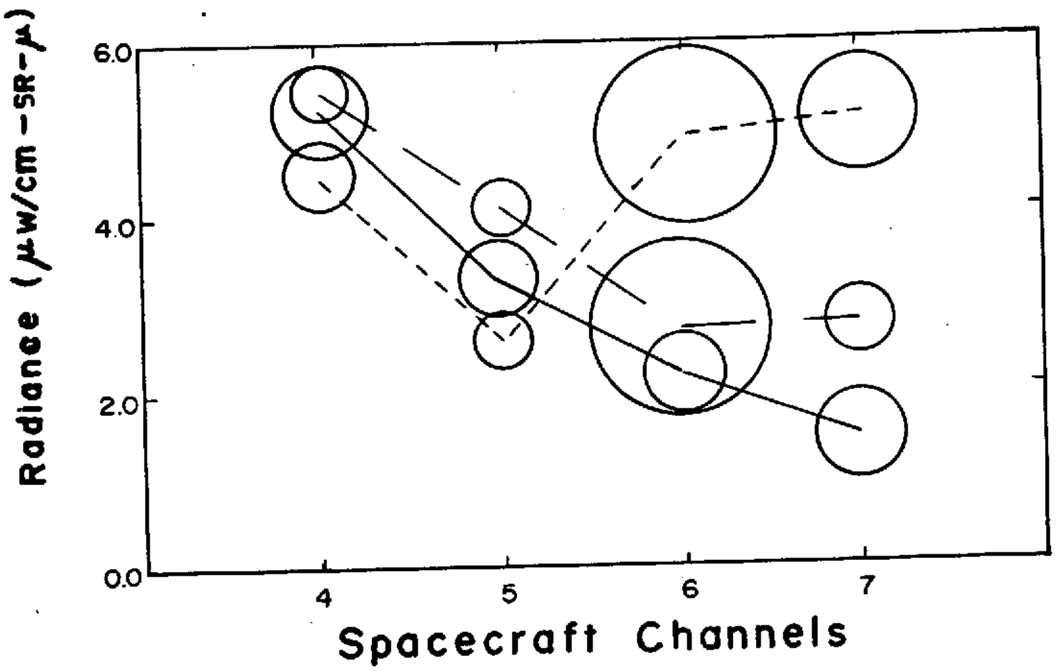

N
E
BARE SOIL
GRAY LEVEL
VEGETATION
GRAY LEVEL
WATER
GRAY LEVEL
RANGE LAND
GRAY LEVEL
AIRCRAFT
SPACECRAFT

Fig. 1.


Radiance (μw/cm − SR − μ)
6.0
4.0
2.0
0.0
4
5
6
7
Spacecraft Channels

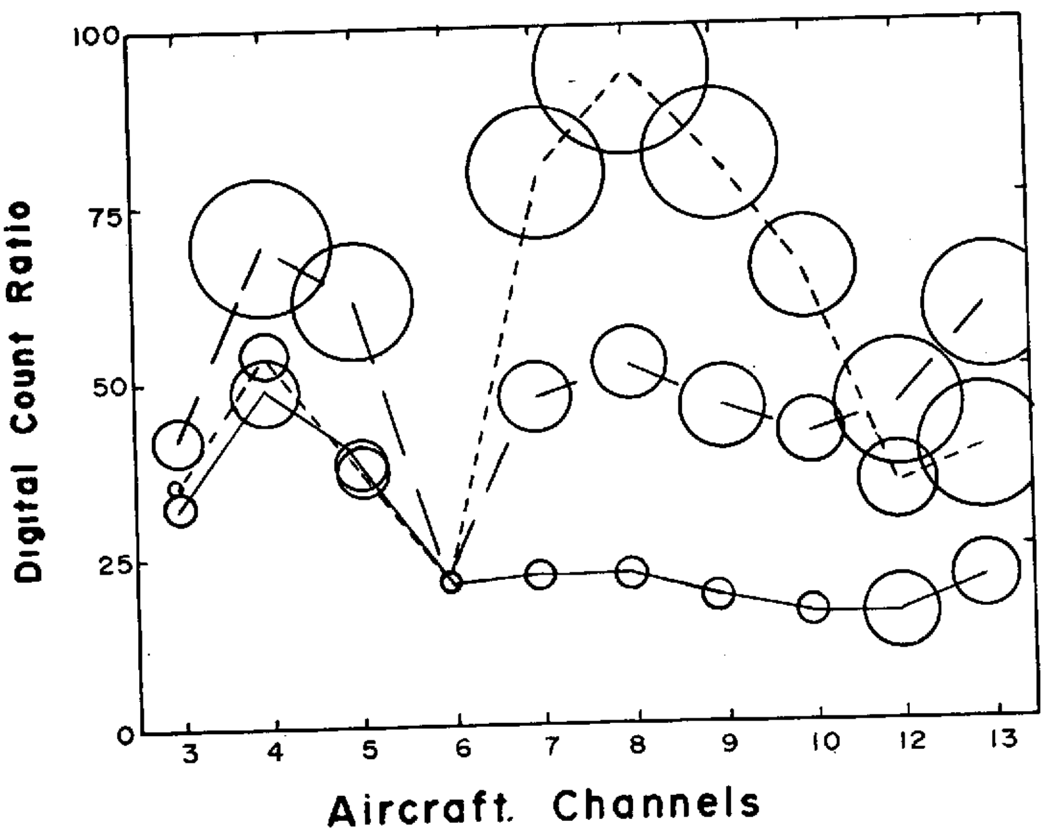

Digital Count Ratio
100
75
50
25
0
3
4
5
6
7
8
9
10
12
13
Aircraft Channels

Fig. 2.

Appendix Table I: Ground truth parameter definitions.

I. Segment Number - Identification code for 160 acre and 1.5 square mile sample blocks (197 total) randomly located throughout Hidalgo County, Texas for the USDA Weslaco ERTS-1 studies.

II. Field Numbers - Identification code for field boundaries within segments and division boundaries within fields.

III. Crop Code - Code number for plant identity as follows:

10 - Broccoli
20 - Carrot
30 - Cabbage
40 - Onion
170 - Spinach
529 - Sorghum
602 - Coastal bermudagrass
658 - Mixed shrubs
750 - Non-agricultural
900 - Bare soil
910 - Dry debris

IV. Crop Cover - Percent of field covered by crop or orchard plants.

V. Weed Cover - Percent of field covered by weeds.

VI. Plant Maturity - A code number ranging from 1 to 9 indicating maturity of plant, such as seedling (1), young seedling (2), harvest (8), and stubble (9).

VII. Plant Height - Height of plant in centimeters.

VIII. Plant Condition - A code number ranging from 1 to 8 indicating plant conditions as follows:

1 - Fully turgid
2 - Mildly turgid
3 - Severely wilted
4 - Lower leaves yellow or brown
5 - Upper leaves yellow or brown
6 - Most leaves dry or dead
7 - Some plants are dead and some are green
8 - Uneven plant height

IX. Soil Condition - A code number ranging from 1 to 9 indicating surface condition; such as plowed (1), disked (2), harrowed (3), bedded (4), listed (5), cultivated (6), floated (7), leveled (8), and crusted (9).

Appendix Table II: Ground truth listing for 36 of 94 fields used in comparing recognition map results for aircraft and spacecraft data collected on January 21, 1973. Ground truth parameters are as follows: Segment number (SEG), field (FLD), crop code (CC), crop cover plus weed cover (PWC), plant maturity (PM), plant height (PH), plant condition (PC), soil condition (SC), and field size (FS).

SEG	FLD[a/]	CC	PWC %	PM	PH cm	PC	SC	FS (Acres)
1043	10*	658	45	4	300	7	9	33.10
1043	21	900	0	0	0	0	5	39.47
1043	22	20	60	2	25	1	9	29.21
1043	31	529	70	2	35	1	9	13.83
1043	32	900	0	0	0	0	4	16.16
1043	40	900	0	0	0	0	5	55.71
2086	10*	40	25	2	10	1	9	51.63
2086	20	40	10	2	10	1	9	7.03
2086	31	40	15	2	10	1	9	49.65
2086	32	750	0	0	0	0	0	1.00
2086	40	40	10	2	15	1	9	27.29
2086	50	750	0	0	0	0	0	11.27
2086	60	750	0	0	0	0	0	11.27
4168	31	170	20	2	15	1	9	18.38
4168	32	10	15	2	10	1	9	18.22
4168	40	900	0	0	0	0	9	36.60
4168	50	910	10	0	0	0	2	16.70
4168	60	602	99	9	20	7	9	20.30
5174	11	30	7	1	5	1	9	13.65
5174	12	40	22	2	20	1	9	34.14
5174	13	40	4	1	5	1	9	16.67
5174	14	40	30	2	25	1	9	3.02
5174	20	900	0	0	0	0	8	56.04
5174	30	30	2	1	1	1	9	43.21
5174	40	900	0	0	0	0	9	2.30
6184	10	900	0	0	0	0	5	27.04
6184	20	20	60	2	25	1	9	5.63
6184	30	900	0	0	0	0	5	39.50
6184	41	900	0	0	0	0	5	27.97
6184	42	30	85	8	30	1	9	14.14
6184	50	900	0	0	0	0	4	47.60
8197	10	900	0	0	0	0	5	60.52
8197	20	30	90	8	30	1	9	7.91
8197	30	80	50	2	20	1	9	17.92
8197	40	900	0	0	0	0	5	40.22
8197	50	910	25	0	0	0	2	14.58

a/ Fields, defined as land areas treated uniformily, vary from crop season to crop season requiring some land to be subdivided into additional fields from time to time.

* Identifies training fields. Only two of seven training fields appear in this selection of 36 of 94 fields.