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SOIL, WATER, AND VEGETATION CONDITIONS IN SOUTH TEXAS

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16. Abstract

Best wavelengths in the 0.4 to 2.5 μm interval have been determined for detecting lead toxicity and ozone damage, distinguishing succulent from woody species, and detecting silverleaf sunflower. Work is also reported on distinguishing crop residue from soil as might be important in preventing soil erosion by wind.

A perpendicular vegetation index (PVI), a measure of the distance from the soil background line, in MSS5 and MSS7 data space, of pixels containing vegetation has been developed and tested as an indicator of vegetation development and crop vigor.

A table look-up procedure has been devised that permits rapid identification of soil background and green biomass or phenological development in LANDSAT scenes without the need for training data. It should be useful where ground truth is unavailable and in conjunction with crop calendar information in decision tree crop discrimination procedures.

Determination of baseline productivity of "mixed brush" rangeland may be feasible when native woody species are dormant.

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PREFACE

Objectives

This contract dealt with use of LANDSAT multispectral scanner (MSS) data for crop identification, hectarage estimation, and relations between crop spectral variation and yield variations in Hidalgo County, Texas; and, with spectral identification of predominant range sites and land uses in Willacy County, Texas. In addition, selected cost-effectiveness comparisons were made between LANDSAT data sources and traditional ground surveys.

Scope of Work

Computer compatible digital magnetic tapes (CCT) of three LANDSAT-1 and nine LANDSAT-2 scenes were obtained and studied on a human interactive digital computer and display system. The crops and land uses were classified periodically for the 397,000 ha Hidalgo County, and range sites and land uses were spectrally identified on 4 dates for an 81,000 ha area in Willacy County. Detailed ground truth for selected grain sorghum fields permitted close examination of the relationships among plant parameters such as height (H), population (POP), leaf area index (LAI), and biomass (BIOM); the digital counts from the LANDSAT MSS; and sorghum yields. These studies were supplemented by smaller scale more specific investigations that employed laboratory spectrophotometer, field spectroradiometer and LANDSAT data on the subjects wind erodibility of soil (disked and nondisked soil with and without wheat straw, dead vs. live vegetation, and dead vs. bare soil reflectance); plant stress detection (lead toxicity, ozone damage, ultraviolet light damage); and, discrimination among plants (citrus varieties, wheat, rangeland plant species, silverleaf sunflower vs. other range plants, and succulent vs. non-succulent plants).

A significant aspect of this work was the emphasis on information extraction. We feel the advances made under this contract for dealing with variations in the soil background and the vegetation indices produced could be invaluable for assessing green biomass, establishing the phenological stages of crops, and setting photosynthetic potentials in world-wide crop production estimation efforts.

Summary and Conclusions

The LANDSAT data space surrounding the soil background line for MSS5 and MSS7 was divided into 10 decision regions (water; cloud shadow; low, medium and high reflecting soil; cloud tops, low, medium, and dense plant cover; and, threshold into which no LANDSAT data should fall), a table look-up procedure devised, and printer symbols assigned such that LANDSAT scenes can be gray mapped to meaningfully display vegetation density and soil conditions without prior knowledge of local crop and soil conditions. The procedure is especially attractive where ground truth is unavailable as in foreign countries, can be used as an editing device to remove nuisance categories in classification such as clouds and cloud shadows, and can sort data rapidly for decision tree analyses.

The perpendicular distance of pixels in MSS bands 5 and 7 data space from the soil background line (on which clouds and cloud shadows fall as the extreme values) has been developed and tested on sorghum and rangeland as an index of vegetation development and crop vigor. It has been named the perpendicular vegetation index (PVI). The calculation defines the position of each pixel along the soil background line; hence, it may contain information on soil conditions "behind" the vegetation.

Reflectance (and absorptance of plant leaves in the 0.4 to 2.5 μm wavelength interval was studied to determine best wavelengths to detect lead toxicity, ozone damage, to distinguish succulent from woody species, to detect silverleaf sunflower, and to determine wheat vigor and distinguish wheat plants from soil. Soil-tillage-straw treated field plots were also studied for distinguishing crop residue from soil as might be important in preventing soil erosion by wind.

Optimal wavelengths for these applications have been determined as follows:

Application	Wavelength(s), μm	Reasons or Effect
Lead (Pb) toxicity	0.5 to 0.75 1.35 to 2.5	Decreased chlorophyll content Decreased water content
Soil erosion by wind	0.75 to 1.3	Soil and straw distinguished
Peperomia i.d.	2.2	Stored water eliminated 2.2 μm peak
Ultraviolet damage to plants	0.26 to 0.36	First leaf layer absorbs ≈95% of T
Ozone damage	1.35 to 2.5	Leaf hydration difference
Wheat vigor	0.55, 0.90, 1.10	Positive correlation with green biomass
Wheat discrimination from soil	0.65, 0.73 1.65, 2.2	Plants obscure soil; Water in plants absorbs strongly, dry soil reflects strongly
Distinguishing succulent vs. woody species	1.35, 1.60 2.20	Water content difference
Detection of weed, silverleaf sunflower	0.45 to 0.75	Dense white pubescence

Range sites were characterized botanically and herbaceous biomass was determined periodically--monthly on a few range sites. An 81,000-hectare study site has been classified by both photointerpretation and computer classification procedures for two overpass dates. The "mixed brush", a category that ranges from 15 to 80% ground cover by woody vegetation gives the most difficulty spectrally. The PVI was highly correlated with biomass of the grassland sites. A December overpass analysis suggested that an estimate of the base herbaceous productivity of the "mixed brush" range sites may be possible in the winter when the woody species are dormant.

These results indicate that forage production differences can be observed using LANDSAT digital data and a forage production map produced for a given range site. This information may be useful for balancing livestock numbers with available forage, determining range readiness, and evaluating cattle distribution over large pastures. It is possible that forage production can be estimated better from LANDSAT data than the range sites can be discriminated spectrally or defined classically from plant community-soil associations. If so, computer generated maps and tables for estimating forage conditions of open rangeland can still be provided range managers even though range sites (that grade into each other spectrally) cannot be well mapped.

Matrices presenting the simple correlation of each ground truth variable with each LANDSAT band show that plant population (POP, plants/ha), percent ground cover (PC) and LAI of grain sorghum are the most consistently related to LANDSAT MSS digital counts (DC). Linear combinations of the other plant parameters such as POP, PC, plant height (PH,cm) account for from 67 to 90% (R^2X100) of the variation in LAI and from 69 to 89% of the variation in grain yield.

Evidently there is approximately a 60 day period during which LANDSAT spectral indicators, such as PVI, relate to grain yields of sorghum. The corresponding physiological development interval is from growing point differentiation (GPD) to halfway between 1/2 bloom (1/2 BLM) and physiological maturity (PM). This finding indicates that a crop such as grain sorghum can be divided into spectral classes based on one or the other of the vegetation indices discussed in this report with a different anticipated yield per hectare associated with each different class. May is the best single month for this purpose in south Texas because leaf area is fully developed and stable during this month. The classes can be mapped by the table look-up procedures also presented.

During this contract period, the USDA Weslaco LANDSAT analysis system has been improved by reducing manual effort, documenting programs and developing cost accounting. An exemplary improvement is the ability to locate sample segment coordinates to the nearest record and pixel in CCT; thus the same ground area can now be readily located in multi-temporal overpasses. The system is tested by periodically classifying the crops and land uses in a 397,000-hectare county.

Recommendations

Because plant stress often decreases leaf chlorophyll concentration, visible light reflectance may be greater for stressed than nonstressed plants at the 0.45- (chlorophyll absorption band), 0.55- (green reflectance peak), and 0.68- (chlorophyll absorption band) μm wavelengths. Generally, linear correlations of reflectance with chlorophyll concentrations have been best at the 0.55- and 0.68-μm wavelengths. Narrower wavebands, ratioed wavebands, and more carefully selected filtration are needed to consistently identify such stresses.

Plant stresses have been detected over the 0.75- to 2.5-μm near infrared region through changes in leaf structure and water content. Further, the work has indicated that 1.65- and 2.2-μm are candidate wavelengths for plant species discrimination.

Soil is much less reflective than green vegetation at 0.9 μm (LANDSAT band 7, 0.80- to 1.1-μm) and much more reflective at 1.65- and 2.2-μm, making each of these latter wavelengths valuable for distinguishing vegetation from bare soil and for assessing vegetation cover or density. NASA is urged to provide a sensor with good signal:noise ratio around either the 1.65- or 2.2-μm wavelength on forthcoming satellite sensor systems such as the thematic mapper of the Earth Observation Satellite. Such a sensor will provide additional spectral information independent of that available in the visible and reflective infrared plateau regions, and should aid greatly in land use classification, crop discrimination, yield estimation, and geologic applications of earth resource satellites.

When the above sensor is provided, the next most limiting information will be ancillary weather data. NASA should cooperate closely with other administrations and departments of the government to develop near real time temperature, insolation, and precipitation information networks.

The vegetation vigor classes that can be automatically mapped will be most useful when the major crops can be discriminated. Thus, there is need for work on operationally implementable decision tree approaches that identify major crops and land uses and determine the hectarage of each prior to assignment of vigor classes. Incorporation of ancillary crop history, crop calendar, and weather information will likely be necessary to raise the crop recognition levels to an acceptable level. If the pixels can not be associated with specific crop or land uses, the generalized vigor classes can still express growing conditions relative to those at the same calendar time or expected phenological stage during a "good" or a "drought" year.

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1.0 INTRODUCTION

1.1 OBJECTIVES

As indicated in the PREFACE, investigations conducted herein built on previous experience and expertise gained through joint ARS-USDA in-house and NASA SR&T and ERTS-1 contract funding. The objectives of this present contract were to test agricultural applications of LANDSAT-1 and -2 data in Willacy and Hidalgo counties in Southern Texas, specifically:

(1) To further refine the achievements gained from analysis of ERTS-1 data with regard to crop identification, acreage estimation, relating spectral variation among fields to yield variation, and relating near-infrared reflectance to crop vigor and leaf area index, in Hidalgo County, Texas, specifically to:

- (a) perform a temporal analysis of crop and soil categories-repetitive cover permitting:
- (b) determine the practicality of dividing a given crop into spectral subclasses based on stage of development and objective indicators of yield potential.

(2) To relate the spectra of the terrain in Willacy County to:

- (a) the 17 range sites that have been identified,
- (b) the nonproductive (tidal flats, sand dunes) and productive (farmland, rangeland) land.

(3) To accomplish a cost-effectiveness analysis, to include a consideration of the functions of crop identification, acreage estimation, yield determination, and related functions as performed during this investigation. (Comparison will be shown between the use of ERTS data and data obtained from usual, long-standing, already-accepted sources.)

1.2 GENERAL APPROACH

These objectives were met through the combined use of ground truth and analyses of LANDSAT MSS CCTs on a human interactive digital computer and display system. Supporting data for interpretation of digital tapes consisted of ground truth taken close to the time of LANDSAT passage, information existing from previous investigations, high and low altitude photography taken since 1971, existing soil and range surveys, USGS topographic maps, and other data sources. These data sources were helpful in selecting training sample sites while a digital display was used to locate the training sample sites in the ERTS CCT tapes. After examination of the statistical nature of the training samples, other resolution elements in the ERTS data were judged by computer techniques as belonging, or not belonging, to classification categories represented by the training samples.

In other cases, procedures unknown at the time of contract award have been devised. The newer procedures are highlighted in the section "INFORMATION EXTRACTION."

Appendix A, entitled "Computerized Information Extraction System Using LANDSAT MSS Data for Surveying Agricultural Crop and Soil Conditions" describes the system devised at Weslaco that integrates the new procedures with the more traditional ones. Included in the system is cost accounting of the computer functions that aid cost benefit analysis of human-computer interactive system with photointerpretation or ground survey methods. Additional descriptions of new procedures are given in Appendix "B".

1.3 DATA PRODUCTS

Table 1.1 is a listing of photoproducts and CCT ordered and received by satellite overpass dates and scene I.D.'s in support of this investigation. Our procedure was to obtain a band 6 black-and-white positive transparency (1:1,000,000 scale) of every scene over our study area for "quick look" cloud condition assessment and digital quality impression, then order 2 color composite transparencies of bands 4, 5, and 7 and CCT of usable scenes. It was usually a month after the satellite overpass before the ASCS Western Aerial Photographic Laboratory at Salt Lake City could identify scenes for us. On the average, a month elapsed between date of mailed orders and receipt of the photoproducts. Orders for CCT (obtainable only from the EROS Data Center, Sioux Falls, So. Dak.) typically required 2 months for delivery. In no case did we receive the CCT within 3 1/2 months of acquisition by satellite.

The same satellite scene encompassed both our coastal (Willacy and Kenedy counties rangeland) and inland (Hidalgo County cropland) study sites. The scene the day after our prime pass overlapped to include some of our most westerly study sites in Hidalgo County, so that we considered the secondary day's data when cloud conditions dictated it or the LANDSAT-2 MSS was turned off before reaching our study sites, as occurred inadvertently once each in 1975 and 1976. The LANDSAT-1 MSS was turned off permanently, as far as we can tell from Table 1, after about 5/1/76.

Table 1.1 shows that we had 3 usable LANDSAT-1 and 4 usable LANDSAT-2 scenes in 1975. The 12/28/75 LANDSAT-2 overpass was very acceptable for the rangeland area, but it is quite close chronologically to the 12/10/75 overpass that was clear over the entire scene. In 1976, 0 LANDSAT-1 and 5 LANDSAT-2 scenes were usable. Of these, only the 5/3/76 coverage occurred during the warm crop season, so that digital data were lacking to relate excellent ground truth to. This lack of cropland data in 1976 was partially recompensed by data obtained on 5 dates (5/3; 5/21; 6/8; 6/26; and 8/1) near Temple, TX. Excellent ground truth was obtained there in 10 grain sorghum fields in conjunction with cooperative studies on a spectral-physiological model for grain sorghum.

Table 1.1 - LANDSAT-1 and -2 overpass dates, scene I.D.'s, cloud conditions, and dates photoproducts and CCT were ordered and received in support of the reported investigations.

Date	Scene I.D.	Photo products Ordered	Photo products Received	CCT Ordered	CCT Received	Cld. %
LANDSAT-1 (Weslaco)						
3/24/75	1974-16142	8/29/75	10/16/75			10
4/11/75	1992-16132	"	"			10
5/17/75	5028-16113	"	"	10/17/75	12/18/75	40
6/4/75	5046-16103	"	"	10/17/75	12/18/75	40
7/10/75	5082-16083	"	"	10/17/75	1/23/76	10
8/15/75	5118-16062	10/17/75	11/17/75			30
8/16/75	5119-16120					20
9/2/75	5136-16052	(12/9/75)	12/16/75			40
9/20/75	5154-16042	"	"			60
10/8/75	5172-16031	"	"			40
4/23/76	5370-15502	(6/22/76)	7/13/76			90
Note: Scanner off 4/29/75, 6/22/75, 7/28/75, 5/11/76, 5/29/76, 6/16/76, 7/4/76, 8/9/76						
LANDSAT-2 (Weslaco)						
4/2/75	2070-16203	8/29/75	10/16/75	7/28/75	9/29/75	20
4/3/75	2071-16261	5/27/75	6/15/75			0
4/20/75	2088-16203	8/29/75	10/16/75			90
5/8/75	2106-16200	"	"			40
5/8/75	2106-16202	"	"			50
5/26/75	2124-16202	"	"	5/14/76	7/7/76	40
6/13/75	MSS turned off	-	-			-
7/1/75	2160-16204	8/29/75	10/16/75			40
7/2/75	2161-16255	8/19/75	9/8/75			
7/2/75	2161-16262					
7/19/75	2178-16202	8/29/75	10/16/75			40
8/6/75	2195-16195	"	"			60
9/11/75	2232-16192	(12/9/75)	12/16/75			30
10/17/75	2268-16190	(12/23/75)	1/6/76	1/30/76	3/4/76	0
12/10/75	2322-16183	(2/25/75)	3/1/76	5/14/76	7/7/76	0
12/28/75	2340-16182	(2/25/76)	3/1/76			20
2/2/76	2376-16175	6/23/76	7/13/76	Unknown	8/2/76	0
4/14/76	2448-16154	(6/22/76)	7/13/76			95
5/2/76	MSS turned off					0
5/3/76	2457-16210	"	"	7/16/76	8/23/76	10
5/20/76	2484-16145	"	"			100
6/8/76	2503-16200	"	"			60
6/25/76	2520-16135	(9/3/76)	9/20/76			50
7/31/76	2556-16125	"	"	9/21/76	11/16/76	25
8/18/76	2574-16122	"	"			85
9/23/76	2610-16112	(11/17/76)	12/6/76	11/17/76	3/16/77	10
10/11/76	2618-16104	(11/17/76)	12/6/76	11/17/76	3/16/77	10

( ) around order date means date order activated at SLC; w/o ( ) = date order mailed.

Figures 1.1 through 1.4 are prints of Hidalgo county at 1:450,000 scale for overpasses on 4/2/75, 7/10/75, 10/17/75, and 12/10/75, respectively. (Note: Some copies of this report contain prints from the color composites while the remainder contain band 6 black-and-white prints.) The prints give a good impression of the seasonal agricultural changes in the county. These and other scenes provided the data for multitemporal analyses.

1.4 CLIMATE AND WEATHER

Since our test sites are located in a sub-humid, semi-tropical climatic regime where the agricultural enterprises consist of irrigated farming, dryland farming, and ranching, rainfall is the dominant factor in determining vegetation conditions from April through November. Temperature is limiting from December through March.

Table 1.2 lists the long-term normal rainfall and the rainfall for 1975 and 1976 by months for 3 weather observation stations within the test site area. Rainfall decreases by 1 cm/4.5 km inland from the coast which yields a natural gradient in indigenous vegetation and plant available soil water. Raymondville is located toward the coastal (eastern) side of the test area, Weslaco is at a mid scene location, and McCook (30 km. NW of Edinburg, TX) is representative of rainfall conditions on the western edge of the study area.

Table 1.2 shows that, compared with long-term normal rainfall, the test site area was experiencing a drought January through April 1975. Dryland grain sorghum yielded only about half as much as in a good rainfall year. July, August, and September rainfall was far above normal resulting in lush rangeland cover in the fall of 1975. In 1976, rainfall through June was somewhat below normal, but its distribution was timely and average dryland yields were obtained. Between July and December 1976, all-time record rainfall was recorded, leaving many areas with standing water.

Table 1.2 -- Long-term normal, 1975 and 1976 rainfall in mm by months for three locations within South Texas LANDSAT follow-on study area.[1]

	McCook			Raymondville			Weslaco		
	Long term[2]	'75	'76	Long term	'75	'76	Long term	'75	'76
Jan.	39	32	16	41	36	15	36	30	31
Feb.	33	14	1	33	23	1	29	14	0
Mar.	25	0	38	22	4	22	20	1	19
Apr.	35	1	65	39	1	74	37	0	86
May	82	59	65	95	100	44	73	30	42
June	68	48	11	68	116	94	64	35	23
July	25	201	179	33	159	192	32	247	234
Aug.	53	87	9	70	145	83	59	116	76
Sept.	93	132	58	130	307	135	100	149	129
Oct.	63	56	114	67	37	135	59	23	129
Nov.	24	0	96	35	15	108	34	0	105
Dec.	23	19	37	24	32	43	23	44	40
Total	563	658	689	657	975	946	566	689	914

[1] 1975 data from Potter, T. D. 1976. Climatology Data - Texas Annual Summary 1975. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Vol. 80, No. 13. 31 pp. 1976 data from the monthly summaries, same series.

[2] Long-term normal is 30-year average for the years 1941 through 1970.

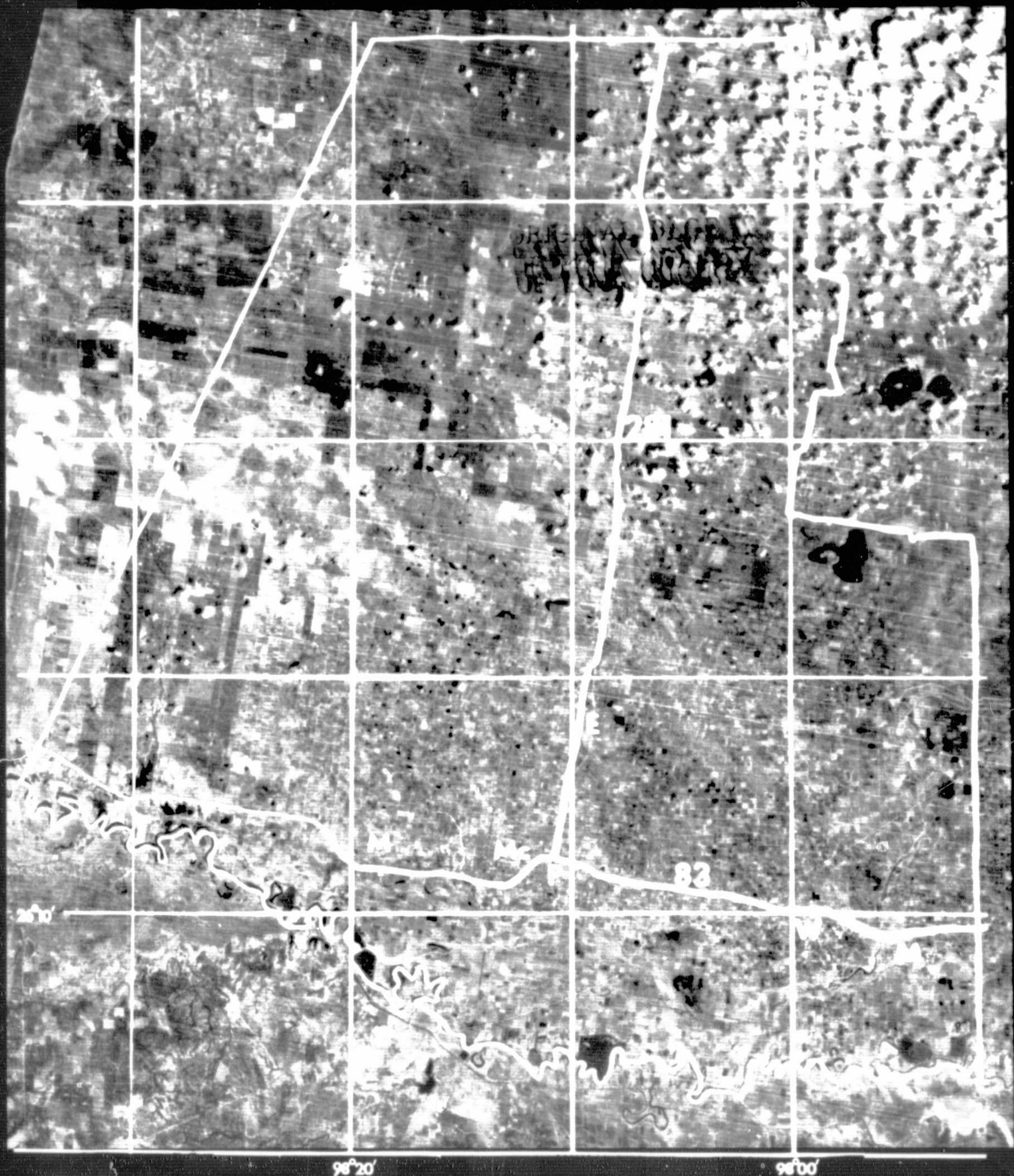


Fig. 1.1

LANDSAT-2 color positive print (bands 4, 5, and 7; scale 1:450,000) depicting crop and soil conditions in Hidalgo County, Texas (397,000 ha), for April 2, 1975, overpass (scene I.D. 2070-16203). Superimposed on the image are an outline of the county, latitude and longitude coordinates, the Rio Grande, and highways 83 and 281. Cream colored areas are bare soil, reddish tones are vegetation, and dark blue areas are water. County was experiencing a severe drought (low rainfall, high temperatures).

Fig. 1.2

LANDSAT-1 color positive print (bands 4, 5, and 7; scale 1:450,000) depicting crop and soil conditions in Hidalgo County, Texas (397,000 ha), for July 10, 1975, overpass (scene I.D. 5082-16083). Cream colored areas are bare soil, reddish tones are vegetation, and dark blue areas are water. County was experiencing a severe drought.

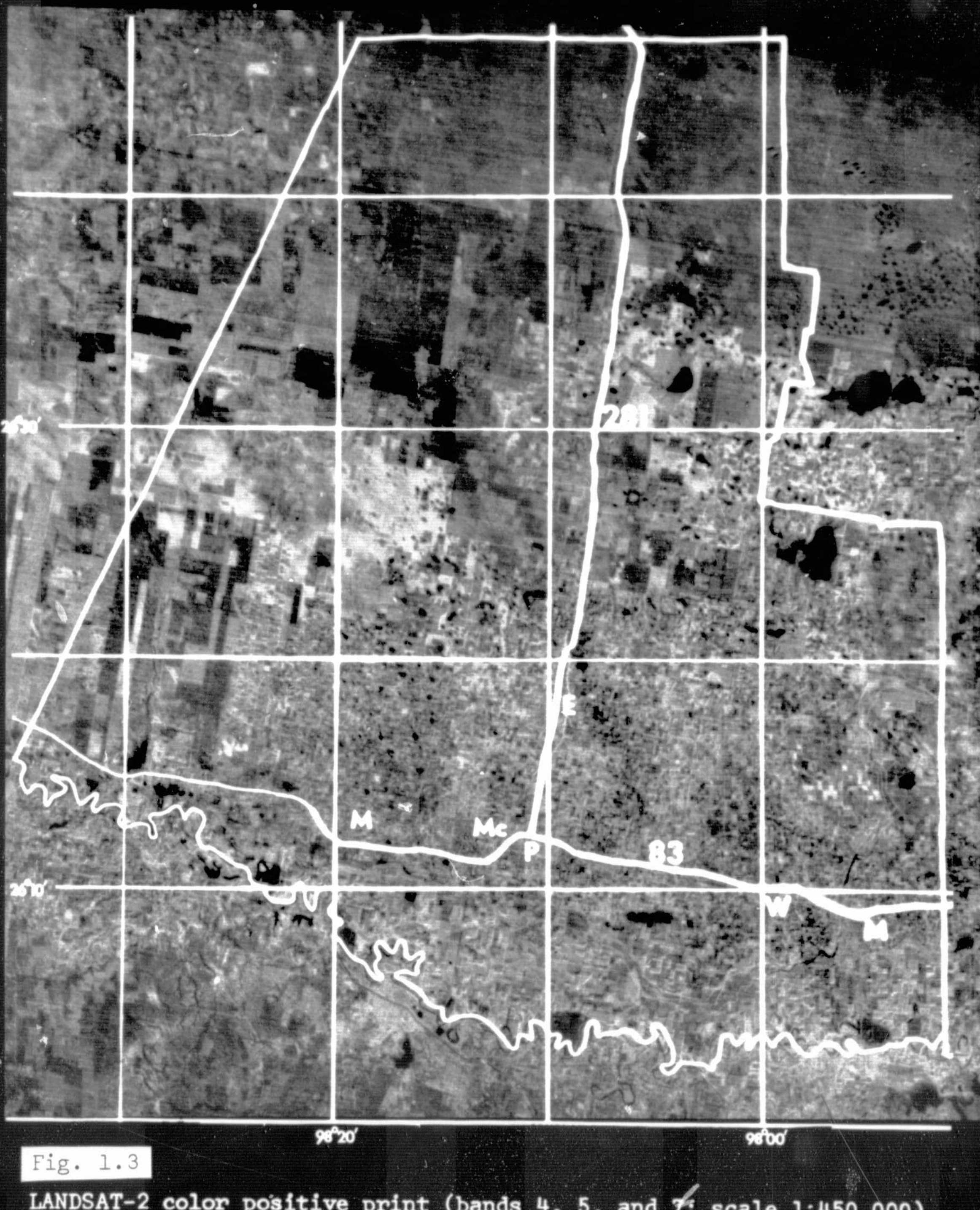


Fig. 1.3

LANDSAT-2 color positive print (bands 4, 5, and 7; scale 1:450,000) depicting crop and soil conditions in Hidalgo County, Texas (397,000 ha), for October 17, 1975, overpass (scene I.D. 2268-16190). Cream colored areas are bare soil, reddish tones are vegetation, and dark blue areas are water. Drought was broken by rains beginning July 13.

Fig. 1.4

LANDSAT-2 color positive print (bands 4, 5, and 7; scale 1:450,000) depicting crop and soil conditions in Hidalgo County, Texas (397,000 ha), for December 10, 1975, overpass (scene I.D. 2322-16183). Cream colored areas are bare soil, reddish tones are vegetation, and dark blue areas are water. Wet conditions continued but temperatures were too low for most plants to grow.

2.0 INFORMATION EXTRACTION

2.1 Table Look-up Procedure for Rapidly Mapping Vegetation Cover and Crop Development.

A manuscript with the same title as this subsection has been prepared by A. J. Richardson and C. L. Wiegand for the June 1977 Symposium on Machine Processing of Remote Sensing Data at Purdue University. The comprehensive summary follows:

Efforts to interpret vegetated surface reflectance from aircraft and satellite multispectral scanner (MSS) observations have been hampered by soil background signals that are superimposed on information about vegetation. Soil reflectance varies with soil type, water content, and tillage. Kauth and Thomas (1975) determined that the data space distribution of soil reflectance variation in LANDSAT data is confined to a plane in 4-dimensional space or a line in 2-dimensional space. Our objective was to develop a table look-up process for coping with the soil background in LANDSAT MSS digital data space that we believe will lead to an operational use of LANDSAT data to better monitor the productivity of range, forest, and crop lands.

For six LANDSAT-1 and -2 overpass dates (4/2, 5/17, 6/4, 7/10, 10/17, and 12/10/75) of the south Texas area, the mean MSS digital data for water, clouds, cloud shadows, high reflecting soil, low reflecting soil, and sorghum at various stages of maturity were extracted, for ground-truthed land areas, from LANDSAT computer compatible tapes (CCT) for bands 5 and 7. A linear correlation of band 5 on band 7 was calculated using the MSS digital means from cloud, cloud shadow, high reflecting soil, and low reflecting soil for all six LANDSAT overpass dates. The soil background line, for which cloud and cloud shadows formed the upper and lower extensions, respectively, was defined by MSS5 = -0.01 + 2.4 MSS7 and characterized by $r^2 = 0.972$ and Sy.x = ±6 digital counts. Thus, we discovered that Kauth's line of soils is a family of overlapping soil categories that can be extended to include clouds and cloud shadows.

Soil water content and soil tillage conditions vary from observation date to observation date causing the signature of a given field to migrate downward along the line when wet and upward from the median position when in a dry crusted condition. Increasing crop development or vigor is manifested by a migration of vegetation points perpendicularly away from this soil background line.

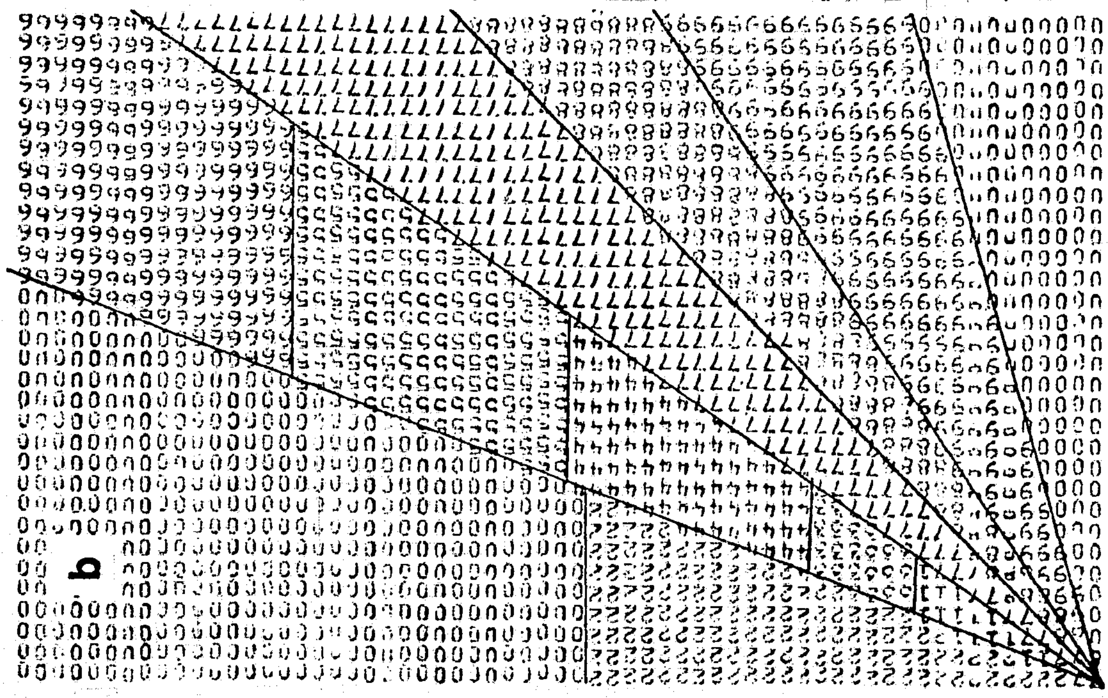
Based on the above findings, a table look-up technique for classifying plant, soil, water, and cloud conditions for any LANDSAT overpass for any date for any study area location has been devised as shown in Figures 2.1a and 2.1b. The LANDSAT data space, determined by bands MSS5 and MSS7, have been divided into decision regions corresponding to 10 general categories as shown in Figure 2.1a. Kauth's line of soil, which serves as a cardinal reference, is shown to be an inverted cone with apex at the origin that can be thought of as an expanding brightness scale composed of low (3), medium (4), and high (5) reflecting soil. The cone is terminated at the bottom by shadow (1) and is bounded at the top by the sensor saturation response for clouds (6). As sun angle or illumination decreases, the range of soil reflectance is lessened and the data are compressed toward the apex of the cone at the origin. Similarly, the variations of vegetation reflectance for low (7), medium (8), and high (9) vegetation cover follow conical paths that become narrower with decreasing sun angle or illumination. Water (2) is shown to be on the opposite side of the soil brightness scale from vegetation. The regions into which no LANDSAT data are expected to fall are called thresholds (0).

The signature categories of Figure 2.1a were defined as numbers ranging from 0 to 9 in the table depicted by Figure 2.1b. The candidate MSS5 and MSS7 signature pair is used as an address for the table in Figure 2.1b. The number at that specific address defines the signature category of the candidate signature pair. The process is repeated for each signature pair. Classification maps are prepared by printing the appropriate symbol for each classification decision. The decision boundaries representing degrees of soil brightness and densities of vegetation cover are arbitrary within our experience to date. More applications and tests of them are needed to define meaningful boundaries for particular crop and soil conditions. However, we have mapped a 390,000 ha test county for 4 satellite overpass dates with results that are in very close agreement with reality (Table 2.1).

These results indicate that based on past experience without any ground truth, the table look-up technique will allow delineation of any LANDSAT scene into vegetative cover stages, degrees of soil brightness, water, cloud and cloud shadow. Such information used in conjunction with ancillary data about rainfall, temperatures, evapotranspiration, and crop calendars should lead to strategies useful for monitoring crop development, and for associating vegetation vigor and yield in large area crop yield prediction efforts. The procedure could also be directly useful and implementable as an editing procedure at the front end of decision tree analyses in which data are directed to the appropriate flow network for further processing and analysis based on the categories water, soil, and vegetation into which they fall. The ability to classify clouds and cloud shadows permits ground areas behind clouds or in the shadows of clouds (in nonmountainous land areas) to be edited out of data sets before classification procedures are implemented, or to incorporate these training signatures into classification algorithms. Thus, the technique we described can be used in rapid machine processing and classification procedures.

The procedures described entail a significant departure from the mainstream of current pattern recognition and remote sensing practice in which training samples chosen from within a data set are characterized and associated with ground conditions, then all other pixels are compared by a maximum likelihood or other algorithm with the training subset and classified. In the present procedure spectra historically characteristic of soil, water, vegetation, clouds, and cloud shadows are used to classify all of these categories, and to yield subcategories of soil and vegetation. Used alone, the procedures can rapidly map vegetation conditions. When the composition of the crop mixture in a scene is known, the procedures should be useful to check on phenological development, to assess drought conditions or other growing conditions relative to normal years and, hence, help predict yield performance. In any case, the procedures offer opportunities for refreshing alternatives to past practice. They seem particularly applicable to characterizing vegetation densities and quantifying bare soil amounts as indicators of drought, evapotranspiration, soil erosion by wind or water, and rainfall run-off.

If the plant, soil, and water spectra are essentially universal as they appear to be, the procedures are especially attractive when ground truth is unavailable--as in foreign countries. Even where ground truth is available, the table look-up appears to reduce the amount required. It also saves computer and operator time as an editing device to remove nuisance categories in classification such as clouds and cloud shadows. Thus, it seems to have very cost effective application in any number of candidate operational applications or application subsystems. Placement of a dollar value or cost benefit ratio on it would require an analysis of specific applications.



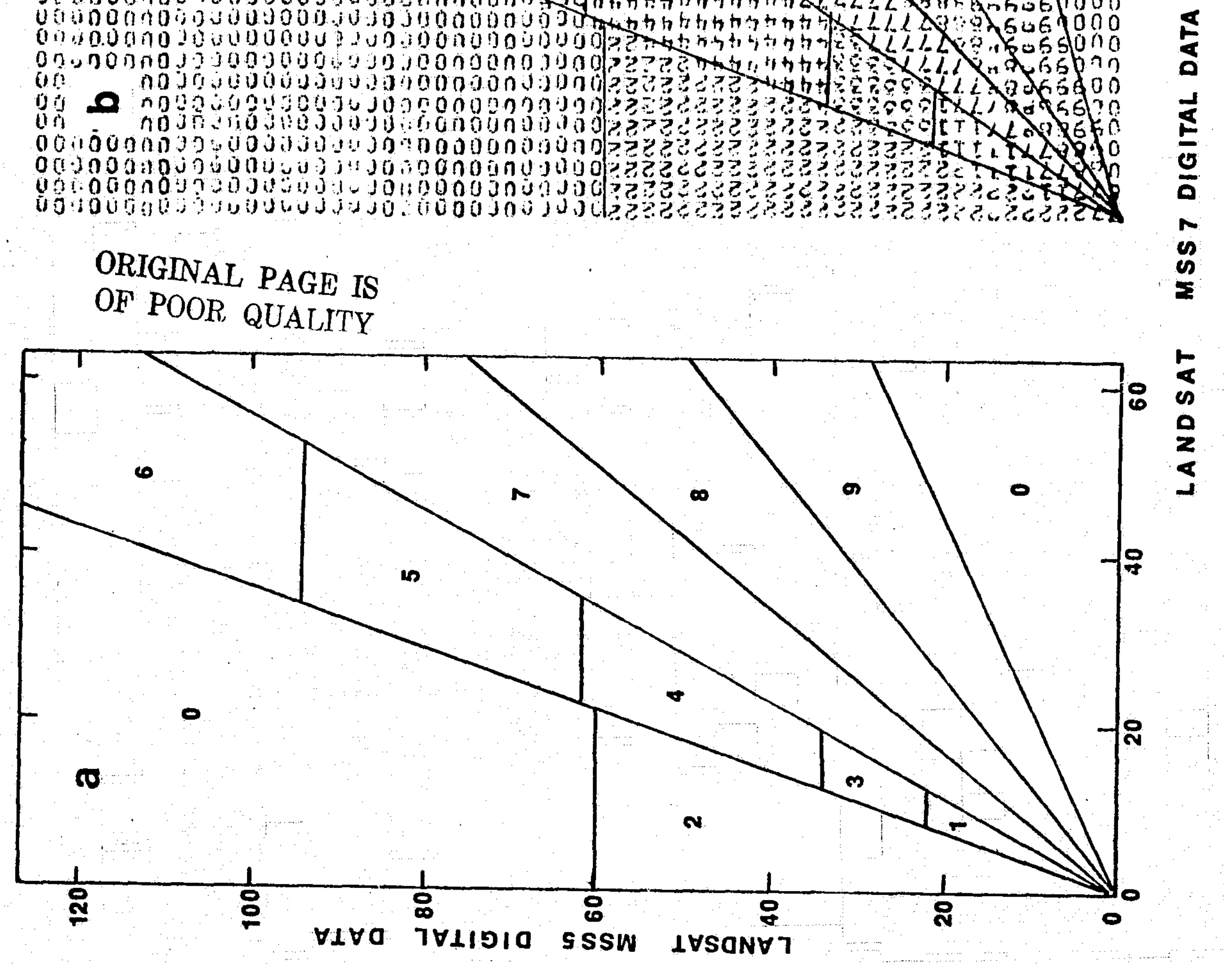


Fig. 2.1a Diagram showing division of LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories as follows: Threshold (0), cloud shadow (1), water (2), low reflecting soil (3), medium reflecting soil (4), high reflecting soil (5), clouds (6), low cover vegetation (7), medium cover vegetation (8), and high cover vegetation (9).

Fig. 2.1b Table look-up matrix devised to implement the division of LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories as follows: Threshold (0), cloud shadow (1), water (2), low reflecting soil (3), medium reflecting soil (4), high reflecting soil (5), clouds (6), low cover vegetation (7), medium cover vegetation (8), and high cover vegetation (9).

Table 2.1 Table look-up acreage estimation results of vegetation, soil, and water conditions in Hidalgo County, Texas, for 4 LANDSAT overpass dates. The sun elevation above the local horizon is given, in parenthesis, for each date.

Vegetation, soil, & water conditions	LANDSAT-1 and -2 overpass dates							
	4/2/75	(51°)	7/10/76	(56°)	10/17/75	(44°)	12/10/75	(32°)
	Hectares (Thousand)	Percent	Hectares (Thousand)	Percent	Hectares (Thousand)	Percent	Hectares (Thousand)	Percent
Water	4	1	3	1	5	1	5	1
Cloud shadows	4	1	1	0	1	0	2	0
Fallow soil	161	38	175	41	154	36	169	40
Low reflectance	44	11	59	14	20	5	84	20
Med reflectance	113	26	115	27	125	29	85	20
High reflectance	4	1	1	0	9	2	0	0
Cloud	1	0	0	0	0	0	0	0
Vegetation	251	60	248	59	268	63	258	59
Low density	213	51	190	45	183	43	194	45
Medium density	34	8	45	11	65	15	17	4
High density	4	0	13	3	20	5	17	4
Threshold	0	0	0	0	0	0	0	0
Total	421	100	427	100	428	100	429	100

2.2 DISTINGUISHING VEGETATION FROM SOIL BACKGROUND

Experience has been that crops are discriminated with acceptable accuracy by the time they have developed enough ground cover to obscure the soil background. Until then, confusion among crops and with bare soil is high. For example, we have observed that cropped fields with ground cover up to 40% are often misclassified as bare. Consequently, we reasoned that soil variation is superimposed on the crop spectra at incomplete plant covers that interferes with discrimination. Thus, we began to investigate the distribution of soil reflectance variation in LANDSAT MSS data, so that we might be able to account for or remove it. When we discovered (or rediscovered after Kauth, op. cit.) that soils occupy a more or less stable position in MSS data space, we began to investigate whether the soil background could serve as a reference against which to gauge vegetation development. These investigations are summarized in a manuscript, "Criteria for Distinguishing Vegetation from Soil Background Information and Their Use in Processing LANDSAT MSS Data," by A. J. Richardson and C. L. Wiegand that has been submitted to Photogrammetric Engineering and Remote Sensing for publication consideration. It is included in this report as Appendix B.

Especially pertinent in this manuscript is the description of a Perpendicular Vegetation Index (PVI) defined as the perpendicular distance in MSS band 5 and 7 data space from a candidate vegetation point to the soil background line defined in the subsection 2.1 and in Appendix B. The distance from the soil background is a characterizer of vegetation density or vigor among natural or cultural plant communities (or of crop development within a single crop). However, the calculation of PVI requires a determination of the coordinates of the intersection of the perpendicular with the soil background line. Since the point of intersection for a given scene element can be expected to migrate downward from the median position when the soil is wet or has just been tilled and upward as it is bleached by the sun or is rain-crusted, it is anticipated that information about the physical condition of the soil behind the plants may be gained. Shading of the soil by plants would also cause it to darken, so the difference between the intersection point and the cloud shadow point may also yield information on the amount of shadow in the composite scene mixture composed of plants, soil, and shadow. We have not yet investigated the seasonal migration of the soil background intercept. We lack detailed ground truth on the physical condition of the soil behind the plants and documentation of the soil and plant shadow amounts. Thus, we may be unable, with present data, to make definite interpretations.

2.3 LANDSAT VEGETATION INDICES VERSUS SORGHUM PLANT PARAMETERS AND GRAIN YIELDS.

In the last section, 2.2, and in Appendix B of this report, we present information on various vegetation indices. To recapitulate, these indices are the Transformed Vegetation Index (TVI), the Perpendicular Vegetation Index (PVI), and the Green Vegetation Index (GVI) defined in terms of LANDSAT MSS bands as follows:

$$TVI = \sqrt{\left(\frac{7 - 5}{7 + 5}\right) + 0.5}$$ .. TVI6 uses band 6 instead of 7.

$$PVI = \sqrt{(5g - 5p)^2 + (7g - 7p)^2}$$ where in

g is the point of intersection on the soil background line of a perpendicular from the position in 5 and 7 data space occupied by a candidate pixel (7p, 5p), containing vegetation or plant information. PVI 6 uses MSS band 6 instead of band 7.

GVI = -0.290(4) - 0.562(5) + 0.600(6) + 0.491(7). This index, also known as Kauth's green index, is a transformed index that is perpendicular to the soil brightness index, SBI. The latter is not defined here.

The simple correlation coefficients, 4, relating grain yields of irrigated sorghum in 1973 and 1975 with the vegetation indices TVI, TVI6, GVI, PVI, and PVI6 are listed in Table 2.3.1. There was only one usable satellite overpass in 1973, but there were four distributed over the growing season in 1975. The 5/26/75 data lack one day being taken on the same day of the year as the 1973 data.

The simple correlations have about the same magnitude, except for the 6/4/75 data, for all the vegetation indices. Thus, if any are useful, they should all be. Table 2.3.2 presents the yield (kg/ha), the PVI on each of four overpass dates, and the simple correlation between PVI and yield on each overpass date. Missing data are due to clouds that obscured two fields on each 5/26 and 6/04. The PVI are shown to increase between successive dates through 5/26, as the crop developed. By 5/26 the plants had headed and grain filling was in progress. We can not account for the irregularity in the PVI numbers on 6/04. However, Mr. Gerbermann of our staff has observed that the LAI of grain sorghum is a maximum when the heads emerge from the boot, and that thereafter the lower leaves senesce rapidly. Grain sorghum is also highly susceptible to foliar diseases that cause leaf necrosis during its grain filling and maturation periods, i.e. after it reaches bloom stage. These and other data we have lead us to believe that spectral indicators of yield in grain sorghum, that are assessing the amount of green biomass, can not be made later than about half way between 1/2 bloom and physiological maturity.

The surprising thing to us is that the vegetation indicators are useful as early in the growing season as they are. Average planting date for grain sorghum at our study site is 3/1. By 4/1 sorghum has an LAI of only 0.2 to 0.3. The data in Table 2.3.2 and literature references on sorghum growth and development (Vanderlip and Reeves, 1972; Arkin, Vanderlip, and Ritchie, 1977) indicate that whereever grain sorghum is grown, there will be about a 60-day period during which LANDSAT spectral indicators may relate to grain yields.

The indications are that a crop such as grain sorghum or wheat may well be divided into spectral classes based on one or the other of the vegetation indices with a different yield per hectare associated with each different class. The classes can be mapped by the table look-up procedures presented in section 2.1 and Appendix B of this report.

Figure 2.3.1 relates all available May 1973, 1975, and 1976 PVI numbers to grain sorghum yields in those years. The only reason the May data are included is that by May, grain sorghum plants have reached full leaf development so that reflectance is stable, and comparable among years. For the 3 years of data, sorghum grain yield (kg/ha) is expressed by

$$\text{Yield} = 1266 + 199\ \text{PVI}.$$

The standard error of estimate is ± 1058 kg/ha and PVI explains 55% of the variation in yield. Thus, it appears that we are able to relate a spectral indicator of vegetation conditions to yield across years.

In Table 2.3.3 we present the simple correlations between the spectral vegetation indices and each of the ground truths, leaf area index (LAI), percent plant cover (PC), plant height (PH), plant population (POP), and grain yield for dryland and irrigated grain sorghum. The reason we segregate the irrigated and nonirrigated grain sorghum is that predominant planting configurations and seeding rates differ. Under irrigation, the better farmers are planting two rows of grain sorghum about 20 cm apart on beds spaced 100 cm apart using seeding rates up to 16 kg/ha (14 lb/ac). In the dryland, rows are typically 100 cm apart and 10 kg/ha (8 to 10 lb/ac) of seed is planted. As mentioned in the INTRODUCTION, 1975 was a drought year. The 1975 data in Table 2.3.3 for the nonirrigated sorghum show that the vegetation indices and plant population were negatively correlated. The ground truth listing shows that the dryland field with the highest plant population produced the lowest yield. That information plus the positive correlation between dryland yield in 1975 and the vegetation indices indicate that the fields with the highest populations ran out of water and the plants dessicated (and turned brown). Consequently, the lower population fields had more green, or live, plant material and produced the better yields.

The simple correlation between the vegetation indices and the ground truth are not consistently high for any one ground truth. However, our cumulative experience is that plant population and percent cover are perhaps the two plant parameters that relate most closely to the spectral indicators of vegetation conditions. Leaf area index can be excellent but is not consistently so and is time consuming, so we are tending to de-emphasize

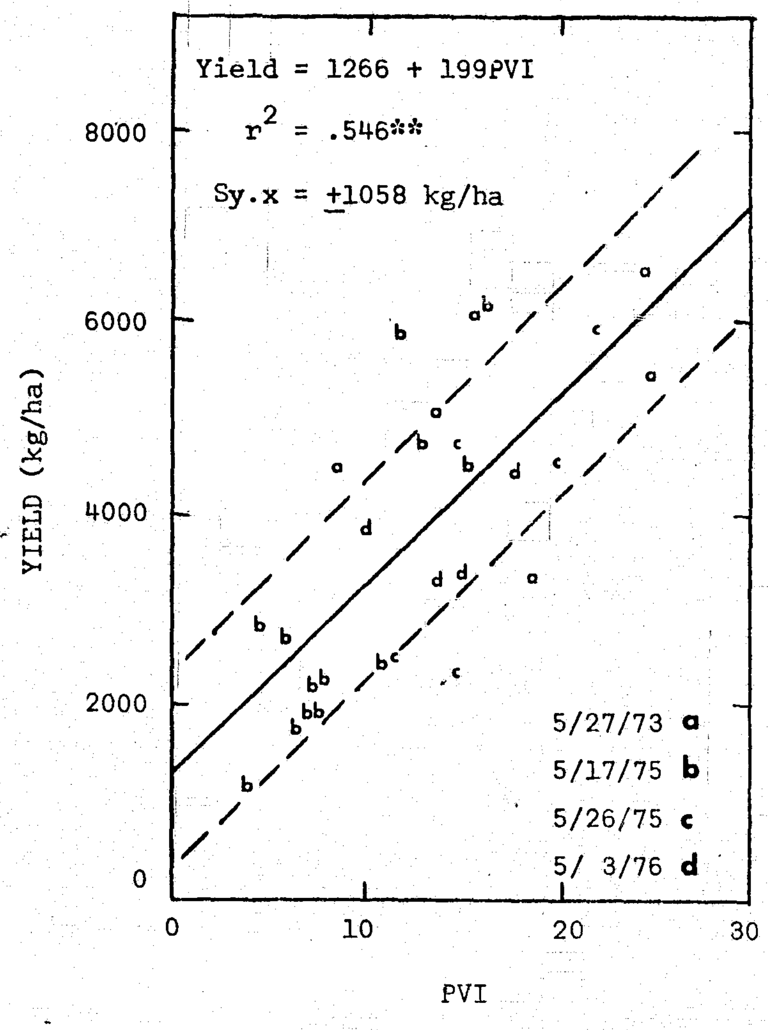


Fig. 2.3.1 Relation between PVI and sorghum grain yield (kg/ha) in May 1973, 1975, and 1976.

Table 2.3.1 Simple correlation of irrigated sorghum grain yields (kg/ha) with the vegetation indices in 1973 and 1975.

VEG.	DATE				
INDEX	5/27/73	4/2/75	5/17/75	5/26/75	6/4/75
			SIMPLE CORRELATION, r		
TVI	0.634	0.709	0.644	0.822	0.290
TVI6	0.777	0.752	0.549	0.759	0.401
GVI	0.775	0.776*	0.678	0.755	0.237
PVI	0.676	0.738	0.740	0.806	-0.027
PVI6	0.850*	0.788*	0.638	0.708	0.167
n	6	7	7	5	5

* Significant at the 0.05 probability level.

it. [Note: In considering the correlations in Table 2.3.3, one has to remember that (a) the number of paired observations is low, (b) ground truth measurements paired with the satellite data sometimes extended over as much as a three week period, and (c) some of the MSS field means were affected by field boundaries (Malila, Cicone, and Gleason, 1976, pp. 20-29). Thus there are multiple sources of variability in the data.]

Relationships between individual MSS spectral bands and the ground truth and of the various plant parameters with each other will be presented in section 3.1 of this report. Data presented in that and this section will mutually support the deductions reached.

Table 2.3.2. Grain yields in 1975, the perpendicular vegetation index (PVI), and the simple correlation of PVI with grain yields for 4 overpass dates in 1975.

Segment Number	Yield kg/ha	Date 04/02/75	05/17/75	05/26/75	06/04/75
		- - - - - - - - - - - - - - PVI	- - - - - - - - - - - - - -		
1020-2	5868	6.9	11.6	21.9	17.2
1020-3	4562	5.9	15.0	19.7	12.6
2070-1	2459	0.0	10.8	11.2	--
2071-1	2815	3.1	4.2	--	--
3105-1	6131	11.2	15.9	--	12.9
4149-1	2295	6.7	7.6	14.5	15.2
4149-3	4755	6.6	12.9	14.5	18.6
Correlation, r	--	0.738	0.740	0.806	-0.027
Combined 04/02/75 and 05/17/75 correlation	--	0.845*			

Missing data caused by clouds over fields.
*Significant at the 0.05 probability level.

Table 2.3.3. Simple correlation of leaf area index (LAI), percent plant cover (PC), plant height (PH), plant population (POP), and grain yield with the vegetation index (VI) models for both irrigated and nonirrigated grain sorghum.

		IRRIGATED					NONIRRIGATED					
YR	VI MODEL	LAI	PC	PH cm	POP Plts/Ha	YIELD Kg/Ha		LAI	PC	PH cm	POP Plts/Ha	YIELD Kg/Ha
		CORRELATION COEF., r										
1973	PVI	.729*	.700*	.790**	.852**	.676*						
(5/27)	PVI6	.738*	.606	.815**	.883**	.850**				NO DATA		
	TVI	.627	.761*	.850**	.790**	.634*						
(10)	TVI6	.645*	.648*	.840**	.858**	.777**						
	GVI	.748*	.655*	.806**	.881**	.775**						
1975	PVI	.252	.227	.061	.714*	.738*	1975	.083	.686	.044	-.600	.527
(4/2)	PVI6	.232	.218	.053	.754*	.788*	(5/17)	.249	.530	-.413	-.265	.134
	TVI	.282	.217	.070	.747*	.709*		.173	.639	.009	-.506	.457
(8)	TVI6	.255	.260	.046	.788*	.752*	(6)	.339	.499	-.407	-.191	.090
	GVI	.249	.230	.067	.742*	.776*		.230	.585	-.316	-.336	.212
1975	PVI	.883*	.349	.453	.661	.806	1975	.175	.105	-.080	-.380	-.043
(5/26)	PVI6	.856*	.503	.360	.470	.708	(6/4)	.286	.367	.155	-.568	.218
	TVI	.951**	.467	.707	.865*	.822*		.302	.245	.029	-.393	.058
(6)	TVI6	.956**	.627	.695	.760	.759	(7)	.425	.532	.285	-.528	.186
	GVI	.861*	.416	.391	.552	.755		.300	.313	.004	-.470	.067
1975	PVI	-.064	.100	.132	.186	-.027	1976	--	.917**	.523	.311	.518
(6/4)	PVI6	.045	.173	.145	.132	.167	(5/3)	--	.770	.237	.002	.228
	TVI	.019	.169	.411	.408	.290		--	.853*	.848*	.602	.844*
(5)	TVI6	.071	.203	.411	.404	.401	(6)	--	.764	.831*	.537	.824*
	GVI	.118	.261	.288	.301	.237		--	.845*	.371	.149	.355

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
Numbers in ( ) are number of paired observations in the analysis.

2.4 Optimum Wavelengths for Discriminating Wheat

Another factor that influences discrimination of any crop from others and from the soil background is the wavelengths available (or chosen) to accomplish the discrimination. Field spectrometer measurements of the reflectance spectra of two wheat cultivars on 9 dates during the 1975-1976 growing season provided the opportunity to examine responses at 7 wavelengths--0.55, 0.65, 0.73, 0.90, 1.10, 1.65 and 2.2 µm. A manuscript entitled, "Seasonal Changes in Reflectance of Two Wheat Cultivars," by R. W. Leamer, J. R. Noriega, and C. L. Wiegand Has been submitted to Agron. J. for publication consideration.

Figure 2.4.1 compares the mean spectra for bare soil and wheat as measured on 12/31/75. Soil was much less reflective than the wheat at 0.90 and 1.1 µm and much more reflective at 1.65 and 2.2 µm, making each of these wavelengths valuable for distinguishing vegetation from the soil background and for assessing vegetation cover or density. The contrast between green vegetation and soil is greater at 0.9 than at 1.1 µm , and greater at 2.2 than at 1.65 µm.

The low reflectance of wheat and soil in the visible wavelengths (0.55, 0.65, and 0.73 µm) helps explain the difficulty in distinguishing cropped from bare fields at incomplete covers with sensors such as those on LANDSAT. The data argue convincingly for the inclusion of sensors centered around 1.65 or 2.2 µm in the sensor configurations of the thematic mapper and other future earth resource satellite MSS.

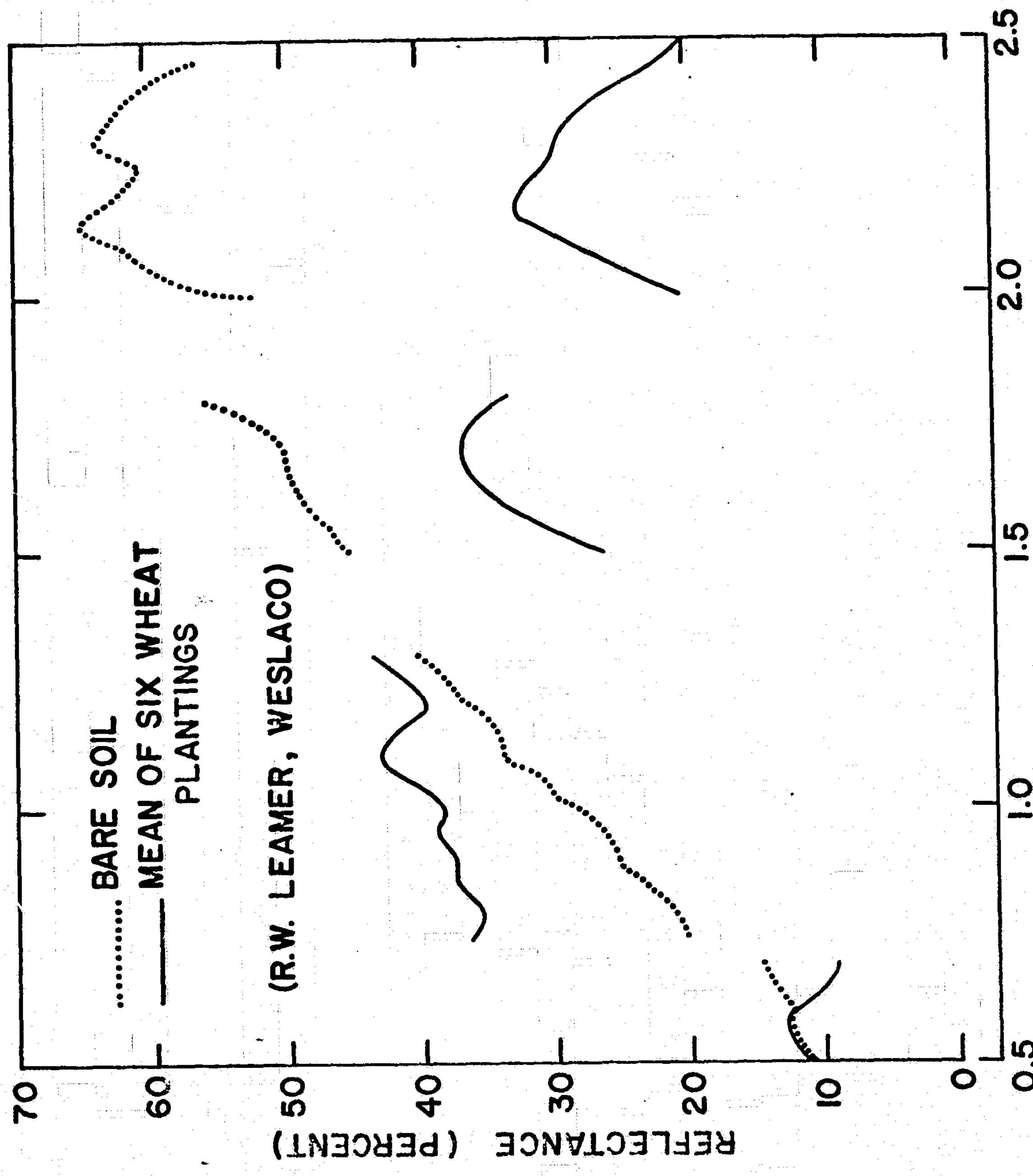


Fig. 2.4.1 Reflectance of bare soil and wheat over the 0.5 to 2.5 μm wavelength interval, as measured with a field spectrometer on 12/31/75 at Weslaco, Texas.

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3.0 CROPLAND APPLICATIONS

3.1 Spectrally meaningful ground truth and ground truth interrelationships

As indicated in Appendix A, we typically record crop species; stage of maturity; row spacing; plant height; percent ground cover by plants; row direction; Munsell color of soil; recent cultural practices such as tillage; irrigation, harvest, defoliation; and, qualitative notes on weediness, general plant vigor, and plant stand for the sample fields in the County. For intensively studied fields we have determined LAI and plant population (POP), also.

The question arises, what ground truth is meaningfully related to the LANDSAT MSS data? To answer the question, coefficients for the simple linear correlation of each ground truth variable and each LANDSAT band have been calculated with every other variable and listed in a matrice. Also, coefficients of determination were calculated for multiple correlations of yield and LAI with POP, plant cover (PC), and plant height (PH).

From these listings it appears that POP (plants/ha), percent ground cover by plant (PC) and LAI are the most consistently related to the LANDSAT MSS digital counts (DC). Table 3.1.1 presents the simple linear correlation coefficients between each of the MSS bands and POP, PC, and LAI for a sampling of grain sorghum fields in 1973, 1975, and 1976. The number of fields per data set ranged from 5 to 8; hence a large correlation coefficient is needed to attain statistical significance.

(Note: Soil typically has a higher reflectance than plants in LANDSAT bands 4 and 5 (visible light wavelengths); therefore, as POP, PC, or LAI increase the MSS response in these bands decreases, resulting in a negative correlation. Conversely, plants are more reflective than soil in the infrared bands 6 and 7, and thus, the MSS signal increases with vegetation density, so these bands are positively correlated with the vegetation indicators.)

LAI is a very labor intensive measurement to make since it entails removal of every leaf from each sampled plant (2 to 10 plants, or 1 m of row are generally used) and either optically planimetering or manually measuring the length and width of the individual leaves. Thus, it is worth questioning whether LAI is a necessary measurement, and whether it can be estimated from other plant parameters such as POP, PC, PH and dry weight or biomass (BIOM). Table 3.1.2 lists the coefficients of determination (R^2) for LAI estimated from various combinations of the other plant parameters. The other variables are shown to account for from 67 to 90% (R^2 X 100) of the variation in LAI.

Also shown in Table 3.1.2 is the proportion of the variation in grain yield accounted for by the same plant parameters. They are shown to account for from 69 to 89% (R^2 X 100) of the variation in grain yield.

Table 3.1.1 Simple linear correlation coefficients, r, between individual LANDSAT MSS bands digital counts and plant population (POP), percent ground cover by plants (PC) and leaf area index (LAI) for a sampling of grain sorghum fields in 1973, 1975, and 1976.

	GRD. TRTH.	IRRIGATED BANDS 4	5	6	7		NONIRRIGATED BANDS 4	5	6	7
		Linear correlation coefficient, r								
1973	POP	--	--	.803**	.775**		NO DATA			
(5/27)	PC	-.687*	-.677*	--	.571					
(10)	LAI	--	--	.841**	.838**					
1975	POP	--	-.744*	--	--		NO GROUND TRUTH			
(4/2)	PC	--	--	--	.391					
(8)	LAI	--	--	--	.373					
(5/17)	POP	-.628	-.607	.515	.746		-.722	--	--	--
(6)	PC	--	--	--	.502	(6)	--	.580	--	--
	LAI	--	--	--	.544		--	-.758	--	--
(6/4)	POP	-.881*	--	--	--		--	--	--	--
(5)	PC	-.533	--	--	--	(7)	-.715	--	--	--
	LAI	-.380	--	--	--		-.654	--	--	--
1976	POP	NO MSS DATA					-.703	--	--	--
(5/3)	PC					(6)	--	--	--	.674
	LAI						--	--	--	.627

* Significant at 0.05 level. ** Significant at 0.01 level. Month and day in parenthesis is date of satellite overpass; number in parenthesis is number of paired observations in statistical analysis.

Table 3.1.2 Grain yield of sorghum and LAI as functions of plant population (POP), percent ground cover by plants (PC), and plant height (PH) for three data sets.

YR.	PLANT PARAMETERS	YIELD	LAI
		R^2	
1973	POP, PC	.716**	.867**
	POP, PH	.824**	.843**
	POP, PH, PC	.887**	.868**
1975 (Apr. G.T.)	POP, PC	.694**	.902**
	POP, PH	.694**	.854**
	POP, PH, PC	.696**	.903**
1975 (May G.T.)	POP, PC	.696**	.853**
	POP, PH	.723**	.666**
	POP, PH, PC	.723**	.871**

** Significant at 0.01 level.

3.2 Grain sorghum phenology and seasonal ground truth relationships.

In 1976, we began making intensive ground truth measurements in one irrigated and one dryland grain sorghum field on a weekly basis, as opposed to dates close to satellite overpasses. The fields and individual plants were also inspected two or three times per week to define the date of physiological events. Those of keen interest were emergence (EMER), growing point differentiation (GPD), the date when half the heads were in bloom (1/2 BLM) and physiological maturity (PM) of the grain (Vanderlip and Reeves, 1972). These latter studies are cooperative with Texas Agricultural Experiment Station (TAES) and ARS personnel at Temple, Texas, with whom we are developing a spectral-physiological model for grain sorghum.

Figure 3.2.1 presents the PH and LAI during the growing season in the intensively studied, irrigated grain sorghum field. The ground truths were measured on 2 plants at each of 8 locations within the field.

The data of Figure 3.2.2 show that the simple linear correlation coefficients ranged from 0.01 to 0.88, with a value of 0.6 being about average. Both BIOM and LAI were calculated on a per hectare basis, hence are related to POP. The weakest relation would be expected between PH and POP. The poor relation between PH and LAI, BIOM, and POP on 4/30 is believed associated with the variation among plant heights at this time (plants were "booting") and not to irregularity in LAI, BIOM, and POP. The plants were at half bloom on 5/15 (Figure 3.2.1), so PH was no longer related to LAI, BIOM, and POP on 5/20 and 5/27.

The important thing about Figure 3.2.2 is that, considering explainable exceptions, the ground truth inter-relations hold from the time they were initiated 5 days after GPD through 1/2 BLM. (Recall that we concluded in section 2.3 that the perpendicular vegetation index for grain sorghum is apparently meaningful in terms of grain yield from early April to about the end of May).

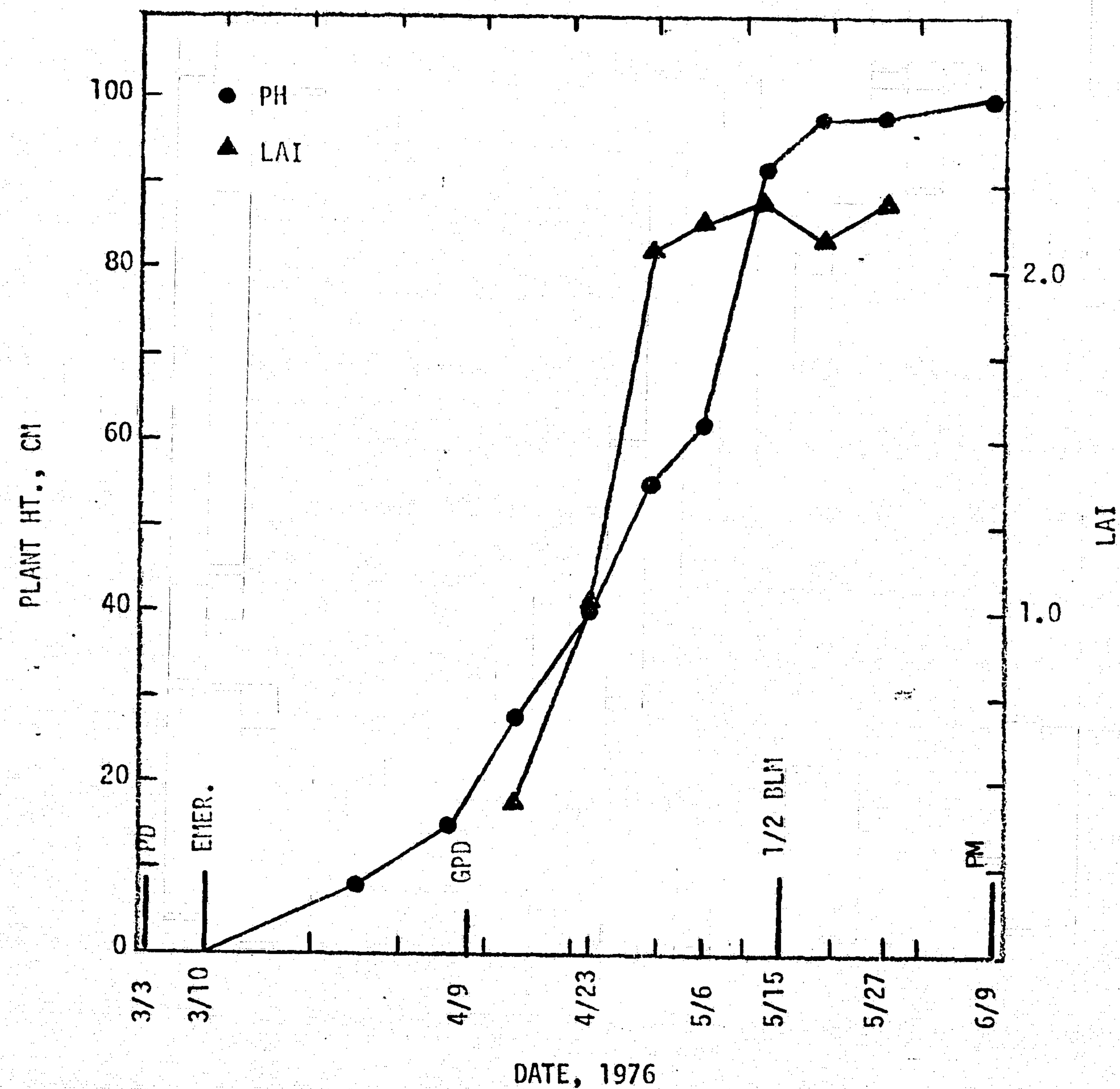

Fig. 3.2.1 Time-scaled plant height (PH) and LAI in an irrigated grain sorghum field in 1976. Dates of planting (PD), emergence (EMER), growing point differentiation (GPD), half bloom (1/2 BLM) and physiological maturity of the grain (PM) are indicated on the time scale.

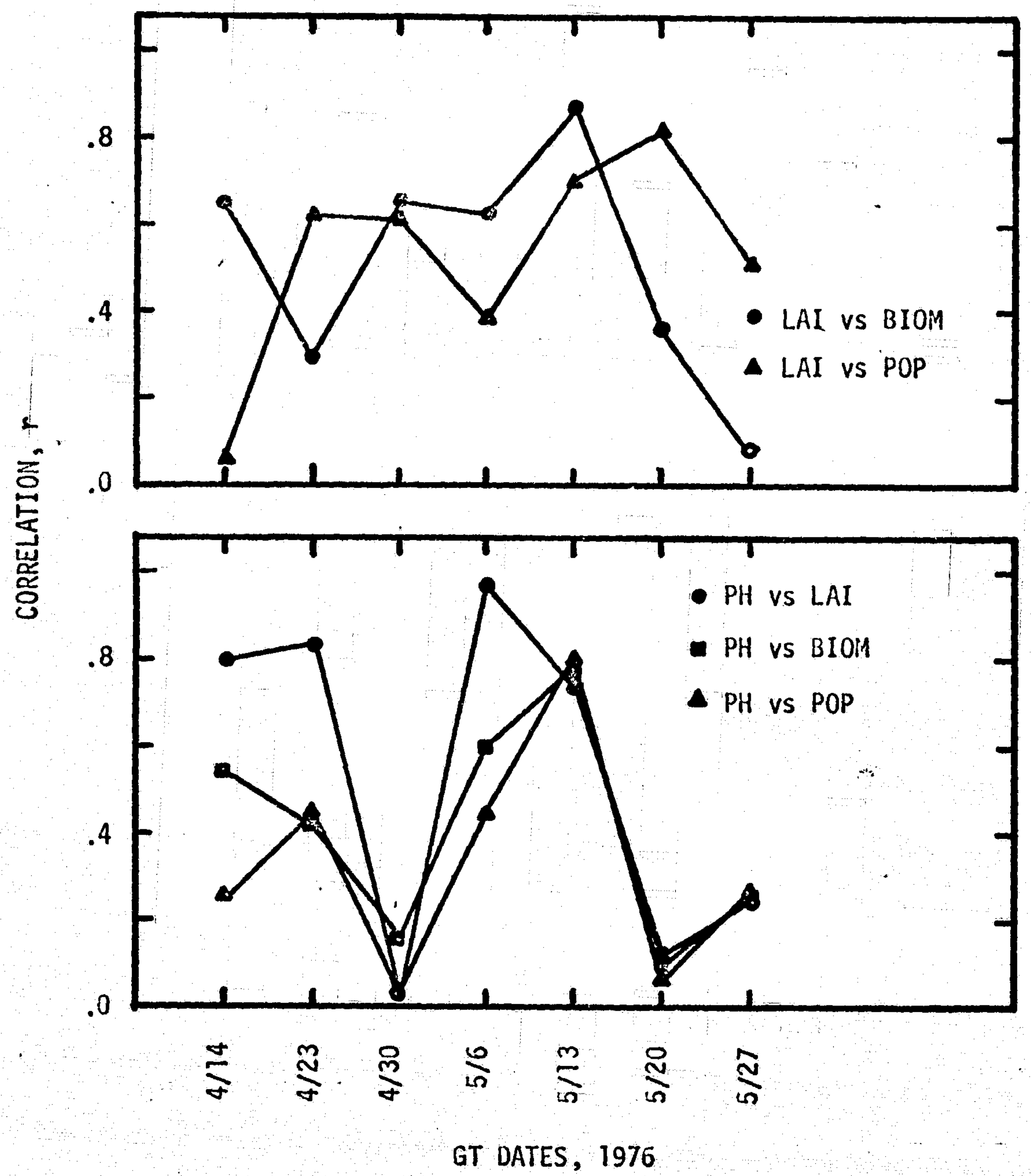

Fig. 3.2.2 Seasonal inter-relationships among LAI, BIOM, PH, and POP for the same field as Fig. 3.2.1.

3.3 Soil erosion by wind

A number of studies have been conducted at Weslaco that are pertinent to understanding the effects of straw, plant residue, and tillage on the erodibility of soil to wind. Abstracts reporting this work follow.

3.3.1 Disked and nondisked soil with and without wheat straw

A paper entitled, "Field-measured spectroradiometric reflectances of disked and nondisked soil with and without wheat straw," by H. W. Gausman, R. W. Leamer, J. R. Noriega, R. R. Rodriguez, and C. L. Wiegand, has been submitted to *Soil Sci. Soc. Am. J.* for publication. The Abstract follows:

The objective was to compare field-measured spectroradiometric reflectances of nondisked bare soil with or without littered wheat (*Triticum aestivum* L.) straw and bare soil that was disked directly or after littering with wheat straw. This information is needed to develop a procedure for predicting potential soil erosion using aircraft or satellite multispectral scanner reflectance measurements.

A ground-based spectroradiometer was used to measure reflected radiation from six soil-tillage-wheat straw treatments: disked and nondisked soil each with wheat straw at rates equivalent to 2.24 and 4.48 metric tons/ha and without straw, respectively.

The near-infrared region (0.75 to 1.3 μm), exemplified by the 1.05-μm wavelength, appeared to be better than the visible (0.45 to 0.75 μm) or water absorption wavebands (1.5 to 1.8 μm and 2.0 to 2.5 μm) for distinguishing among reflectances of the soil-tillage-straw treatments.

Results indicated that LANDSAT multispectral scanner's band 7 (0.8 to 1.1 μm) might be used to distinguish nondisked bare soils from those with different amounts of straw on their surface; however, there probably would be some confusion among spectra of nondisked bare soils, disked bare soils, and disked soils with low amounts of straw incorporated in them.

Further research is needed on the effects of other soils, soil moisture contents, kinds and amounts of plant residue, tillage operations, and their interactions on reflectance.

3.3.2 Dead vs. Live Vegetation

A paper entitled, "Infinite reflectance of dead compared with live vegetation," by H. W. Gausman, R. R. Rodriguez, and A. J. Richardson, has been published in Agron. J. 68:295-296. The Abstract follows.

The objective was to compare the infinite reflectance (R_∞) of dead and live corn (Zea mays L.) leaves over the 0.5- to 2.5-µm waveband to find a means of distinguishing live from dead vegetation for remote sensing purposes; previous studies have been concerned only with R_∞ of live leaves. In this study, for both dead and live leaves, reflectance measurements were made on a single leaf section and for sections stacked two, three, four, five, six, seven, and eight at a time over a spectrophotometer's port. Live leaf R_∞ was essentially attained by stacking two leaves for the 0.5- to 0.75-µm waveband (chlorophyll absorption region), eight leaves for the 0.75- to 1.35-µm waveband (near-infrared region), and three leaves for the 1.35- to 2.5-µm waveband (water absorption region). Dead leaf R_∞ was reached over the entire 0.5- to 2.5-µm waveband by stacking only two or three leaves. Thus, aircraft and spacecraft reflectance measuring techniques probably cannot distinguish density differences of dead vegetation but they should distinguish density differences of live vegetation. Near-infrared reflectance differences between dead and live vegetation also should be detectable with satellite multispectral scanner data.

3.3.3 Dead Leaves' vs. Bare Soils' Reflectances

A paper entitled, "Spectrophotometric reflectance differences between dead leaves and bare soils," by H. W. Gausman, R. R. Rodriguez, and C. L. Wiegand, has been published in J. Rio Grande Valley Hort. Soc. 30:103-107. 1976. The Abstract follows.

Reflectance differences between dead leaves and bare soils were characterized by measuring spectrophotometric reflectance in the laboratory over the 0.5- to 2.5-µm waveband for dead leaves from six crops: avocado (Persea americana Mill.), citrus [Citrus sinensis (L.) Osbeck], corn (Zea mays L.), cotton (Gossypium hirsutum L.), sorghum [Sorghum bicolor (L.) Moench.], and sugarcane (Saccharum officinarum L.), and for the respective bare soils next to the place where the dead leaves were lying on the ground.

Reflectance differences between the dead leaves of five of the six crops and the respective bare soils were largest (15.3 to 24.5 percentage points) within the near-infrared waveband (0.75 to 1.35 µm) except for sugarcane whose largest reflectance difference was 19.2 percentage points at the 1.9-µm wavelength; however, the difference was 18.7 percentage points at the 0.85-µm wavelength within the near-infrared waveband. Thus, this waveband should be the best spectral region to distinguish dead leaves (leaf litter) from bare soils.

3.4 Plant Stress Detection

3.4.1 Lead Toxicity

An abstract of a paper entitled, "Effect of lead on reflectance of Mexican squash plant leaves," by D. E. Escobar and H. W. Gausman, has been published in the 1976 Agronomy Abstracts. The Abstract follows.

Mexican squash plants (*Cucurbita pepo* L., cv. Tatume) were grown hydroponically with four treatments: no added Pb (control) and with Pb added at rates of 100, 500, and 1,500 ppm. Leaf reflectances were measured spectrophotometrically over the 0.5- to 2.5-μm waveband. The 1,500-ppm Pb treatment severely stunted the plants compared with the control and 100- and 500-ppm treatments. The 100- and 500-ppm Pb treatments decreased leaf chlorophyll concentrations and thereby significantly (p .05) increased visible light (0.5 to 0.75 μm) reflectance at the 0.55 μm wavelength, compared with the control treatment; near-infrared light (0.75 to 1.35 μm) reflectance was not significantly affected. In the 1.35- to 2.5-μm waveband, the water absorption region reflectances for 100- and 500-ppm Pb-treated leaves were significantly lower than for control leaves at the 1.45-, 1.65- and 2.2-μm wavelengths.

3.4.2 Ozone Damage to Plants

A paper entitled, "Reflectance and previsual detection of ozone-damaged cantaloupe plants, *Cucumis melo* L.," by H. W. Gausman, D. E. Escobar, R. R. Rodriguez, C. E. Thomas, and R. L. Bowen, is being submitted to Photogram. Engin. and Rem. Sens. The Abstract follows.

Ozone accounts for up to 90% of pollution injury to vegetation in the United States; excess ozone affects plant growth, development, and yield. Yield reductions may even occur from ozone damage that cannot be seen. Laboratory and field reflectance measurements showed that ozone-damaged cantaloupe (*Cucumis melo* L.) leaves had less water and higher reflectance than nondamaged leaves. Cantaloupe plants with light, severe, and very severe ozone damage were easily distinguished from nondamaged plants by the reflectance measurements made in the 1.35- to 2.5-μm near-infrared water absorption waveband. Ozone-damaged leaf areas were detected photographically 16 hr before they could be seen visually. Sensors are available for use with aircraft and spacecraft that may be used some day to routinely detect ozone-damaged crops.

3.4.3 Ultraviolet Light (UV-B) Damage to Plants

A paper entitled, "Leaf ultraviolet light reflectance, transmittance, and absorptance of ten crop species," by R. R. Rodriguez and H. W. Gausman, is to be published in the J. Rio Grande Valley Hort. Soc. The Abstract follows.

Nitrogen oxide effluents of high-flying craft or chlorofluoromethane refrigerants and aerosol can propellants that diffuse to the stratosphere might reduce atmospheric ozone and increase the amount of middle-ultraviolet or UV-B radiation (280 to 315 nm) reaching the earth's surface with possible biologically damaging effects. We spectrophotometrically measured the leaf reflectance, transmittance, and absorptance of UV radiation over the 200- to 360-nm waveband for 10 crop species: blackeye pea, corn, cotton, grain sorghum, pinto bean, redblush grapefruit, soybean, sugarcane, sunflower, and tomato. Leaves of the 10 crops reflected from about 4 to 6% and absorbed from about 94 to 95% of UV-B radiation; none was transmitted. Therefore, outer plant canopy leaves might protect inner canopy leaves from damage by absorbing much of the nonreflected UV-B radiation. However, the transmissivity of UV-B damaged crop leaves needs to be determined.

3.5 Discriminating Among Plant Genera

3.5.1 Discrimination Among Citrus Varieties

A paper entitled, "Reflectance and photographic characteristics of three citrus varieties for discrimination purposes," by H. W. Gausman, D. E. Escobar, and C. L. Wiegand, has been submitted for publication in Remote Sensing of Earth Resources, Tullahoma, Tennessee. The Abstract follows.

Reflectance spectra were measured spectroradiometrically for single leaves in the laboratory and for tree canopies in the field, and aerial infrared color photos were taken for three citrus varieties [Valencia and Marrs oranges (Citrus sinensis (L.) Osbeck,) and Redblush grapefruit (Citrus paradisi Macf.)] to determine whether they were distinguishable based on their reflectance and photographic characteristics.

Redblush had the highest and Marrs had the lowest field- and laboratory-measured visible light (0.5 to 0.75 μm) reflectance; whereas, Redblush and Valencia had the highest and lowest near-infrared light (0.75 to 2.5 μm) reflectance. However, differences in reflectance among the varieties were larger for field measurements on intact trees than for laboratory measurements of single leaves over the entire 0.5- to 2.5-μm waveband.

Field measurements of visible light reflectance were directly related to the infrared color film's tonal characteristics; high reflectance (low chlorophyll concentration) gave a "pinkish" color and low reflectance (high chlorophyll concentration) gave a dark red color. Consequently, densitometric measurements made on an infrared color transparency of tree canopies with red-filtered light gave a statistically significant discrimination among the three varieties in agreement with their differences in chlorophyll concentrations.

Thus, discriminations were made among the three citrus varieties from both spectroradiometric and photographic characteristics of their foliage independently of soil background.

3.5.2 Distinguishing Between Grapefruit and Orange Trees

A paper entitled, "Use of LANDSAT-1 data to distinguish grapefruit from orange trees and estimate their hectarages," by H. W. Gausman, D. E. Escobar, A. J. Richardson, R. L. Bowen, and C. L. Wiegand, has been submitted to J. Rio Grande Valley Hort. Soc. for publication consideration. The Abstract and a figure follow.

Our objective was to determine if Earth Resources Technology Satellite (LANDSAT-1) multispectral scanner (MSS) data could be used to distinguish between Redblush grapefruit (*Citrus paradisi* Macf.) and orange (*Citrus sinensis* (L.) Osbeck) citrus varieties and estimate their hectarages satisfactorily. Accordingly, LANDSAT-1 MSS data for a December 11, 1973, overpass (scene I.D. 1506-16293) were used in conjunction with Productive Properties' 600-ha citrus farm in Hidalgo County, Texas. Computer-aided variety classification accuracies for the farm with MSS data were 83, 91, and 86% for Redblush grapefruit, orange, and total hectarages, respectively. The percentage comparisons of computer and farm manager's farm inventory estimates for Redblush grapefruit, orange, and total hectarages were 16.9% underestimate, 13.9% overestimate, and 2.4% underestimate, respectivly. These classification and hectarage comparison accuracies indicate that there is a good potential for computer-aided inventories of grapefruit and orange citrus orchards with satellite MSS data. This projected use will become more realistic with further refinements in MSS ground resolution, and data acquisition and processing.

3.5.3 Distinguishing Among Rangeland Plant Species

A paper entitled, "Canopy reflectance-structure-film image relations among three south Texas rangeland plants," by H. W. Gausman, J. H. Everitt, A. H. Gerbermann, and R. L. Bowen, has been accepted for publication in the J. of Range Management. The Highlight follows.

Field spectroradiometric measurements for canopy reflectances of three important south Texas plants (cenizo, honey mesquite, live oak) were used successfully to predict their color infrared film images and distinguishability: cenizo, whitish; honey mesquite, relatively light magenta; and live oak, darker magenta.

Fig. 3.5.2 The upper picture is a LANDSAT-1 color positive print composite [MSS bands 4, 5, and 7 from an overpass for December 11, 1973, (ID-1506-16293)] of the Lower Rio Grande Valley of Texas showing the location of the Productive Properties, Inc., citrus farm by dashed lines. The middle picture is a close-up oblique infrared color photograph (positive print) of the farm taken on September 22, 1975, at 3048 m. The lower picture is a computer printout classification map from the LANDSAT-1 data of the citrus farm showing the localized areas of grapefruit (•), oranges ($), water bodies and bare soil (/). Middle and lower pictures are delineated for comparison.

3.5.4 Plant Discrimination and Leaf Anatomy

A paper entitled, "Relation of *Peperomia obtusifolia's* anomalous leaf reflectance to its leaf anatomy," by H. W. Gausman, E. B. Knipling, and D. E. Escobar, has been accepted for publication by *Photogramm. Eng. and Remote Sens.* The Abstract follows.

We explained the absence of a near-infrared light reflectance peak, at about the 2.2-µm wavelength, from *Peperomia obtusifolia* A. Dietr. leaves by comparing their spectrophotometric measurements for upper and lower surfaces and anatomical components, including untreated, dehydrated, and hydrated hypodermises. This absence was caused by light absorptance by water stored in the cells of *Peperomia's* leaf hypodermis. This additional knowledge about the interaction of light with plant leaf anatomy supports previous evidence that future design of multispectral scanners should include a waveband centered about the 2.2-µm wavelength to enhance plant species discrimination by remote sensing.

3.5.5 Detection of Silverleaf Sunflower, a Noxious Weed

An abstract entitled, "Detection of silverleaf sunflower (*Helianthus argophyllus* Torr. & Gray) in south Texas pastures by I-R color aerial photography," by H. W. Gausman, R. M. Menges, D. E. Escobar, J. H. Everitt, and R. Bowen, has been published in the 1977 *Weed Science Society of America Abstracts*. The Abstract follows.

Silverleaf sunflower (*Helianthus argophyllus* Torr. & Gray) is unpalatable to cattle and has become a problem in South Texas due to its increase in sandy pasture lands. The young plant parts of the weed are densely white-tomentose. This pubescence caused a spectrophotometrically measured fourfold and one and four tenths-fold increase in visible (0.45 to 0.75 µm) and near-infrared (0.75 to 1.35 µm) reflectance, respectively, compared with the reflectance of sparsely-hairy leaves of another sunflower species (*H. annus* L.). This increased reflectance of silverleaf sunflower caused images on EASTMAN KODAK R Aerochrome infrared color type 2443 transparencies and positive prints to be "pinkish" compared with darker magenta responses for other plant species. This ability to distinguish silverleaf sunflower with I-R color aerial photography will be useful to locate its endemic areas, to monitor its spread, and possibly to effect control procedures.

3.5.6 Distinguishing Succulent from Nonsucculent Plants

A paper entitled, "Distinguishing succulent plant reflectance spectra from those typical of crop and woody plants," by H. W. Gausman, D. E. Escobar, J. H. Everitt, A. J. Richardson, and R. R. Rodriguez, is being processed internally for publication approval. The Abstract follows.

We compared laboratory spectrophotometrically measured leaf reflectances of six succulents (peperomia, possum-grape, prickly pear, spiderwort, Texas tuberose, wolfberry) with those of four nonsucculents (cenizo, honey mesquite, cotton, sugarcane) for plant species discrimination. Succulents (average leaf water content of 92.2%) could be distinguished from nonsucculents (average leaf water content of 71.2%) within the near-infrared water absorption waveband (1.35 to 2.5 μm). This was substantiated by field spectrophotometric reflectances of plant canopies. Sensor bands encompassing either the 1.6- or 2.2-μm wavelengths should be useful to distinguish succulent from nonsucculent plant species.

3.6 Economic Importance of One Cropland Application--Soil Erosion by Wind

A reconnaissance study made by the Soil Erosion Service (now Soil Conservation Service, SCS) in 1934 indicated that 282,218,000 acres of formerly productive land had been severely damaged by soil erosion. Standing crop residues, crop residue littered on the soil surface, and stubble mulching reduce soil erosion by wind and water and trap snow. Research has shown that LANDSAT-1 MSS data were often able to distinguish soils with crop residues from bare soils (see 3.3); such data also indicate the ground cover by living vegetation.

Soil erosion by wind is especially a serious problem on the Great Plains between longitudes 100° to 105° West. So serious is the situation that the SCS and ARS are cooperating in documenting crop residue, soil conditions, vegetative cover and other factors in the wind erosion equation by ground measurements and observations at up to 300 sites three times annually, between last fall tillage and April 15, for 3 consecutive years to improve procedures to estimate and report wind erosion damage based on statistical sampling techniques.

LANDSAT spectral information complements the above effort by adding new dimensions of information. Hopefully, spectral work will be carefully integrated with the cooperative SCS-ARS ground sampling effort. Maps and other documents will be obtained from the SCS and the Wind Erosion Laboratory, Manhattan, KS, that locate the fields being periodically observed. LANDSAT images will be purchased from the ASCS Photographic Laboratory at Salt Lake City and computer compatible digital tapes will be purchased from the EROS Data Center at Sioux Falls, SD. The test fields will be located in the images and tapes and their reflectance in each of the four spectral bands, 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, and 0.8 to 1.1 μm, will be determined. Equations will be developed to predict crop residue and ground cover of living vegetation from the spectral data. The spectral data will also be tested to determine its ability to predict the wind erodibility class assigned to each field by the ground measurements. Successful completion of the above steps leads logically to estimating wind erosion conditions in a large number of fields surrounding the test fields.

3.7 Cost/Benefit Analysis--Distinguishing Between Grapefruit and Orange Trees

LANDSAT data were used to successfully distinguish between grapefruit and orange tree citrus varieties (see 3.52) on a 600-ha citrus farm. The operational time, rate, and cost accounting datails for surveying this citrus farm follow:

	Program name	Computer-aided operational steps for citrus survey	Time (hr)	*Rate = ($/hr)	Cost ($)
1.	PP012	Gray map study area	0.25	30	7.50
2.	--	Manually determine training field locations	4.00	5	20.00
3.	DS005	Select training field data	0.15	30	4.50
4.	DS010	Factor analysis of training data	0.10	30	3.00
5.	DS015	Factor plot of training data	0.10	30	3.00
6.	DS025	Calculate training statistics	0.10	30	3.00
7.	DS030	Calculate Eppler look-up table	0.45	30	13.50
8.	DS035	Classify training data	0.50	30	15.00
9.	DS040	Classify study area	0.08	30	2.40
	Total				71.90

The LANDSAT survey cost was $0.12/ha or about 120./1,000 ha for the complete analysis of this single farm. Extending this analysis to all 25,000 ha of citrus in Hidalgo County would increase the execution time of DS040 only to 3.33 hr (25,000 ha/600 ha citrus farm x 0.08 hr) for a total increase cost of $169.40 (3.33 hr x $30. - $2.40 + $71.90). Thus, the LANDSAT survey cost would be $6.78/1,000 ha for all citrus in the County.

A conservative estimate for a ground-based survey to distinguish grapefruit from oranges is $1.45/ha. (Estimate provided by W. G. Hart, Research Leader, Citrus Insects Research, USDA, ARS, Weslaco, TX.) When this cost is projected to the citrus hectarage in Hidalgo County (25,000 ha x $1.45), the total cost would be $36,250. Thus, the cost of a County survey with LANDSAT data ($169.40), compared with the cost of ground-based survey ($36,250.), would provide an estimated savings of $36,081. or a cost/benefit ratio of 1/213.

4.0 RANGELAND APPLICATIONS

4.1 Editorial note

The 1900 hectare El Sauz ranch in Willacy County was to be the test site for the rangeland work of this contract since it had been soil mapped by the SCS and 17 range sites had been identified. However, the ranch changed hands after the proposal was submitted, and the new owner would not permit access to the ranch. Therefore, it was necessary to find alternative ranch cooperators. The new cooperators are the Yturria ranches in Willacy and Kenedy Counties and the Port Mansfield Navigation District. These sites are adjacent (north and east) to the El Sauz Ranch, and many of the range sites are the same.

Ground observations and herbaceous biomass measurements were made periodically during 1975 and 1976 at 27 sites within the study area. These 27 sampling sites constituted 12 range and land uses. The 12 range type sites provided the training statistics for computer recognition of an area surrounding and including the training sites that totalled 81,000 hectares.

Of the 12 range types, 8 supported vegetation.

Results of the studies conducted are summarized in the following sections.

4.2 Utilization of satellite data for inventorying rangelands in south Texas.

A manuscript by the title of this section is in preparation by J. H. Everitt, A. J. Richardson, A. H. Gerbermann, C. L. Wiegand and M. A. Alaniz for the Fall 1977, ASP-ACSM Meeting in Little Rock, AR. The Abstract follows:

An 81,000 hectare area in Kenedy and Willacy Counties, Texas was used as a test site for inventorying rangeland and various other land use categories using MSS data collected from LANDSAT-2 satellite overpasses dated October 17 and December 10, 1975, respectively. Level I and II category land use percentages for each overpass were compared with photo interpretation percentage estimated from a ground-correlated 1:100,000 scale LANDSAT color composite print. A highly significant correlation ($r = 0.977^{**}$) was found between the photo interpretation and computer classification hectarages for the October overpass. The correlation was not significant for the December overpass largely because about half of the most extensive level II rangeland category, mixed brush (10 to 80% ground cover by woody vegetation), was classified as grassland in December when woody species were dormant and a frost had weakened the green vegetation signals received.

Level I land use (rangeland, wetland, agricultural land, water, and barron land) hectarage estimates from both the October and December computer classifications were similar to photo interpretation estimates, indicating the ability to estimate level I categories in either October or December. However, discrimination of level II rangeland category (grasslands, mixed brush, and live oak rangeland) hectarages were time of year dependent. The data indicate the possibility of establishing a baseline forage productivity of the mixed brush when the woody species are dormant and the need to define the mixed brush category more precisely, both ecologically and spectrally.

Table 4.2.1 compares the photo interpretation and computer derived hectarages and land area percentages for the 81,000 hectare study area in the October 17, 1975 LANDSAT scene (I.D. 2268-16190). Categories are listed by a modification of Anderson's land use classification system. The photo interpretation percentages and computer estimated percentages are generally close for the five level I categories. Among the level II categories, the higher percentage grasslands in the computer than in the photo interpretation percentages is probably due to the computer classifying some of the more open areas in the mixed brush rangeland and live oak rangeland as grassland.

Figure 4.2.1 presents the training site digital count means for each of 7 spectral categories for the October 17, 1975 LANDSAT-2 overpass. Among the rangeland categories of Table 4.2.1, the spectral means of Figure 4.2.1 indicate some difficulty in distinguishing live oak and mixed brush from each other. For these two categories, the best spectral separation occurs in band 5. Most other categories are quite distinctive in bands 6 and 7. Wetlands and water "look" much alike in bands 6 and 7, but are very different in bands 4 and 5. The barren land category--composed of sand dunes, tidal flats, and salt flats--are all sandy on the surface and very reflective in all bands.

4.3 Estimating open rangeland forage production with LANDSAT MSS and weather information.

A manuscript by the title of this section is in preparation by A. J. Richardson, J. H. Everitt, and C. L. Wiegand for the Fall 1977 ASP-ACSM Meeting in Little Rock, AR. The Abstract follows:

Rangeland biomass data have been correlated with spectral vegetation indices, derived from LANDSAT MSS data, and seasonal weather data. LANDSAT data from 12 range sites in Willacy and Cameron Counties were collected October 17 and December 10, 1975, and July 31 and September 23, 1976. Daily temperature and precipitation were recorded for two range sites in the same area for 8 months (March through October) in the 1976 growing season. The linear correlation of biomass with the LANDSAT derived perpendicular vegetation index was highly significant ($r = 0.926^{**}$) using 7 sites over four dates in two different years. A quadratic regression analysis of biomass on thermal units and an antecedent precipitation index

Table 4.2.1 Comparison of photo interpretation percentages for the various rangeland use categories with computer estimated percentages in Kenedy and Willacy Counties study area. MSS bands 5, 6, and 7 of the October 17, 1975 overpass were used. Categories are listed using a modification of Anderson's land use classification system.

Land use categories	Photo interpretation		Computer	
	Size in hectares	Percent of study area	Size in hectares	Percent of study area
01. Rangeland	58,482	72.2	53,946	66.6
01. Grasslands (improved grasslands, reestablished to introduced grasses, or native grasses and herbs)	2,916	3.6	5,508	6.8
02. Mixed brush rangeland (deep sand, coastal sand, and tight sandy loam range sites)	43,416	53.6	33,372	41.2
03. Live Oak rangeland (sandy mound range site)	12,150	15.0	15,066	18.6
02. Wetland (lagunas, depressions)	3,159	3.9	2,268	2.8
03. Agricultural land (Idle cropland, bare soil)	11,259	12.9	12,636	15.6
04. Barren land (Sand dunes, tidal flats, and salty flats (predominantly bare soil)	4,374	5.4	3.321	4.1
05. Water	3,726	4.6	3.159	3.9
Threshold	--	--	5,670	7.0
Total	81,000	100.0	81,000	100.0

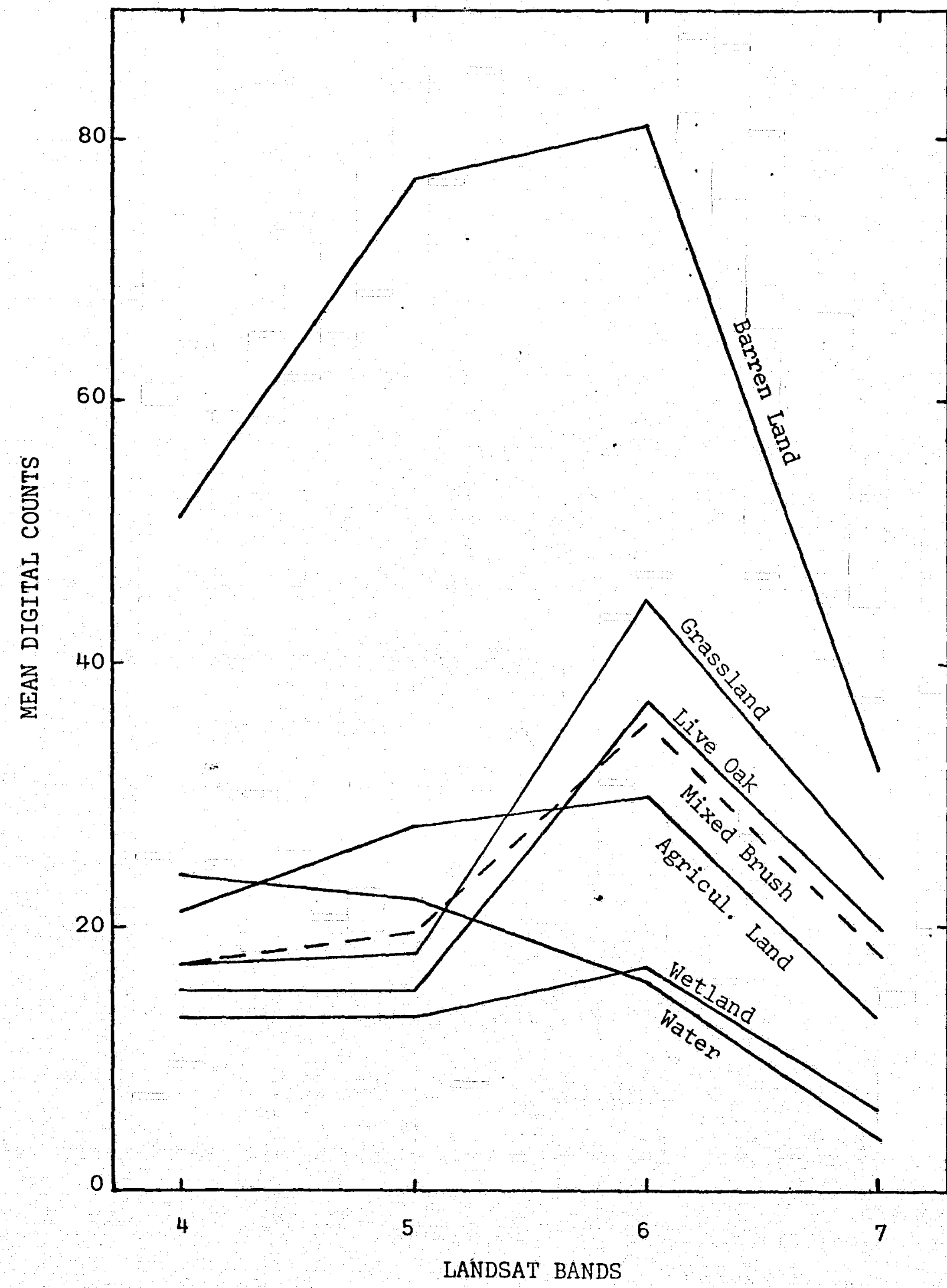

Fig. 4.2.1 Mean digital counts for seven land use categories (training sites) for 4 MSS bands from the October 17, 1975, LANDSAT overpass.

for two rangeland sites for the 1976 growing season was also significant (R = 0.840* and 0.924*). These results indicate that satellite and weather data used in combination can improve the reliability of range forage production estimates. Such procedures would aid range managers in assessing range condition and animal carrying capacities of range holdings that are large and inaccessible.

Table 4.3.1 presents the LANDSAT digital data, the calculated values of 8 different vegetation indices, and the herbaceous biomass for 12 sites within the 81,000 hectare study area for the October 17, 1975, LANDSAT overpass. Data from 3 other satellite overpass dates (12/10/75; 7/31/76; 9/23/76) have been similarly summarized. Notice that the simple correlation coefficient for 7 of the 8 vegetation indices and biomass is 0.95 or greater (highly significant); whereas, the simple correlation between biomass and individual LANDSAT band digital data is not statistically significant for any of the bands. This is strong evidence that the vegetation indices are much more useful than the raw digital counts for relating spectra of rangeland to forage productivity.

When the PVI and biomass data for open range grass sites and barren land for all four analysis dates were combined, the regression analysis was as shown in Figure 4.3.1. The highly significant linear correlation coefficient (r = 0.926**) and the standard error of estimate ($S_{y \cdot x} = \pm 612$ kg/ha) indicate this single relation could estimate forage production pretty well for any time of the growing season for any year.

The results of these last two report sections indicate that forage production can be estimated better from LANDSAT data than the range sites can be discriminated spectrally or defined classically from plant community-soil associations. If so, computer generated maps and tables for estimating forage conditions of open rangeland can still be provided range managers even though range sites (that grade into each other spectrally) cannot be well mapped.

Table 4.3.1 Mean LANDSAT digital data, vegetation indices, and herbaceous biomass for 12 training sites within an 81,000 hectare study area. Scene used was October 17, 1975 (I.D. 2268-16190). Sun elevation was 44° and sun azimuth was 137°. The MSS data were corrected for sun angle before calculation of the vegetation indices.

Rangeland Training Site Description	Site number	LANDSAT MSS Bands				Vegetation Indices								Herbaceous Biomass Production
		MSS4	MSS5	MSS6	MSS7	TVI	TVI6	RVI	PVI	PVI6	DVI	SBI	GVI	kg/ha
Tight Sandy Loam														
Mixed Brush	(1)	16	17	35	18	0.73	0.93	0.94	10	13	26	43	16	404
Improved Grass	(2)	20	21	51	27	0.79	0.96	0.78	17	21	44	59	26	4752
Aliciagrass	(3)	18	19	47	25	0.80	0.97	0.75	16	20	42	54	25	3730
Coastal Sand														
Native Grass	(4)	22	25	42	20	0.63	0.87	1.24	9	12	23	55	15	2922
Sandy Mound														
Live Oak Brush	(5)	17	17	41	22	0.79	0.96	0.77	14	17	36	48	21	--
Deep Sand														
Mesquite Brush	(6)	18	21	40	20	0.69	0.90	1.05	11	13	28	50	17	604
Improved Grass	(7)	20	25	43	22	0.66	0.88	1.14	11	13	27	56	17	1884
Salty Flat														
Native Grass	(8)	39	51	59	25	0.38	0.76	2.10	3	7	8	91	7	660
Soils														
Tidal Flats	(9)	47	62	66	28	0.35	0.73	2.20	2	5	5	105	5	0
Idle Cropland	(10)	24	30	33	14	0.37	0.73	2.15	1	2	4	52	3	0
Sand Dune	(11)	49	71	79	32	0.35	0.74	2.23	2	8	5	120	[illegible]	0
Lagunas														
Wet	(12)	14	14	18	6	0.30	0.79	2.40	0	2	0	27	2	0
Simple Correlation With Biomass (r)		-0.53	-0.55	-0.06	0.28	.96**	.95**	-.96**	.97**	.95**	.97**	-.34	.95**	

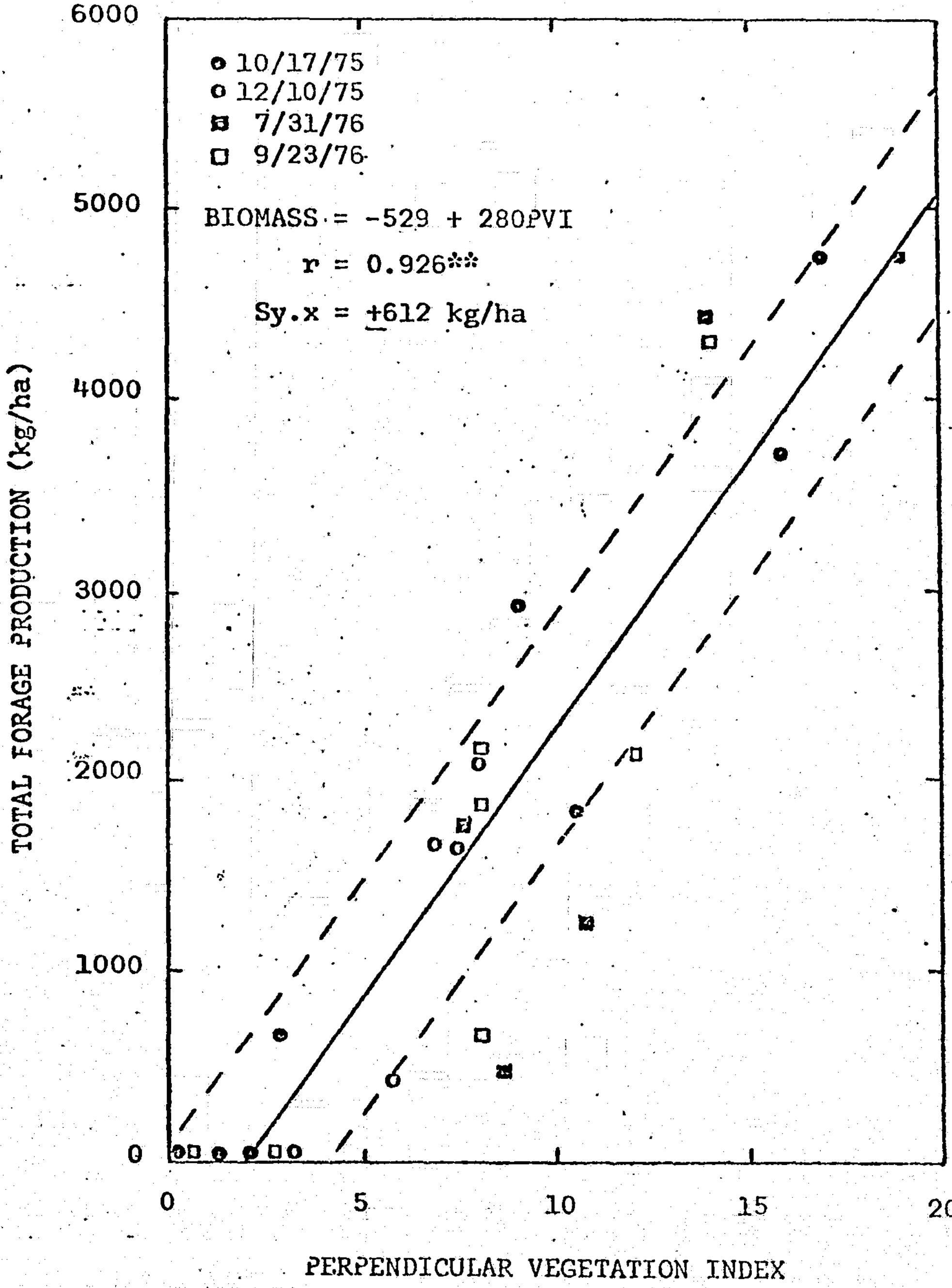

Fig. 4.3.1 Overall regression analysis of total forage production collected on October 17 and December 10, 1975, and July 31 and September 23, 1976, with the perpendicular vegetation index determined from LANDSAT MSS bands 5 and 7. The regressions include 5 grass sites and 4 bare soil sites. Mixed brush, live oak brush, and mesquite brush were not included in the regression because these sites have woody canopy covers that obscure the herbaceous understory.

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APPENDIX A

A. COMPUTERIZED INFORMATION EXTRACTION SYSTEM USING LANDSAT MSS DATA FOR SURVEYING AGRICULTURAL CROP AND SOIL CONDITIONS

A. J. Richardson, R. Riojas, and R. W. Schwab

A.1 INTRODUCTION

This report documents an Earth Resource Technology Satellite (LANDSAT) agricultural crop and soil condition information extraction system that uses computer-aided procedures. Current efforts include demonstrations of the potential for satellite inventorying of: (1) natural resources (Colwell, 1968) such as cotton and sorghum in Texas and winter wheat in Kansas (Stockton et al., 1975), (2) geology and forestry conditions in Oregon (Lawrence and Herzog, 1975), (3) corn and soybean crops in Indiana and Illinois (Malila et al., 1975), and (4) many other investigations (Morain and Williams, 1975). This report summarizes the experience and knowledge gained since the launch of LANDSAT-1 in July 1972, in developing an operational LANDSAT survey system in agriculture at Weslaco, Texas (Richardson et al., 1976a).

Natural resource inventory systems are usually evaluated for accuracy, reliability, timeliness, and cost effectiveness of the procedures employed. Therefore, the time and cost of the computer-aided operations using LANDSAT data and the accuracy of the resulting LANDSAT hectarage estimates for various crop and soil conditions in Hidalgo County, Texas were determined.

A.2 EXPERIMENTAL DESIGN

A.21 Test Site for LANDSAT Studies

Hidalgo County, Texas, was chosen as the area for data collection and analyses because of its nearly year-around-growing-season, the diversity of its approximately 100 million dollars/year agricultural enterprises, and its convenience for ground truthing. An entire county was chosen because this is the governmental unit by which agricultural census data are collected and summarized, and it is the geographical unit that is usually used for administering crop allotment and acreage restrictions.

The need for extensive county ground truth for comparing the reliability and accuracy of the LANDSAT data interpretations, prompted us to request USDA-SRS statisticians to design a sampling procedure that would allow a valid summary of data for the county from the sample. Hidalgo County contains three major agricultural areas that may be designated as northern, central, and southern. The northern region is mainly native and improved pasture and rangeland with dryland farming practiced where land has been put into dryland row-crop production. The central region is practically all irrigated. The cultivated land is generally broken into small fields that are 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 divided the county into 1,000-acre (400 ha) segments in the northern region, 160-acre (64 ha) segments in the central and southern regions, and assigned 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 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 were chosen from the 3,927 segments listed for the county (Fig. 1). Thus, the sampled area is 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 was ground-truthed and numbered. Fields are, by definition, areas within which cultural practices are homogeneous. The number of fields fluctuates slightly. The total number of fields in the 197 segments is approximately 1,400. Not all are ground truthed on every satellite overpass date. Ground truth taken twice a year--in December and April--adequately identified the contents of the fields (Gerbermann, et al., 1975). Ground truth is necessary to document the dynamic soil surface and plant development conditions.

Typical ground truth includes crop species, stage of maturity, row spacing, plant height, percent ground cover, row direction, Munsell color of soil, recent cultural practices such as tillage, irrigation, harvest, defoliation, and such additional qualitative information as notes on weediness, general plant vigor, and plant stand.

When ground truth is taken, the field information is coded 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 satellite data analysis. 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 chances of data loss.

Considerable information of agricultural importance can be extracted from the ground truth data; however, the main reason for collecting such a complete set of records is to use them to judge the reliability and accuracy of the county-wide interpretation of LANDSAT data. Such data also provide the training and test fields used in computerized recognition algorithms.

A.22 LANDSAT-1 and -2 MSS Digital Data

The LANDSAT MSS is a four-band scanner operating in the solar-reflective spectral region from 0.5 to 1.1 μm (Thomas, 1975). It consists of six detectors for each of the four bands. The MSS scans west to east crosstrack swaths 185-km wide at a nominal altitude of 918.6 km, imaging six scan lines across in each of the four bands simultaneously. The spacecraft's north to south orbital motion produces a long track spacing between the scan swaths. Video outputs from each detector in the scanner are transmitted to ground stations and compiled on video tapes. These tapes are sent to the NASA Data Processing Facility (NDPF) at the Goddard Space Flight Center (GSFC), Greenbelt, Maryland and the Earth Resources Observation Satellite (EROS) Center at Sioux Falls, South Dakota. These centers correct, calibrate, and format the raw MSS data into a usable digital form on four computer compatible tapes (CCT) that represent a 185-km (115 mi) square ground scene imaged by LANDSAT-1 or -2.

A scene is made up of 2,340 parallel scan lines (records) that contain 3,120 video picture elements (pixels) for each of the four MSS spectral bands. Thomas (1975) found that satellite altitude changes scan line length by ± 4 km (± 67.5 pixels). Each of the four CCT making up one scene contains imaged data for one 46.25- by 185-km strip that contains 780 pixels by 2,340 records. Thus, each pixel is 59.3 m (194.6 ft.) (west to east) by 79.1 m (259.5 ft.) (north to south) in size, that represents a 0.469 ha (1.159 acre) area on the earth surface. A CCT contains more image data than does a corresponding 1:1,000,000 scale film transparency or print. The additional data comes from 42 scan lines before and after the film scene.

This simplified discussion of LANDSAT-1 and -2 MSS data does not consider the effects of geometric variation due to altitude of spacecraft, earth rotation skew, orbital velocity change, scan time skew, non-linear scan sweep, scan angle error, and frame rotation (Anuta, 1973).

A.3 ACCOUNTING DETAILS

We compared the cost of the computer-aided surveys of crop and soil conditions in Hidalgo County with the cost of performing them by conventional methods. A summary of the major computer-aided operations for county crop and soil condition surveys is given in Table 1 along with computer program names. The total time and cost for each operation were determined while computer processing LANDSAT surveys of the county for April 2, July 10, and October 17, 1975 LANDSAT overpasses, during the period 1/5/76 to 10/8/76. Operator time was recorded for non-computer operations of the computer-aided county survey.

The experimental design for Hidalgo County allows survey estimates to be determined from either ground truth data or LANDSAT MSS data. Therefore, cost account comparisons are between county surveys from ground truth data alone versus the LANDSAT computer-aided operations alone.

A.31 Assumptions

Assumptions were made to facilitate the cost comparison of the computer-aided operations with established survey methods (such as those of the Texas Crop and Livestock Reporting Service): (1) satellite, computer equipment, and computer program development costs were not considered because these had been previously developed/acquired, (2) the ground truth collection costs were not considered a part of the computer-aided survey costs because the amount of ground truth collected would be much less than that collected as part of this study, (3) the cost for the ground truth collection operations in this study was assumed to be representative of the cost for established survey methods, and (4) the cost of reporting results (manuscript preparation, report production for dissemination) for either computer-aided or established survey methods was assumed to be about the same. Thus, cost/benefit comparisons for this study included the Table 1 preprocessing steps itemized under (A) and the data summary steps itemized under (C) for computer-aided survey methods. The cost of established survey methods are those itemized under (B) in Table 1.

A.32 Cost/Benefit Analysis

Table 1 shows that the total time for all computer program operations was 274.37 hours costing $8,231.10 at a rate of $30/hour over a 10-month period; January 5, 1976 to October 8, 1976. Over this 196 working-day-period, prime computer operation time available was 1,568 hours so that the computer-aided LANDSAT survey system accounted for 17.5% of prime time computer activity on the average at Weslaco, Texas (274.37 / 1,568.00 X 100 = 17.5%). Since three LANDSAT overpasses have been analyzed during this period (April 2, July 10, and October 17, 1975), this is an average of 91.46 computer hours or $2,743.70 to analyze one set of data. Using the formula,

$$\text{Total Days To Analyze One LANDSAT Overpass} = \frac{\text{To Computer Time To Analyze LANDSAT Overpass,}}{\frac{\text{8 Hours}}{\text{Person}} \times \frac{\text{Percent Prime Time Computer}}{\text{Utilization Rate}} \times \text{Number of Persons}}$$

the total number of days (number of Persons = 1) required to analyze one LANDSAT overpass on the average is 65.3 days. Since the work was not done in an operational environment, this time period is much longer than it should be for timely reporting of results. If percent prime time computer utilization rate were 100%, then the time period is 11.43 days. Also, if the number of persons is greater than 1, then the time period becomes shorter.

Total cost for operating the computerized LANDSAT survey system for 196 working days was $8,231.10 (computer program operations) plus $3,320.00 (non-computer operations) or $11,551.10 (total includes preprocessing, ground truth, and data summary operation). The total cost for ground truth collection operations was $626.80 (computer) plus $1,200.00 (non-computer) that equaled $1,462.80. The $1,462.80 figure is for only one ground truth set, the one collected for the July 10, 1975, LANDSAT overpass. Subtracting $1,462.80 from $11,551.10 leaves $10,088.30 for preprocessing and data summary operations. The $10,088.30 figure is for three LANDSAT overpasses in 1975 for an average of $3,362.77 per overpass. Thus, the cost ratio of computer-aided to ground truth survey operations was $3,362.77 / $1,462.80 = 2.30 in favor of ground truth survey operations. These figures represent a cost of $8.62/1,000 ha (390,000 ha in county) for computer-aided survey procedures and $3.75/1,000 ha for ground truth survey procedures. The computer analysis made a decision on every ha in the county, however, whereas the ground survey results are based on a 4% sample of the county area. An equally exhaustive survey by ground results would cost approximately 25 times what the 4% sample survey cost, or approximately $90./1,000 ha (1.00/.04)(3.75) = 93.75.

These figures compare to those compiled by Jensen et al. (1975) for an inventory of cropland and non-cropland over 184,500 ha in Kern County, California. Their costs using photointerpretation methods versus LANDSAT MSS imagery were $0.49 to $0.74/1,000 ha.

Hardy and Hunt (1975) have determined that pocket stereoscope equipment ($12.50/stereoscope) will provide adequate inventories of land use and natural resources based on studies of a 12,950,000-ha (50,000 sq mi) area in northeastern United States. Their figures indicate that these inventories could be conducted at a cost of $24.13/1,000 ha ($6.25/sq mi) over a 12-year time frame using high altitude black and white photography.

A.4 COMPUTER-AIDED OPERATIONS

Computer-aided operational steps are listed and referenced according to the outline given in Table 1. Actual setup and operational details are provided in line printer listings that can be provided on request. Samples of the system outputs and effectiveness of the system as evaluated in previous studies are given.

A.41 Preliminary Steps

Computer-compatible tapes containing MSS radiometrically scene-corrected digital data including Hidalgo County are obtained for cloud-free overpasses to evaluate LANDSAT agricultural surveys. The 919-km satellite altitude provides large aerial coverage with minimum sun angle and vignetting effects on reflectivities across the scene. The CCT coverage for Hidalgo County is verified by viewing film transparencies, and data quality is assessed by displaying the four LANDSAT-1 MSS bands on a DICOMED D-36 visual display. The LANDSAT-1 CCT are duplicated, and the CCT's covering Hidalgo County are merged if CCT coverage and data quality have been found acceptable. The above procedures are steps A-1 through A-5 in Table 1.

A.42 Earth Coordinate Calibration

Preprocessing MSS data operations are centered around a method for registering LANDSAT digital data (steps A-6 to A-11, Table 1) to ground truth information by methods that correlate earth coordinate systems to LANDSAT MSS data coordinates (Malila, et al., 1973). Special attention was given to this problem because location of experimental sites or sample segments is time-consuming and difficult (Kanemasu, et al., 1975) and if not performed accurately classification errors can occur that lead to incorrect land use interpretations. We use 30 landmarks in Hidalgo County to calculate regression equations that register earth coordinates (longitude and latitude) on USGS 7 1/2 minute series quadrangle maps to LANDSAT CCT record and pixel coordinates for any LANDSAT overpass. These regression equations allow estimation of record and pixel coordinates within standard errors of estimates ranging from ±0.58 to ±1.84 in record or pixel for any given earth coordinate pair (Table 2).

The earth coordinate calibration results are used to register the identification number of each of the 197 county sample segments (steps A-12 to A-15, Table 1) to the estimated northwest corner CCT record and pixel coordinate locations on the 17-line printer gray map coverage strips of the county. Knowledge of the approximate location of the sample segments on the line printer gray map strips (and thus on the CCT's) greatly speeds their exact location (Fig. 2) as do aerial photographs that depict field boundaries and man-made features. The earth coordinate registration results also permit determination of county boundaries in terms of a series of 14 quadralaterals (Fig. 3) used to select the MSS digital data for Hidalgo County only. For some analyses it may be desirable to divide the county into rangeland (A) and cropland (B) sections (Fig. 4). These county data are recorded on separate tape files.

A.43 Selection of Segment and Field Satellite Data

Segment and field boundaries are defined (step A-16 to A-23, Table 1) in terms of CCT record and pixel offset coordinates, punched on cards, that reference the northwest corner record and pixel coordinates for each of the 197 segments and the approximately 1,400 fields within these segments. These offset CCT coordinates are changed only when farm managers alter field boundaries. Field and segment CCT's are generated, using these offset coordinates, that contain only the MSS digital data from each segment or field. The field and segment CCT's are checked for data selection accuracy.

A.44 Ground Truth Operations

Ground truth operations (steps B-1 to B-15, Table 1) are based on data collected in the field for each LANDSAT overpass for each of the 197 sample sites. These data are punched on cards and are checked for accuracy and reasonableness by a series of computer programs. These programs check the consistency of ground truth for each of the approximately 1,400 fields. The ground truth is then stored on computer disk files. The mean digital data computed for each of the 1,400 fields, using the field CCT, is merged with the ground truth stored on the computer disk file.

A.45 Analysis of LANDSAT Training Data

The merged ground truth and field mean digital data stored on the computer disk file are used to determine the multispectral groupings of crop and soil conditions in the county (steps C-1 to C-8, Table 1). Scatter diagrams are generated, using LANDSAT MSS bands 5 and 7, that group fields with similar spectral characteristics in clusters (Fig. 5). Field membership within these clusters are printed with alphanumeric labels indicating the ground truth identification of the fields within the spectrally similar clusters. Since the fields within these scatter diagram clusters statistically represent the county, then training fields selected from these clusters will be representative of specific crop and soil conditions to be surveyed within the county (Driscoll, et al., 1972).

The spectral separability and distinctness of the MSS digital values of training fields must be evaluated (steps C-9 to C-15, Table 1) and the best LANDSAT MSS channels for separating these crop and soil conditions using divergence algorithms (Jones, 1973), must also be determined. It may prove necessary to repeat operational steps C-1 to C-8 again if separabtility of training fields is not optimum. Training statistics for generating look-up tables (Eppler, et al., 1971) that implement the maximum likelihood classification procedures (Fu, et al., 1969) are calculated once training field spectral separation is optimum.

Classification results (steps C-16 to C-17, Table 1) are compared with LANDSAT color transparencies and prints for 10 selected areas within the county, using the county merged tape, for a second verification of training field spectral representativeness (Fig. 7). Steps C-1 to C-8 may be repeated again if these classifications do not seem reasonable.

A.46 Hectarage Estimations and Classification Accuracy

Survey results are complete when classification of fields, segments, and county are finished (steps C-19 to C-22, Table 1). Classification of field CCT provides information, that is stored in the ground truth disk file, for determining classification accuracy of the test fields and for computer hectarage estimates of Hidalgo County based on MSS digital data selected for each test field. These classification results can be summarized for per field and per pixel classification accuracy for each crop and soil condition of interest in the scene. Crop and soil conditions can be defined according to crop codes that logically describe the crop or soil condition being studied. For example, all citrus crop codes fall between 400 and 500. The codes 400, 420, and 490 that identify oranges, grapefruit, and mixed citrus, respectively, can be composited into one citrus category for summarizing classification accuracies and hectarage estimates.

Classification of the segment CCT provides information, punched on cards, that can be used to calculate the regression of computer estimates on ground truth. These regression equations can then be used to correct the hectarage estimate developed for each crop and soil condition in Hidalgo County using procedures developed by Ray and Huddleston (1976).

A.47 Classification Maps

Once classification of the complete county is finished (step C-22, Table 1) then classification maps may be generated to visually inspect classification accuracy of crop and soil conditions within Hidalgo County. The optional step of 9-point classification smoothing (Richardson and Gleason, 1975) may be performed if required (step C-23, Table 1). The scale of the classification results must be changed (step C-24, Table 1) so that classification results can be more conveniently handled and studied by the analyst A final map, generated at one of 5 different scales, is printed on the computer line printer (step C-25, Table 1). Examples of the output produced by these steps are shown in Figures 7, 8, and 9 for Hidalgo County. The scale has been changed by a 1:5 reduction factor that degrades the original resolution from 0.47 ha/pixel to 11/7 ha/pixel. The computer hectarage estimate for Hidalgo County is determined at this time also (step C-26, Table 1).

These computer operations result in the basic statistical information needed by an analyst to evaluate the accuracy of the computer-aided inventory of Hidalgo County. These operations could also be used to inventory any other area of interest, such as another county, a drainage basin, or a land resource unit.

A.5 EVALUATION OF COMPUTER-AIDED OPERATIONS

The LACIE (Large Area Crop Inventory Experiment) now being conducted at the Johnson Space Center in Houston, Texas, is the largest of the crop survey programs. the LACIE program reports a 10% error in the estimation of wheat hectarage (McDonald, et al., 1975) in the United States while the U. S. Department of Agriculture (USDA), Statistical Reporting Service (SRS) claims a 1 to 2% error. The hectarage estimates of citrus, cotton and sorghum, sugarcane, and vegetables for Hidalgo County differed by 32, 8, 8, and 47%, respectively, from the Texas Crop and Livestock Reporting Service (TCLRS) estimates for these four crops. The computer-aided estimates have been determined since August 1972 using the procedures described in this report (Richardson, et al., 1976a; Richardson, et al., 1976b). The citrus hectarage estimate was high primarily because citrus was confused with native brush. As many as 40 different vegetable crops are planted; some fields are just being planted while others are ready for harvest. Hence, they are a spectrally diverse category for which errors of commission are large.

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FIGURE CAPTIONS

Figure 1 Map of Hidalgo County showing distribution of 197 experimental segments used to statistically study the county with ground truth and LANDSAT MSS data. The northwest corner coordinates of these segments (longitude and latitude) are used with programs PP025 or PP026 to estimate approximate position of each segment on line printer gray maps.

Figure 2 Location of five typical experimental segments in the southern part of Hidalgo County as shown on aircraft and satellite imagery. The northwest corners of segments are registered to LANDSAT CCT record and pixel coordinates using programs PP015, PP020, PP025, and PP026.

Figure 3 Diagram of the 14 quadrilaterals used to approximate the actual boundaries of Hidalgo County. The LANDSAT MSS data contained within these boundaries were used to generate computer hectarage estimation for crop and soil conditions within the county. The quadrilaterals are registered to the merged CCT with program PP030. The county CCT is then generated with program PP045. Classification of county is performed with program DS055.

Figure 4 Division of Hidalgo County into rangeland (A) and cropland (B) sections for separate analysis. This division is implemented with subroutines in programs DS070 and DS071.

Figure 5 Two dimensional scatter diagrams, using LANDSAT MSS channels 5 and 7, of the mean digital values (January 21, 1973 LANDSAT-1 overpass) determined for 67 of 1,400 test fields randomly located in Hidalgo County. Training fields are marked with an asterisk for four spectrally distinct categories (vegetable, citrus, rangeland, and idle cropland). Definition of four character field identifiers are as follows: class identification (character 1), northern (N), central (C), or southern (S) region of county (character 2), code number ranging from 0 to 9 for 0 to 90% crop cover (character 3), and crop and soil condition code ranging from 0 to 9. This scatter diagram is generated using program DS000.

Figure 6 Ten areas in Hidalgo County that are classified for detailed verification of training spectral representation to LANDSAT color transparencies. These areas are classified using programs DS040, DS041, or DS042.

Figure 7 Classification map of Hidalgo County for a January 21, 1973, LANDSAT-1 overpass. Resolution is 11.7 ha/symbol. Definition of crop and soil condition terms of pixel line printer symbols is given as follows: vegetable (/ overprinted -), citrus (blank), mixed grass (/), mixed shrubs (-), McAllen soil association (M overprinted W), Harlingen soil association ($), water (.), and threshold (T). This map was generated by program DS070.

Figure 8 Classification map of Hidalgo County for a May 27, 1973 LANDSAT-1 overpass. Resolution is 11.7 ha/symbol. Definition of crop and soil condition terms of pixel line printer symbols is given as follows: cotton and sorghum (0), citrus (blank), mixed grass(/), mixed shrubs (-), McAllen soil association (M overprinted with a W), Harlingen soil association ($), water (.), and threshold (T). This map was generated by program DS070.

Figure 9 Classification map of Hidalgo County for a December 11, 1973 LANDSAT-1 overpass. Resolution is 11.7 ha/symbol. Definition of crop and soil conditions in terms of pixel line printer symbols is given as follows: sugarcane (M overprinted W), high reflecting soil (/), low reflecting soil (-), other vegetation (blank), and water (.). This map was generated by program DS070.

Table 1. Operational time, rate, and cost accounting details listed according to the steps of the LANDSAT Survey System of the USDA, Weslaco, Texas. (Period extends from 1/5/76 to 10/8/76 and covers analysis of 3 scenes under headings A and C, and one under heading B.)

Abbreviated Outline of Operational Steps for LANDSAT Agricultural Survey System	Program Name	Time (Hr) x	Rate ($/Hr) =	Cost ($)
A. Preprocess (PP) Multispectral Scanner (MSS) Data Operations				
1. Check for cloud free coverage	-	-	-	
2. Order computer compatible tapes (CCT) ($200/Set)	-	-	-	
3. Determine data quality of received CCT's	PP000	2.97	30	89.10
4. Duplicate LANDSAT CCT of good quality	PP001	2.60	30	78.00
5. Merge CCT's that include study site (County)	PP005	5.81	30	174.30
6. Initial merged CCT calibration to USGS Map	PP010	19.20	30	576.00
7. Gray map landmarks (two band)	PP010	-	30	-
8. Gray map landmarks (one band)	PP011	-	30	-
9. Gray map landmarks (signature simplex)	PP012	-	30	-
10. Determine landmark CCT coordinates	-	40.00	5	200.00
11. Final merged CCT calibration to USGS Map	PP015	0.98	30	29.40
12. Register 17 county gray map coverage strips	PP020	0.14	30	4.20
13. Generate 17 county gray map coverage strips	PP025	11.71	30	351.30
14. Generate 17 county gray map coverage strips	PP026	-	30	-
15. Locate segment and test fields	-	240.00	5	1200.00
16. Determine segment NW corner coordinates	-	30.00	5	150.00
17. Register segment selection areas	-	24.00	5	120.00
18. Determine changes to field boundaries	-	90.00	5	450.00
19. Register county boundaries to merged CCT	PP030	0.06	30	1.80
20. Generate field CCT (1400 CCT files)	PP035	19.49	30	584.70
21. Generate Segment CCT (197 CCT files)	PP035	5.64	30	169.20
22. Check field and segment CCT	PP040	2.83	30	84.90
23. Generate county CCT (1 CCT file)	PP045	0.78	30	23.40
Total for computer operations	-	72.21	30	2166.30
Total non-computer operations	-	424.00	5	2120.00
Total for all PP Operational steps	-	496.21	-	4286.30

Table 1. continued

Abbreviated Outline of Operational Steps for LANDSAT Agricultural Survey System	Program Name	Time (Hr)	x	Rate ($/Hr)	=	Cost ($)
B. Ground Truth (GT) Collection Operations						
1. Acquire ground truth data	-	240.00		5		1200.00
2. Create ground truth disk file	GT000	0.16		30		4.80
3. Zero ground truth disk file	GT001	-		30		-
4. Copy ground truth to disk file	GT005	0.78		30		23.40
5. Edit ground truth data	GT010	0.09		30		2.70
6. Calculate and merge MSS field means with GT	GT015	4.92		30		147.60
7. Copy GT from disk to CCT (back-up CCT)	GT016	0.56		30		16.80
8. Copy GT from back-up CCT to disk	GT017	-		30		-
9. List GT back-up CCT on printer	GT018	0.17		30		5.10
10. List GT back-up CCT ID numbers on printer	GT019	-		30		-
11. List GT and MSS means on printer	GT020	0.97		30		29.10
12. List GT and MSS classifications on printer	GT021	-		30		-
13. Copy crop codes and names from disk	GT022	-		30		-
14. Copy crop codes and names from cards	GT023	-		30		-
15. Determine ground truth acreage estimate	GT025	1.11		30		33.30
Totals for computer operations	-	8.76		30		262.80
Total for non-computer operations	-	240.00		5		1200.00
Totals for all GT operational steps	-	248.76		-		1462.80

Table 1. continued

Abbreviated Outline of Operational Steps for LANDSAT Agricultural Survey System	Program Name	Time (Hr)	x Rate ($/Hr)	= Cost ($)*
C. Data Summary (DS) Operations				
1. Scatter diagram field means	DS000	9.70	30	291.00
2. Scatter diagram field means W/R to soil BG	DS001	-	30	-
3. Select training field data (10 cat., 10 band)	DS005	26.10	30	783.00
4. Select training field data (20 cat., 4 band)	DS006	-	30	-
5. Factor analysis (10 cat., 10 band)	DS010	5.90	30	177.00
6. Factor analysis (20 cat., 4 band)	DS011	-	30	-
7. Factor plot of training data	DS015	8.20	30	246.00
8. Scatter plot of training data	DS016	-	30	-
9. Determine optimum channels	DS020	-	30	-
10. Calculate training statistics	DS025	3.90	30	117.00
11. List basic training statistics to printer	DS026	-	30	-
12. Generate look-up tables	DS030	35.30	30	1059.00
13. Copy look-up statistics from disk to back-up CCT	DS031	-	30	-
14. Copy look-up statistics from back-up CCT to disk	DS032	-	30	-
15. Classify training fields	DS035	3.60	30	108.00
16. Check classification results (look-up)	DS040	33.10	30	993.00
17. Check classification results (quadratic)	DS041	-	30	-
18. Check classification results (sign. simp.)	DS042	-	30	-
19. Classify test fields	DS045	5.50	30	165.00
20. Summarize test field classification results	DS046	-	30	-
21. Classify segments	DS050	5.60	30	168.00
22. Classify county	DS055	31.20	30	936.00
23. Nine-PNT classification smoothing	DS060	-	30	-
24. Change classification map scale	DS065	8.80	30	264.00
25. Generate county classification map	DS070	16.50	30	495.00
26. Determine computer acreage estimate	DS071	-	30	-
Totals for all DS operational steps	-	193.40	30	5802.30
Totals for PP, GT, and DS computer operations	-	274.37	30	8231.10
Totals for PP and GT non-computer operations	-	664.00	5	3320.00
Totals for all PP, GT, and DS operational steps	-	938.37		11551.10
Percent prime time computer utilization				

Table 2. Regression analysis calibration of computer compatible tape coordinate system (pixel and record) to earth coordinate system (longitude and latitude) using 30 landmarks in Hidalgo County for six LANDSAT overpasses. Regression coefficients and standard errors of estimate are listed.

LANDSAT overpass dates	Pixel = $A_o + A_1$ (Long.) + A_2 (Lat.) [1]				Record = $A_o + A_1$ (Long.) + A_2 (Lat.) [1]			
	A_o	A_1	A_2	Sy•x	A_o	A_1	A_2	Sy•x
1/21/73	179901.1	-1703.83	-453.102	1.50	15792.82	208.682	-1357.10	1.68
5/27/73	179619.3	-1700.57	-453.025	0.76	14979.69	214.690	-1342.94	0.72
12/11/73	177364.7	-1680.43	-436.938	0.82	14913.75	216.715	-1351.30	0.56
4/2/75	177161.5	-1667.46	-476.706	1.62	14761.77	222.105	-1361.06	1.75
7/10/75	179505.9	-1700.96	-449.194	1.84	13420.52	233.612	-1352.85	1.03
10/17/75	178795.02	-1691.11	-449.789	0.72	16402.11	206.033	-1364.94	0.63

[1] The multiple correlation coefficient for all regression analyses was 0.9999.

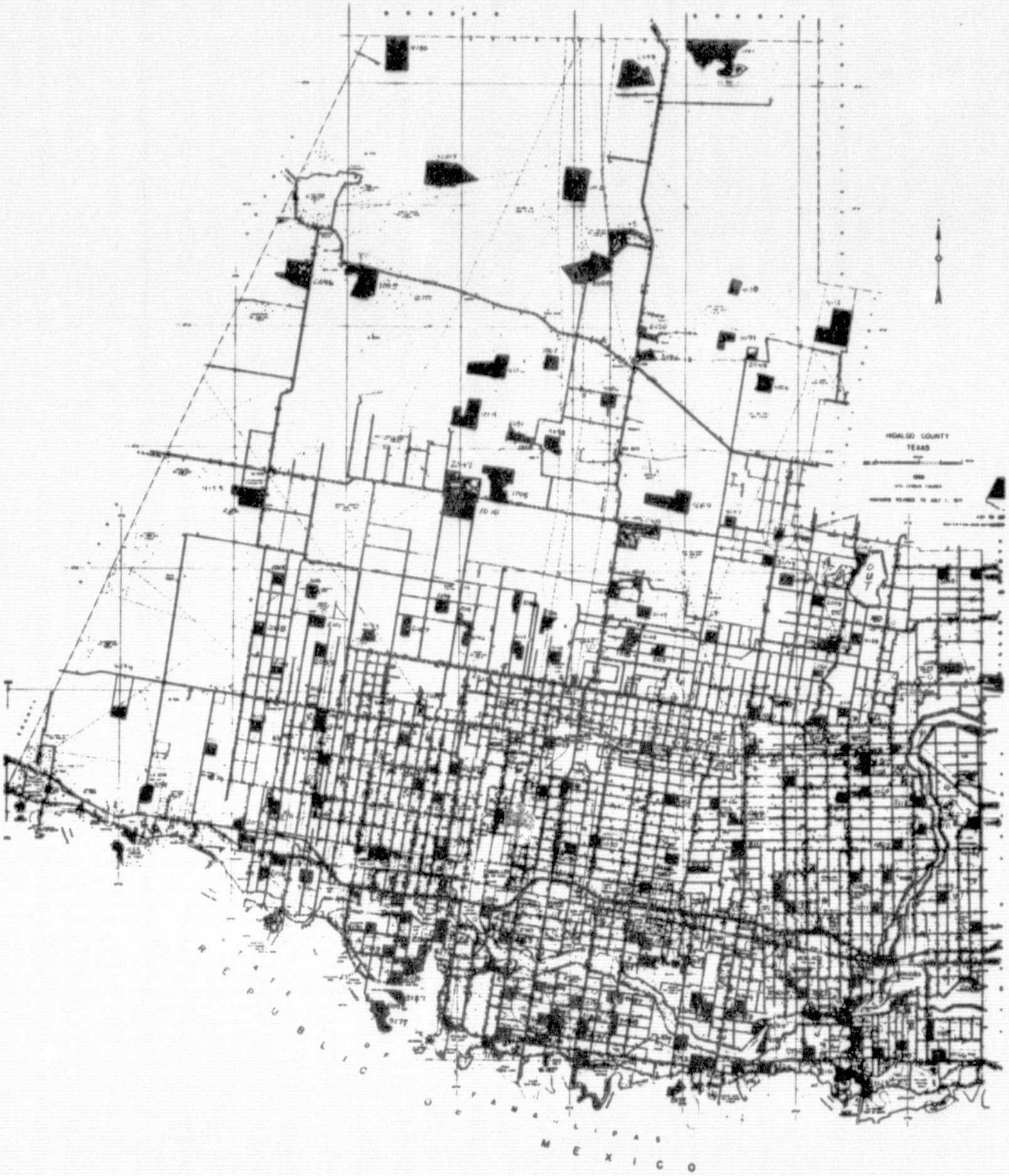
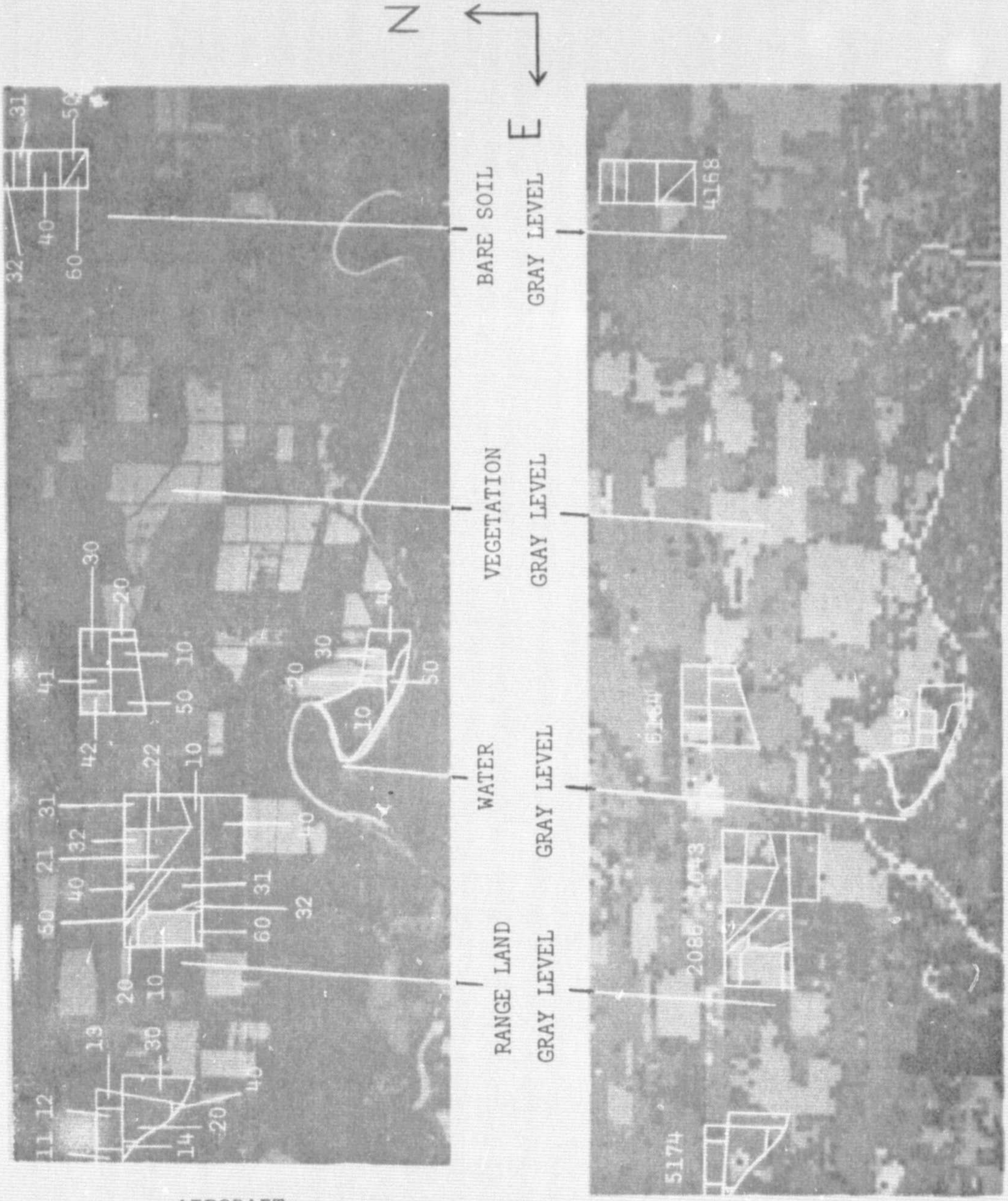


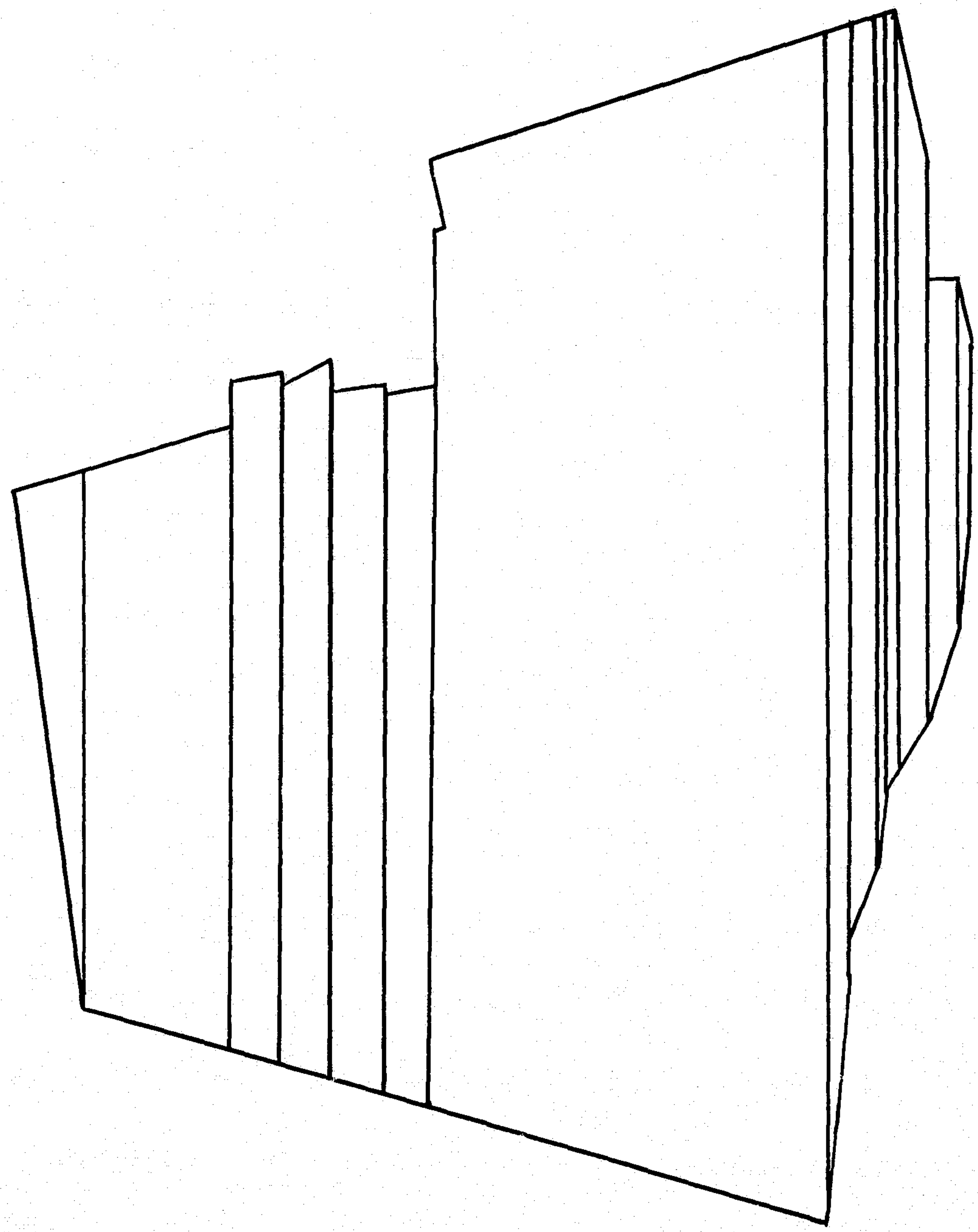
Figure 1. Map of Hidalgo County showing distribution of 197 experimental segments used to statistically study the county with ground truth and LANDSAT MSS data. The northwest corner coordinates of these segments (longitude and latitude) are used with programs PP025 or PP026 to estimate approximate position of each segment on line printer gray maps.



AIRCRAFT

SPACECRAFT

Figure 2. Location of five typical experimental segments in the southern part of Hidalgo County as shown on aircraft and satellite imagery. The northwest corners of segments are registered to LANDSAT CCT record and pixel coordinates using programs PP015, PP020, PP025, and PP026.



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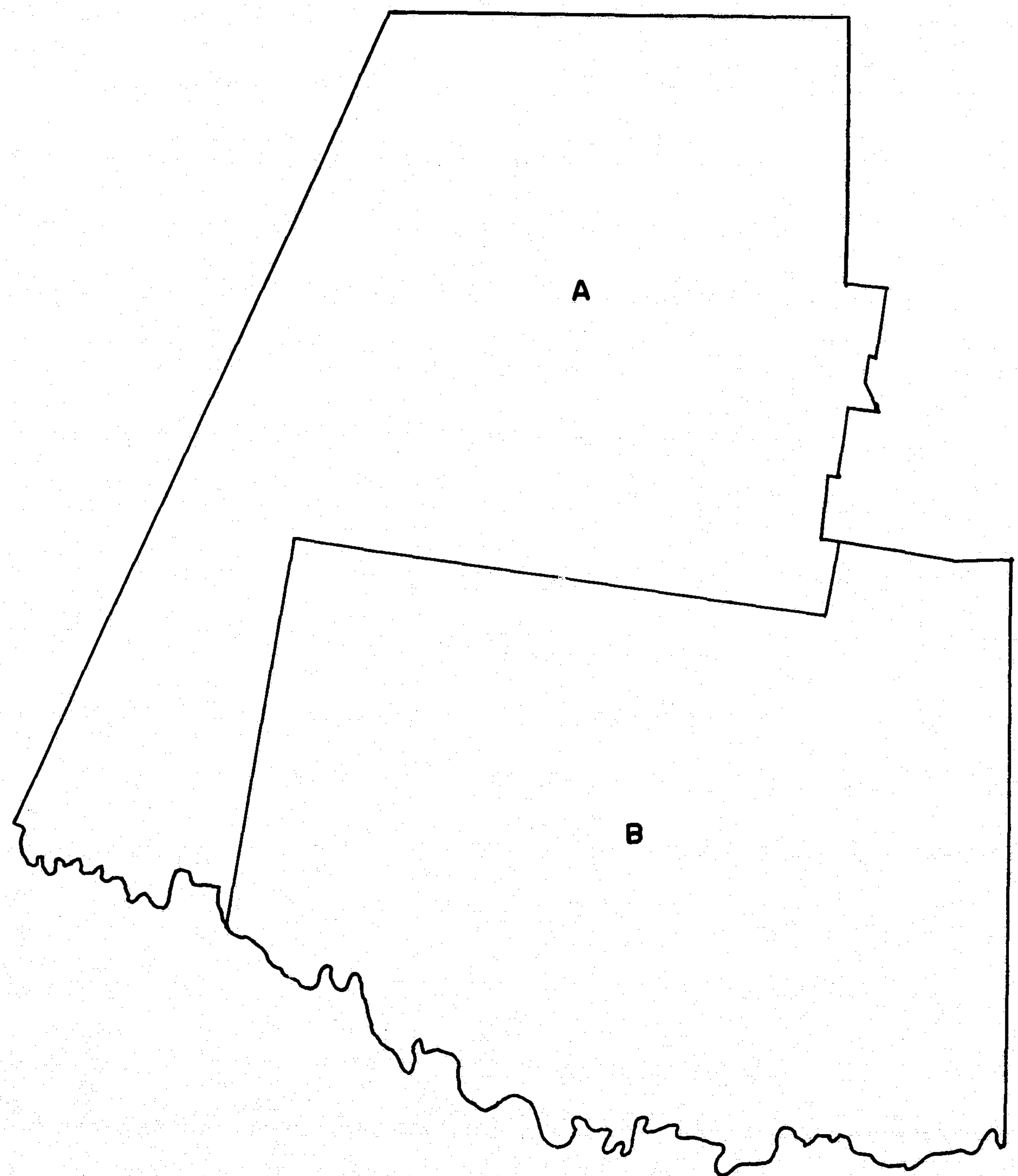

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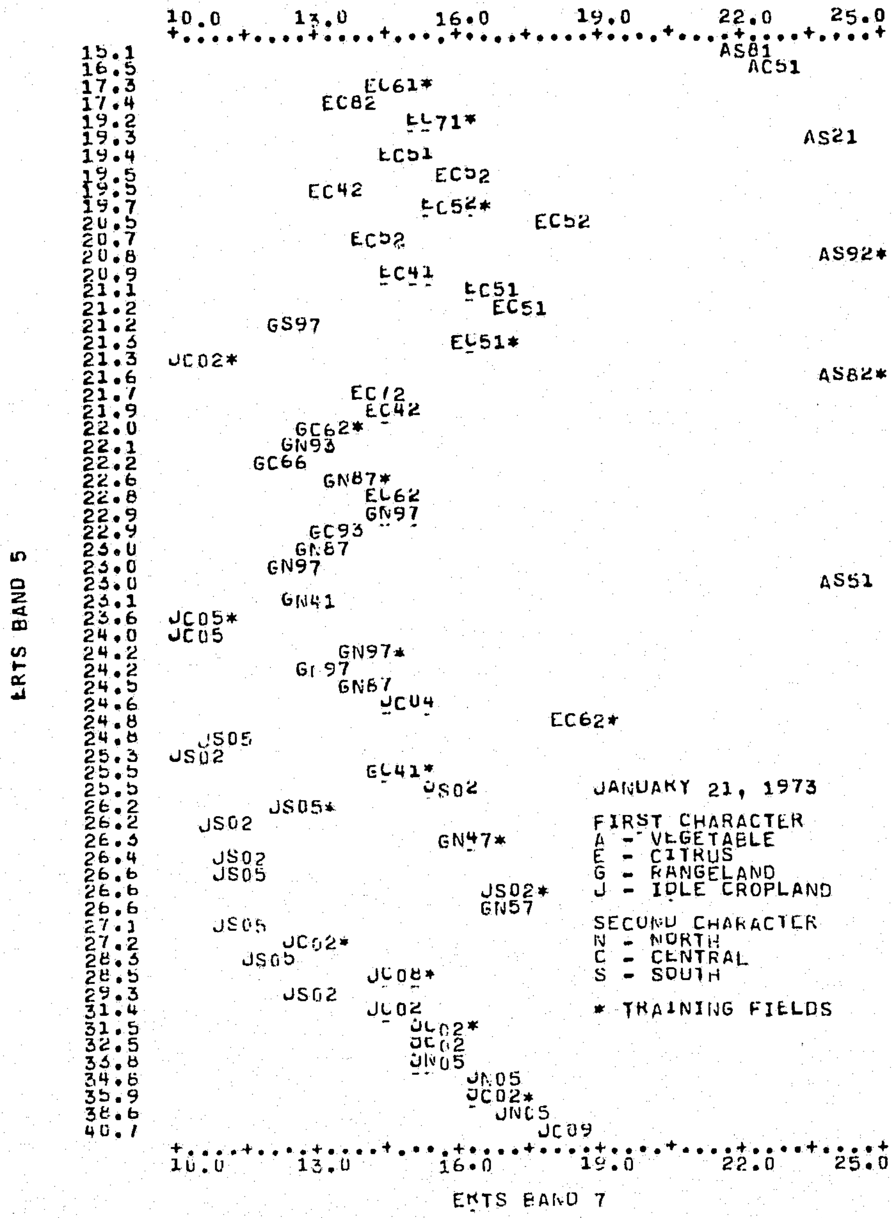
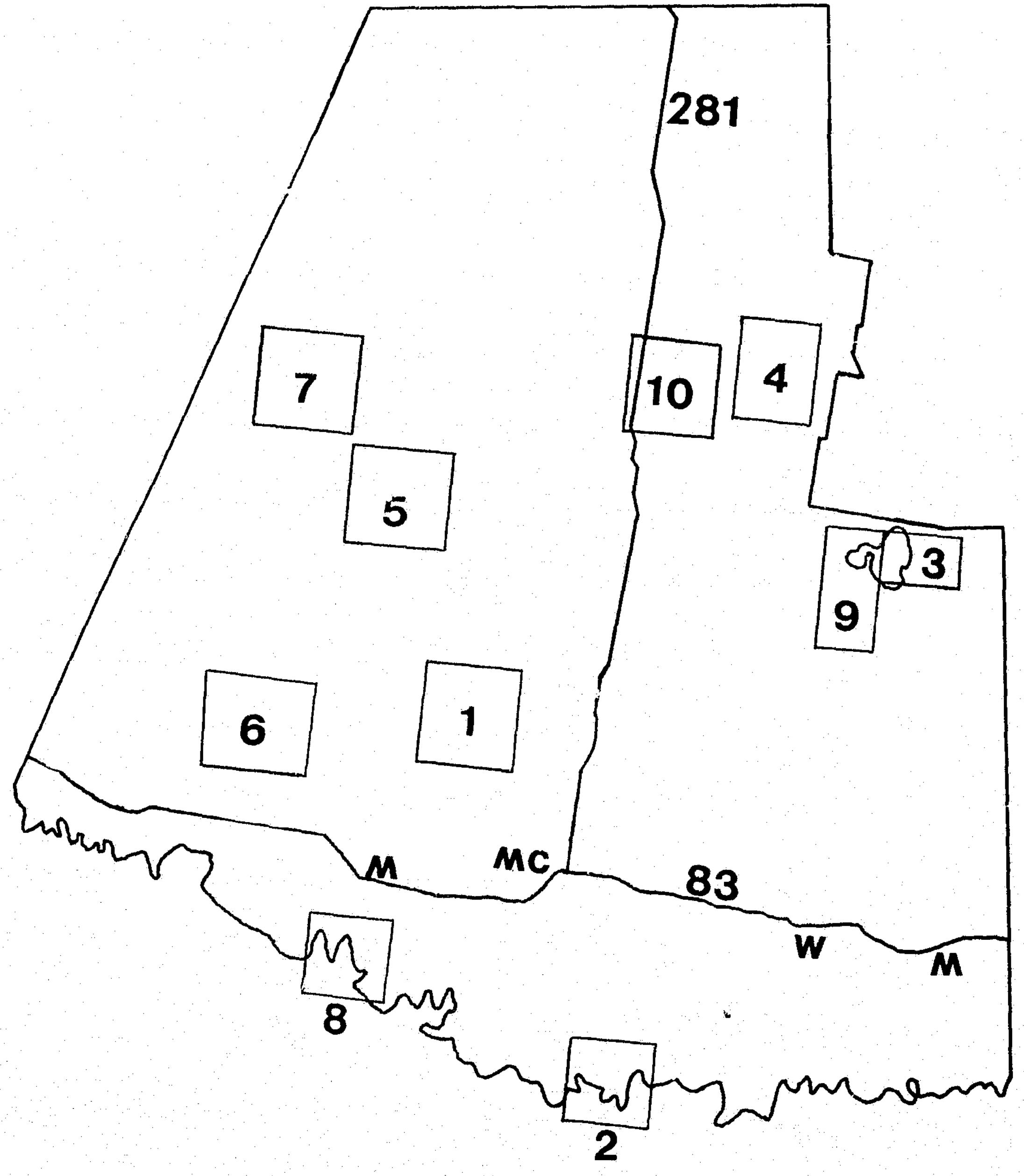


Figure 5. Two dimensional scatter diagrams, using LANDSAT MSS channels 5 and 7, of the mean digital values (January 21, 1973 LANDSAT-1 overpass) determined for 67 of 1,400 test fields randomly located in Hidalgo County. Training fields are marked with an asterisk for four spectrally distinct categories (vegetable, citrus, rangeland, and idle cropland). Definitions of four character field identifiers are as follows: class identification (character 1), northern (N), central (C), or southern (S) region of county (character 2), code number ranging from 0 to 9 for 0 to 90% crop cover (character 3), and crop and soil condition code ranging from 0 to 9. This scatter diagram is generated using program DS000.



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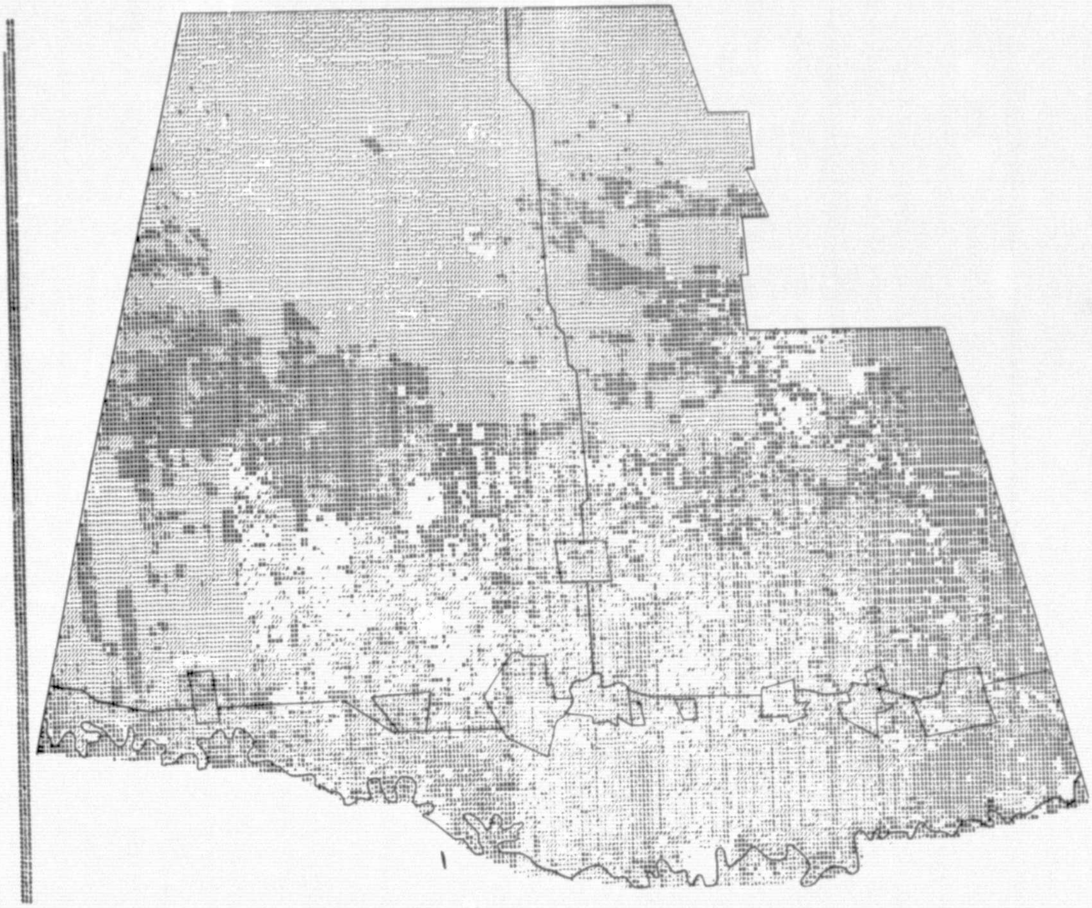

Figure 7. Classification map of Hidalgo County for a January 21, 1973, LANDSAT-1 overpass. Resolution is 11.7 ha/symbol. Definition of crop and soil condition terms of pixel line printer symbols is given as follows: vegetable (/ overprinted -), citrus (blank), mixed grass (/), mixed shrubs (-), McAllen soil association (M overprinted W), Harlingen soil association ($), water (.), and threshold (T). This map was generated by program DS070.

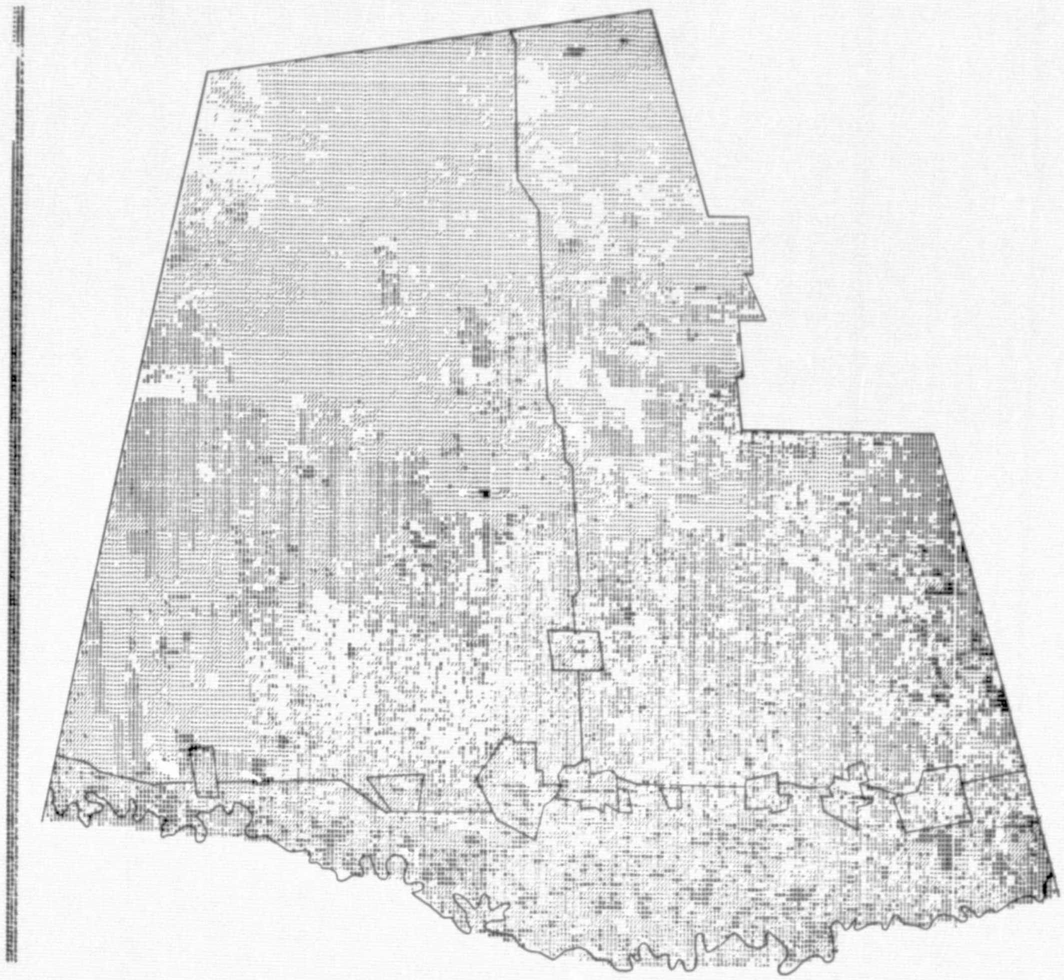

Figure 8. Classification map of Hidalgo County for a May 27, 1973 LANDSAT-1 overpass. Resolution is 11.7 ha/symbol. Definition of crop and soil condition terms of pixel line printer symbols is given as follows: cotton and sorghum (0), citrus (blank), mixed grass (/), mixed shrubs (-), McAllen soil association (M overprinted with W), Harlingen soil association ($), water (.), and threshold (T). This map was generated by program DS070.

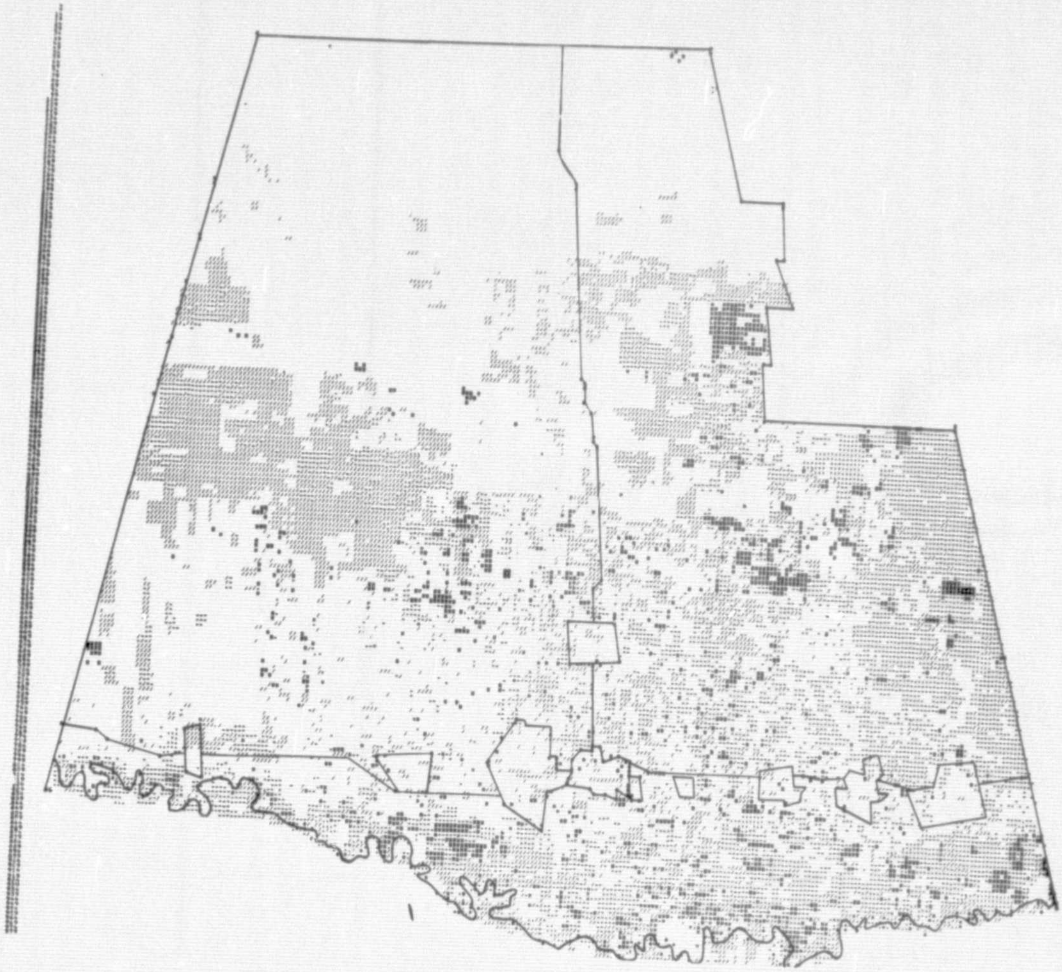

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Figure 9. Classification map of Hidalgo County for A December 11, 1973 LANDSAT-1 overpass. Resolution is 11.7 ha/symbol. Definition of crop and soil conditions in terms of pixel line printer symbols is given as follows: sugarcane (M overprinted W), high reflecting soil (/), low reflecting soil (-), other vegetation (blank), and water (.). This map was generated by program DS070.

CRITERIA FOR DISTINGUISHING VEGETATION FROM SOIL BACKGROUND INFORMATION AND THEIR USE IN PROCESSING LANDSAT MSS DATA[1]

A. J. Richardson and C. L. Wiegand[2]

ABSTRACT

LANDSAT-1 and -2 multispectral scanner (MSS) data from six overpass dates (April 2, May 17, June 4, July 10, October 17, and December 10, 1975) showed that MSS digital data for bare soil, cloud tops, and cloud shadows followed a highly predictable linear relation (soil background line) for MSS bands 5 and 7 (r^2=0.974) and bands 5 and 6 (r^2=0.986). Increasing vegetation development, documented by leaf area index (LAI) measurements, for 1973 and 1975 grain sorghum crops, was associated with displacement of sorghum MSS digital counts perpendicularly away from the soil background line. Consequently, the perpendicular distance of a sorghum MSS measurement from the soil background line was tested as an index of plant vegetative development. Two perpendicular vegetation index models, the PVI and PVI6, yielded significant correlation (r) of 0.723 (significant at the 0.05 level) and 0.812 (significant at the 0.01 level), respectively with LAI.

Correlation coefficients (r) for a transformed vegetation index (TVI6) and a green vegetation index (GVI) that have been used by others were 0.729 (significant at the 0.05 level) and 0.808 (significant at the 0.01 level), respectively, for the same data set. The PVI technique permits the calculation of the coordinates of the intersection of the vegetation and soil background lines; hence, it gives the position of a given pixel on the soil background line that other vegetation indices do not. Since position along the soil background line should vary with soil water content, soil crusting, and crop shadows, the possibility of deducing information about soil surface conditions becomes apparent.

The LANDSAT data space surrounding the soil background line for MSS5 and MSS7 was divided into 10 decision regions corresponding to water; cloud shadow; low, medium, and high reflecting soil; cloud tops; low, medium, and dense plant cover; and, a region (threshold) into which no LANDSAT data are expected to fall. It was demonstrated that, using a table lookup procedure and printer symbols for each decision region, LANDSAT study areas or scenes could be gray mapped to meaningfully display vegetation density and soil condition categories without prior knowledge of local crop and soil conditions.

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[1] Contribution from the Soil and Water Conservation Research, Southern Region, Agricultural Research Service, USDA, Weslaco, Texas. This study was supported in part by the National Aeronautics and Space Administration under Contract No. T-4105B.

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INTRODUCTION

Efforts to interpret vegetated surface reflectance from aircraft and satellite multispectral scanner (MSS) observations have been hampered by soil background signals that are superimposed on or intermingled with information about vegetation. Soil reflectance varies with soil type, water content, and tillage. Several researchers have shown that LANDSAT spectral data relate closely with such vegetation density indicators as biomass, leaf area index, percent cover, and plant population on a given date at a given location. But signature extension to several dates (temporally) and several locations (spatially) is still a problem. A procedure that accounts for soil background could contribute considerably to operational use of LANDSAT and other spectral data to monitor the productivity of range, forest, and crop lands.

Our approach was to first study soil reflectance that supplies the background signal of vegetated surfaces. We assumed that crop and soil condition survey systems that attempt to develop spectral indicators of the seasonal development of vegetation amounts and conditions (Rouse et al., 1973; Deering et al., 1975), plant canopy models for yield estimations (Allen and Richardson, 1968; Suits, 1971; Smith et al., 1973; Tucker and Miller, 1974; Wiegand et al., 1974; Richardson et al., 1975), or pattern recognition techniques for acreage surveys of crop and soil conditions would benefit by procedures that account for soil background variations.

Kauth and Thomas (1976) determined that the data space distribution of soil reflectance variation in LANDSAT data is confined to a line (in two dimensional data space) or a plane (in three dimensional data space). Reflectance variation of developing vegetation grows perpendicularly out of this plane of soils. We reasoned that this inherent distribution of soil reflectance in LANDSAT data space might be usefully applied to better understand the effect of soil background on the spectral indicators of vegetation conditions. Consequently, we investigated the distribution of soil reflectance variation for LANDSAT MSS data, collected in Hidalgo County, Texas, to determine whether it could be used as a reference against which vegetation development could be monitored.

EXPERIMENTAL PROCEDURES

In this study, we used the LANDSAT data space as recorded on the computer compatible tapes (CCT) received from the EROS data center at Sioux Falls, South Dakota, to determine Kauth's (1975) plane of soils.

LANDSAT-1 and -2 overpasses on April 2, May 17, June 4, July 10, October 17, and December 10, 1975, (scene I.D.'s are 2070-16203, 5028-16113, 5046-16103, 5082-16083, 2268-16190, and 2322-16183, respectively) furnished one set of digital data for this study. These scenes were chosen because they encompassed a test county where ground truth was available, and they were cloud free enough to use. Mean digital values for all four LANDSAT multispectral scanner (MSS) bands, MSS4 (0.5 to 0.6 μm), MSS5 (0.6 to 0.7 μm), MSS6 (0.7 to 0.8 μm), and MSS7 (0.8 to 1.1 μm), were extracted from the CCT for water, cloud tops, cloud shadows, and high and low reflecting soil in ground truthed land areas on each of the LANDSAT overpass dates. Sun elevation above the horizon was also obtained from the CCT. A linear correlation analysis between MSS5 and MSS7 was conducted on these data.

A second data set was comprised of mean digital values for sorghum fields at various maturity stages that were extracted from the April 2, May 17, May 26, and June 4, 1975, LANDSAT CCT for dry and irrigated cropland study sites. Sorghum LAI data (Allen and Richardson, 1968; Wiegand et al., 1974) were collected on May 6 and June 3, 1975, for the dry cropland study sites and on April 24 and May 24, 1975, for the irrigated cropland study sites. These ground truth (GT) data were used to document sorghum development for comparison with the MSS data.

A third data set comprised of sorghum LANDSAT-1 digital data collected May 27, 1973, and corresponding LAI measurements, previously reported by Richardson et al. (1975), were compared with results for 1975.

EXPERIMENTAL RESULTS

Soil Background Reflectance

The LANDSAT digital data from the first data set (Table 1) for soil, water, and cloud conditions were used to determine Kauth's plane of soils. Digital counts for water, and for high and low reflecting soil were not determined for May and June 1975, since almost all land areas were cropped. Kauth's plane of soils over six dates was characterized statistically by linear correlation analyses of all possible pairwise combinations of the four LANDSAT MSS bands using sixteen digital counts of cloud tops, cloud shadows, and high and low reflecting soil (Table 2). The pairwise band combinations (4, 5) and (6, 7) were not investigated further, because bands within the visible and infrared are known to be highly intercorrelated. Potter and Mendlowitz (1975 showed that the (4, 5) band combination may be useful for determining haze levels of the atmosphere, but we did not include such considerations in the present study. The pairwise band combinations (4, 6) and (4, 7) were not considered because of their lower correlation coefficients and higher standard errors of estimate ($S_{X_1 . X_2}$) than the band combinations (5, 6) and (5, 7). These latter two combinations were chosen for further study because they have been found useful in the past (Rouse et al., 1973; Wiegand et al., 1974; Deering et al., 1975; Kalensky and Scherk, 1975; Kauth and Thomas, 1976).

The 16 cloud, cloud shadow, and high and low reflectance soil digital count measurements, the best fit linear line, and confidence bands about the linear line, using LANDSAT bands 5 and 7, are shown in Figure 1a. The numbers in the figure are sun elevations in degrees. Since the origin is included within the dashed standard error of estimate lines, the intercept term (-0.01) of the best fit line does not differ statistically from zero. Thus, MSS5 is approximately equal to 2.40MSS7. The 0 to 127 digital value range of MSS5 was twice as large as the 0 to 63 range for MSS7, which accounted for the factor 2 in the slope coefficient for MSS7. If the digital values of MSS7 are doubled, then MSS5= 1.20MSS7.

Figure 1a indicates that Kauth's plane of soils in bands 5 and 7 is a family of overlapping soil brightness levels that can be extended to include clouds and cloud shadows along the best fit line. The slope of this best fit line (soil background line) appears constant from one LANDSAT overpass date to another, and the intercept term differs nonsignificantly from zero. Further investigations are needed to conclusively test whether the plane of soil shifts significantly from one study site to another or from one date to another. Possibly there is an effect on the bare soil line slope and intercept, because of atmospheric haze from scene to scene that will need to be studied further.

Sun Angle Effects

Sun angle effects on bare soil reflectance are shown in Figure 1a. The sun elevations for April 2, May 17, June 6, July 10, October 17, and December 10, 1975 (51, 57, 58, 56, 44, and 32°, respectively) are plotted for cloud (C), high reflecting soil (H), low reflecting soil (L), and shadow (S). In general, the greater the sun elevation the higher a point plots on the soil background line. For example, for the high reflecting soil sites, the sun angle increased from 32° (12/10/75) to 56° (7/10/75) as the points labeled "H" progress up the line. The same correlation is true for low reflecting soil, even though there is some overlap with cloud shadows. The correlation breaks down for clouds slightly because the lowest C value is for 57° (5/17/75). On this date, the clouds were thin and wispy, and the cloud umbras were not very dense. Shadow or cloud umbra reflectance corresponded poorly with sun angle, indicating that cloud translucence variations offset the sun angle effect.

Comparing Vegetation with Soil Background Reflectance

Data (Table 3) collected on May 27, 1973, by the LANDSAT MSS, for sorghum fields with a range of LAI values from 3 to 9 (data set 3) (Richardson et al., 1975), were plotted in Figure 1b for comparison with the 1975 soil background line (data set 2). Each number represents the LAI values (rounded to 1 digit) measured for 10 sorghum fields plotted according to the mean digital data in MSS5 and MSS7. Data points for sorghum fields deviated perpendicularly from the bare soil background line. Furthermore, the sorghum fields with the larger LAI values, corresponding to increasing vegetation density, tended to be displaced furthest from the line. Thus, a measure of the distance of a candidate sorghum point from the line probably could be used as an index of the vegetation amount or condition for that sorghum point. (Note: The LANDSAT digital counts may better characterize the fields than the LAI data because many LAI measurements are required to characterize a field precisely.)

Water deviates from the soil background line, but on the opposite side (Figure 1b) from vegetation. Candidate points (Table 1) representing water (W) are plotted in Figure 1b for April 2, July 10, October 17, and December 10, 1975, MSS data. The perpendicular distance of water from the bare soil line might help to improve water body monitoring techniques (Work and Gilmer, 1976). Work and Gilmer were trying to distinguish transition boundaries of water bodies and shore lines. A better knowledge of soil background reflectance should benefit these kinds of investigations.

Sorghum data (Figure 2) collected on April 2, May 17, May 26, and June 4, 1975, by the LANDSAT MSS, for sorghum fields in dry and irrigated cropland areas with a range of LAI values from 1 to 8, were plotted as further evidence of the lateral deviation of vegetative MSS data from the soil background line (data set 2). The LAI ground truth was collected on May 6 and June 3, 1975, for dryland sorghum and on April 24 and May 24, 1975, for irrigated sorghum.

Figure 2a and b represent sorghum grown under dryland conditions in a year of low rainfall, when LAI was never very high; hence, points representing dryland sorghum fields never deviated very far from the soil background line. Figures 2c to 2f represent sorghum grown under irrigated conditions for various combinations of ground truth (GT) and MSS overpass dates, where LAI was higher, indicating greater sorghum plant vegetative growth; hence, points representing irrigated sorghum fields deviated further from the soil background line than did dryland sorghum fields.

Vegetation Index Modeling

The soil background line could, perhaps, serve as a soil background reference for vegetation index (VI) modeling. Rouse et al. (1973) have developed two spectral VI models using LANDSAT MSS data that they used to compare multitemporal plant biomasses for several locations. Rouse's procedures involved an equation for correcting solar intensity (I_H) as a function of the solar constant (I_o) and sun elevation (α) as follows:

$$I_H = I_o \sin(\alpha), \qquad (1)$$

and equations for determining two Transformed Vegetation Indices (TVI and TVI6) as follows:

$$TVI = \sqrt{\frac{MSS7 - MSS5}{MSS7 + MSS5} + 0.5} \quad \text{, and} \qquad (2)$$

$$TVI6 = \sqrt{\frac{MSS6 - MSS5}{MSS6 + MSS5} + 0.5} \quad . \qquad (3)$$

The MSS7+MSS5 and MSS6+MSS5 terms are "normalizing" terms while the 0.5 term is added to keep the TVI and TVI6 models from becoming negative (Deering et al., 1975). The family of curves of Figure 3a indicates the range of values the TVI has for selected combinations of MSS5 and MSS7 values. The dashed line is the previously derived soil background line with a TVI value equal to 0.35.

A simple ratio of MSS5/MSS7 can be projected conically in Figure 3b as it was in Figure 3a. Thus, graphically a RVI=MSS5/MSS7 would have the same strengths and weaknesses as the TVI model. The RVI is simpler computationally than is the TVI. The dashed line is the soil background line using LANDSAT MSS bands 5 and 7 (Table 2); with a slope of 2.40.

Another VI model that could be used is the perpendicular distance of a vegetation candidate signature point from the soil background line as given by the following equation:

$$PVI=\sqrt{(Rgg5-Rp5)^2+(Rgg7-Rp7)^2} \quad , \qquad (4)$$

where,

- PVI - is the perpendicular VI, defined as the perpendicular distance between the candidate vegetation point and the soil background line,
- Rp - is the reflectance of a candidate vegetation point for LANDSAT bands MSS5 and MSS7, and
- Rgg - is the reflectance of soil background corresponding to a candidate vegetation point.

A graphical interpretation of this equation is given in Figure 4 for LANDSAT bands MSS5 and MSS7. The soil background reflectance is interpreted as the intersection on the soil background line (Rgg5 and Rgg7) with a perpendicular drawn from a candidate signature point (Rp5, Rp7). The coordinates of this intersection on the soil background line, in terms of MSS5 and MSS7, can be found by solving the soil background general equation ($Rg5=a_o+a_1Rg7$) and the vegetation general equation ($Rp5=b_o+b_1Rp7$), that is perpendicular to the soil background equation, for the intersection coordinates (Rgg5, Rgg7) given by

$$Rgg5 = \frac{b_1a_o-b_oa_1}{b_1-a_1} \quad , \text{ and} \qquad (5)$$

$$Rgg7 = \frac{a_o-b_o}{b_1-a_1} \quad . \qquad (6)$$

From Table 2, we determined that $a_1=2.40$ (slope of soil background line for MSS bands 5 and 7) and that a_o does not differ statistically from zero (therefore, $a_o=0$). Also, since a_1 is perpendicular to b_1, then $b_1=-0.417$, so that $b_1-a_1=-2.82$. Substituting these values of a_o, a_1, and b_1 into equation (5) and (6) yields $Rgg5=0.851b_o$ and $Rgg7=0.355b_o$. It can be shown from the vegetation perpendicular equation that $b_o=Rp5+0.417Rp7$, so that for any candidate vegetation signature, defined by the LANDSAT coordinates (Rp5, Rp7), the soil background reflectance coordinates are given by the following equations:

$$Rgg5=0.851Rp5+0.355Rp7, \text{ and} \qquad (7)$$

$$Rgg7=0.355Rp5+0.148Rp7. \qquad (8)$$

Thus, once Rgg5 and Rgg7 are determined for a candidate vegetation measurement (equations 7 and 8), then the PVI (equation 4) can be computed as a spectral indicator of plant development or biomass accumulation. Figure 4 shows that PVI=0 indicates bare soil, a PVI<0 (negative) indicates water, and a PVI>0 (positive) indicates vegetation. A family of curves for selected combinations of LANDSAT MSS bands 5 and 7 values (Figure 5a) shows how the PVI is distributed in LANDSAT 2-dimensional data space.

A computationally simpler method of achieving this same measure is to subtract MSS5 from MSS7 as given by

$$DVI = 2.40MSS7 - MSS5 \quad (9)$$

where DVI is the difference VI, and MSS7 is multiplied by the slope of the linear equation (Table 2) for the soil background line, defined by MSS bands 5 and 7. The graphical interpretation of the DVI in Figure 5b illustrates the correspondence to the PVI in Figure 5a. Figure 5b shows that a DVI=0 indicates bare soil, a DVI<0 (negative) indicates water, and a DVI>0 (positive) indicates vegetation. The disadvantage of this method is that the soil background coordinates (Rgg5, Rgg7) cannot be determined.

It is also possible to formulate another perpendicular distance vegetation index (PVI6) model, using LANDSAT bands 5 and 6 as follows:

$$PVI6 = \sqrt{(Rgg5-Rp5)^2 + (Rgg6-Rp6)^2} \quad , \quad (10)$$

that is similar to the PVI model given by equation (4). The bare soil intersection coordinates for this VI model were determined from the linear equation for bands 5 and 6, given in Table 2. Using the equation coefficients from Table 2, the bare soil intersection coordinates for the PVI6 model are given as follows:

$$Rgg5 = -0.498+0.543Rp5+0.498Rp6 \quad , \text{ and} \quad (11)$$

$$Rgg6 = 2.734+0.498Rp5+0.457Rp6. \quad (12)$$

Kauth and Thomas (1976) have developed a technique for transforming the information contained in LANDSAT 4-dimensional data space (i.e., defined by all 4 LANDSAT MSS bands) into a soil brightness index (SBI) and a green vegetation index (GVI). These transformations could be used as VI models using transformation coefficients given by Kauth as follows:

$$SBI = 0.433MSS4+0.632MSS5+0.586MSS6+0.264MSS7 \quad , \text{ and} \quad (13)$$

$$GVI = -0.290MSS4-0.562MSS5+0.600MSS6+0.491MSS7 \quad . \quad (14)$$

The SBI characterizes the soil background similar to the PVI and PVI6 soil background intersection coordinates. The GVI is a transformed VI.

Thus, we have described eight separate vegetation index models (TVI, TVI6, RVI, PVI, PVI6, DVI, SBI, and GVI) that could be used as indicators of vegetation density development. The PVI and PVI6 models permit calculation of the soil background intersection coordinates, (Rgg5, Rgg7) and (Rgg5, Rgg6), respectively, that we feel is an advantage over the other VI models because these intersection coordinates allowed us to examine reasons (water content differences, shadows, tillage, soil crusting) for differences in reflectance of cropland, rangeland, and forest scenes due to soil background.

Evaluation of Vegetation Indices

The simple correlation coefficients relating the eight VI models (TVI, TVI6, RVI, PVI, PVI6, DVI, SBI, and GVI) with four ground truth parameters, crop cover, shadow cover, plant height, and leaf area index, are given in Table 4. The TVI, TVI6, and RVI models are used by Texas A&M University, College Station, Texas, as indicators of the amount and seasonal condition of rangeland vegetation (Deering et al., 1975). The SBI and GVI are used in the Large Area Crop Inventory Experiment (LACIE) at the Johnson Spacecraft Center, Houston, Texas, for describing important crop phenomena concerning soil background and green development. The PVI, PVI6, and DVI models were developed in this report as indicators of vegetation development.

We found that the single channel correlations (r) of MSS5 with plant height (-0.849**) and MSS6 with leaf area index (0.877**) were higher than those produced by any of the VI models. The TVI6 model yielded the highest correlation with plant height (0.828**); while PVI6 correlated best with leaf area index (0.812**). Thus, these two VI models performed best, probably because of the high individual correlations of MSS5 and MSS6 with plant height and leaf area index, respectively.

As we expected, the SBI did not correlate significantly with any of the four ground truth parameters. The GVI was correlated significantly with crop cover (0.662*), plant height (0.744*), and leaf area index (0.808**).

Those VI models using LANDSAT MSS6 and not MSS7 (i.e., TVI6 and PVI6) correlated better with the ground truth information than the VI models that used MSS7 and not MSS6 (i.e., TVI, RVI, PVI, and DVI). Thus, for this set of 10 sorghum fields, MSS6 contained more information about green vegetation development than did MSS7. More testing is recommended with other sets of data to conclusively determine the superiority of MSS6 to MSS7 and TVI6 and PVI6 models to TVI, RVI, PVI, and DVI models. Although individual LANDSAT bands may sometimes correlate better with yield than the VI models, the VI models provide better capability for temporal (season to season) comparisons of vegetation amounts and conditions.

Implications for Monitoring Plant and Soil Conditions

A gray mapping technique for displaying plant, soil, water, and cloud conditions for any LANDSAT overpass for any date for any study area location was devised as shown in Figure 6a and b. The LANDSAT data space, determined by bands MSS5 and MSS7, were arbitrarily divided into decision regions corresponding to 10 general categories as shown in Figure 6a. These decision boundaries are a good first approximation for dividing LANDSAT data space. Kauth's line of soil is shown as an inverted cone with apex at the origin that can be considered as an expanding brightness scale composed of low (3), medium (4), and high (5) reflecting soil. The cone is terminated at the bottom by shadow (1) and is bounded at the top by the sensor saturation response for clouds (6). As sun angle or illumination decreases, the range of soil reflectance decreases and the data are compressed toward the apex (origin) of the cone. Similarly, the variations of vegetation reflectance for low (7), medium (8), and high (9) vegetation cover follow conical paths that become narrower as sun angle or illumination decreases. Water (2) is shown on the opposite side of the soil brightness scale from vegetation. The regions into which no LANDSAT data are expected to fall are called thresholds (0).

The construction of the decision boundaries among water, bare soil, and vegetation are fairly well known, based on the evidence presented in this paper. But the decision boundaries representing degrees of soil brightness and densities of vegetation cover will evolve as more applications and tests are made of them. Such categories can be expected to be "tuned" regionally for particular crops--like grain sorghum, wheat, and soybeans--and soil conditions. Tuning can also be expected among soils differing in productivity within a physiographic area or crop reporting district, and for irrigated versus nonirrigated crops in supplementally irrigated areas.

The decision boundaries of Figure 6a were implemented as a gray mapping process where the numbers ranging from 0 to 9, were arranged in a table as indicated in Figure 6b. The candidate MSS5 and MSS7 signature pair is used as an address for the table in Figure 6b. The number at that specific address defines the signature category of the candidate signature pair. The process is repeated for each signature pair.

Figures 7 through 9 show the gray map results of crop, soil, and water conditions for a study site in Hidalgo County, Texas, using three of the six LANDSAT overpass dates, April 2, July 10, and October 17, 1975, from data set one. The water body (•) is Delta Lake with two Perennial crops, citrus and sugarcane, nearby. Using this gray mapping technique, the development of the sugarcane field could be monitored with respect to the citrus orchard during these three dates. In April (Figure 7), the citrus orchard is indicated by low (L) to medium (M) cover vegetation (gray map symbols). The sugarcane field is delineated by symbols indicating low (-) and medium (/) reflecting soil with some low cover vegetation, indicative of early season ratoon regrowth. By July (Figure 8), the sugarcane plants have developed considerably, so the sugarcane field is delineated by symbols indicating low to high cover vegetation as compared with low to medium cover vegetation in the citrus orchard. Finally, in October (Figure 9), the sugarcane is approaching maturity and is densely vegetated, while the citrus orchard is in a low to high vegetative cover condition.

The sun elevation varied from 51, 56, and 44°, for April, July, and October, respectively, but the digital values for citrus and sugarcane were automatically referenced to bare soil brightness using the table lookup procedure (Figures 6a and b). Thus, without any ground truth, the gray mapping technique allows delineation of any LANDSAT scene into vegetative cover stages, degrees of soil brightness, and water. The same technique can be used as a classification tool if ground truth is available for specifying meaningful vegetative cover categories or degrees of soil brightness for specific areas and dates.

Therefore, the techniques we describe can be used in rapid machine processing and classification procedures.

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Table 1. Mean digital counts from six LANDSAT-1 and -2 overpasses in 1975 for soil, water, and cloud conditions in Hidalgo and Willacy Counties, Texas. The maximum digital count for LANDSAT multispectral scanner (MSS) bands 4, 5, and 6 is 127 and for 7 it is 63. The number in parenthesis for each overpass date is the sun elevation.

Soil, water, or atmospheric condition	April 2, 1975 (51°) (Scene I.D. 2070-16203)				May 17, 1975 (57°) (Scene I.D. 5028-16113)				June 4, 1975 (59°) (Scene I.D. 5046-16103)			
	MSS4	MSS5	MSS6	MSS7	MSS4	MSS5	MSS6	MSS7	MSS4	MSS5	MSS6	MSS7
	Digital counts											
High reflecting bare soil	48	68	66	24	-	-	-	-	-	-	-	-
Low reflecting bare soil	26	31	36	15	-	-	-	-	-	-	-	-
Cloud	99	109	111	50	97	96	95	40	127	127	118	55
Cloud shadow	24	24	31	12	38	29	33	12	28	20	21	8
Water	34	32	16	2	-	-	-	-	-	-	-	-

Soil, water, or atmospheric condition	July 10, 1975 (56°) (Scene I.D. 5082-16083)				October 17, 1975 (44°) (Scene I.D. 2268-16190)				December 10, 1975 (32°) (Scene I.D. 2322-16183)			
	MSS4	MSS5	MSS6	MSS7	MSS4	MSS5	MSS6	MSS7	MSS4	MSS5	MSS6	MSS7
	Digital counts											
High reflecting bare soil	77	90	86	34	43	63	70	28	39	58	61	24
Low reflecting bare soil	40	43	40	17	22	30	32	14	14	18	18	7
Cloud	120	120	107	45	-	-	-	-	-	-	-	-
Cloud shadow	32	24	26	11	-	-	-	-	-	-	-	-
Water	40	30	17	4	29	26	12	1	17	15	9	1

Table 2. Linear equations determining Kauth's line of soil for all possible pairwise combinations of the 4 LANDSAT MSS bands. Digital count data are for April 2, May 17, June 4, July 10, October 17, and December 10, 1975, from high and low reflecting soil, and cloud and cloud shadows (N=16).

MSS band pairwise combination (X_1, X_2)	Correlation coefficient (r)	Linear equations $X_1=a_o+a_1X_2$	Standard error of estimate $(S_{X_1 \cdot X_2})$
			Digital counts
(4 , 5)	0.967	$X_1=-1.04+0.938X_2$	10
(4 , 6)	0.949	$X_1=-5.45+1.011X_2$	12
(4 , 7)	0.958	$X_1=-1.23+2.257X_2$	11
(5 , 6)	0.993	$X_1=-5.49+1.091X_2$	5
(5 , 7)	0.987	$X_1=-0.01+2.400X_2$	6
(6 , 7)	0.993	$X_1= 5.09+2.200X_2$	4

Table 3. Mean digital data collected from 10 sorghum fields on May 27, 1973 (Scene ID 1308-16323). Average row width was 97.6 cm. Sun elevation was 62° and sun azimuth was 93°. Vegetation indices for eight vegetation index (VI) model transformations, two transformed VI's (TVI and TVI6), ratio VI (RVI), two perpendicular VI's (PVI and PVI6), difference VI (DVI), soil brightness index (SBI), and green VI (GVI), determined from digital data for MSS4, MSS5, MSS6, and MSS7 are listed. The MSS digital data were corrected for radiance and sun angle for calculation of TVI and TVI6. The original digital count data were used to calculate all other transformations.

LANDSAT-1 MSS Bands				Crop cover	Shadow cover	Plant height	Row azimuth	Leaf area index	Vegetation Indice Transformations							
MSS4	MSS5	MSS6	MSS7	%	%	cm	°		TVI	TVI6	RVI	PVI	PVI6	DVI	Green	Bright
38	33	46	34	75	8	75	82	3.0	0.85	0.78	0.97	19	9	49	15	73
48	47	58	34	35	5	45	81	3.9	0.75	0.74	1.38	13	9	35	11	93
38	31	56	30	90	10	110	1	4.1	0.84	0.85	1.03	16	18	42	20	77
38	28	58	29	80	20	110	1	4.2	0.85	0.89	0.97	16	22	42	22	76
43	41	53	26	65	1	60	91	4.2	0.70	0.75	1.58	8	9	22	9	82
39	32	56	31	65	9	85	81	4.9	0.84	0.84	1.03	16	17	43	20	78
33	24	60	37	70	30	85	3	5.1	0.95	0.94	0.65	25	26	66	31	74
34	24	65	40	90	5	110	89	6.9	0.97	0.95	0.60	28	29	73	35	79
37	27	67	40	85	15	100	3	7.3	0.94	0.93	0.68	27	29	70	34	83
36	28	65	38	90	2	110	91	8.5	0.93	0.92	0.74	24	27	64	31	81

Table 4. Simple linear correlation coefficients between eight vegetation indice models, based on LANDSAT digital count data collected for 10 sorghum fields on May 27, 1973, and ground truth information for the same fields.

Vegetation Indice Models	Ground truth information			
	Crop cover	Shadow cover	Plant height	Leaf area index
	- - - - - - - correlation coefficients, r - - - - - - -			
TVI	0.657*	0.446	0.717*	0.655*
TVI6	0.716*	0.466	0.828**	0.729*
RVI	-0.662*	-0.453	-0.733*	-0.630
PVI	0.565	0.324	0.596	0.723*
PVI6	0.681*	0.382	0.794**	0.812**
DVI	0.564	0.325	0.595	0.723*
GVI	0.662*	0.370	0.744*	0.808**
SBI	-0.621	-0.457	-0.539	0.132

LANDSAT MSS Bands	Ground truth information			
	Crop cover	Shadow cover	Plant height	Leaf area index
	- - - - - - - correlation coefficients, r - - - - - - -			
MSS4	-0.797**	-0.476	-0.773*	-0.482
MSS5	-0.809**	-0.518	-0.849**	-0.529
MSS6	0.342	0.124	0.502	0.877**
MSS7	0.295	0.137	0.314	0.702*

* Statistically significant at 0.01 probability level.

** Statistically significant at 0.05 probability level.

FIGURE CAPTIONS

Figure 1 Scatter diagram of digital data (a) from LANDSAT bands 5 and 7 for cloud tops (C), cloud shadows (S), high reflecting soil (H), and low reflecting soil (L). Sun elevation for each category was as follows; April 2 (51°), May 17 (57°), June 4 (58°), July 10 (56°), October 17 (44°), and December 10 (32°), 1975. The regression line (MSS5=0.01+2.4MSS7) and standard error of estimate ($S_{X_1 \cdot X_2}=\pm 6$) are plotted as solid and dashed lines, respectively. The coefficient of determination was $r^2=0.974$*. Scatter diagram of digital data (b) from LANDSAT bands 5 and 7 for 10 sorghum fields collected on May 27, 1973. Sorghum fields are identified by their LAI value rounded to 1 digit. Water (W) from four LANDSAT overpasses, April 2, July 10, October 17, and December 10, 1975, are also plotted. The solid line is the soil background line determined from Figure 1a.

Figure 2 Scatter diagrams of MSS data in LANDSAT bands 5 and 7 for sorghum fields grown under dry cropland conditions (a and b) and irrigated cropland conditions (c through f). Sorghum fields are identified by their LAI value rounded to 1 digit. Each figure is a different combination of MSS and ground truth (GT) data collection dates for 1975 as follows; (a) 5/17 and 5/6, (b) 6/4 and 6/3, (c) 4/2 and 4/24, (d) 5/17 and 4/24, (e) 5/26 and 5/24, and (f) 6/4 and 5/24, respectively.

Figure 3 Diagrams showing distribution of (a) the Transformed Vegetation Index (TVI) and (b) Ratio Vegetation Index (RVI) in LANDSAT data space as defined by bands 5 and 7. TVI is defined by:

$$TVI=\sqrt{(MSS7-MSS5)/(MSS7-MSS5)+0.5} \quad \text{and}$$

RVI by RVI=MSS5/MSS7.

Figure 4 Diagram illustrating principle of the perpendicular vegetation index (PVI) model. A perpendicular from candidate plant coordinates (Rp5, Rp7) intersects the soil background line at coordinates (Rgg5, Rgg7). As shown a PVI<0 (negative) indicates water, a PVI=0 indicates soil, and a PVI>0 (positive) indicates vegetation.

Figure 5 Scatter diagrams showing distribution of (a) the Perpendicular Vegetation Index (PVI) and (b) the Differenced Vegetation Index (DVI) in LANDSAT data space as defined by bands 5 and 7. The PVI is defined by:

$$PVI=\sqrt{(Rgg5-Rp5)^2+(Rgg7-Rg7)^2} \quad \text{and}$$

DVI by DVI=2.4MSS-MSS5.

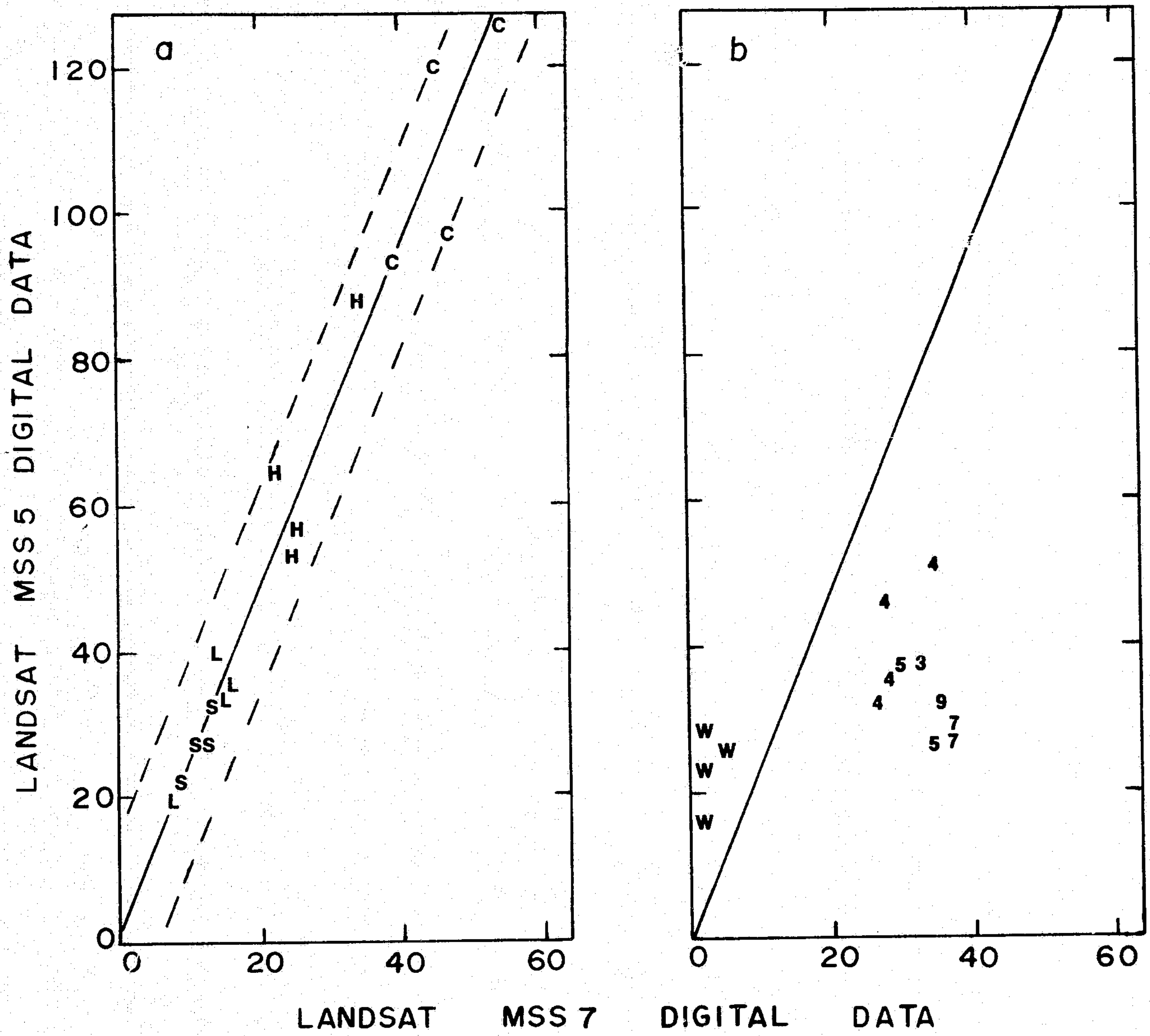
Figure 6 Diagram (a) shows the division of LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories as follows: Threshold (0), cloud shadow (6), water (2), low reflecting soil (3), medium reflecting soil (4), high reflecting soil (5), clouds (6), low vigor vegetation (7), medium vigor vegetation (8), and high vigor vegetation (9). Table lookup matrix (b) was devised to implement the division of LANDSAT data space from Figure 6a.

Figure 7 Gray map printout of a water body (Delta Lake), a sugarcane field, and a citrus orchard, in Hidalgo County, Texas. The gray map is based on a table lookup technique that divides LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories; threshold (T), water (∘), cloud shadow (Z), low reflecting soil (-), medium reflecting soil (/), high reflecting soil (+), low cover vegetation (L), medium cover vegetation (M), and high cover vegetation (H). This gray map corresponding to an April 2, 1975, LANDSAT overpass delineates immature sugarcane with bare soil and low vegetation cover symbols. An established citrus orchard is delineated with low and medium vegetation cover symbols.

Figure 8 The same symbology as for Figure 7, for a July 10, 1975, LANDSAT overpass. The rapidly growing sugarcane is delineated with low to high cover vegetation symbols, and the established citrus orchard is delineated with low to medium cover vegetation symbols.

Figure 9 The same symbology as for Figure 7, for an October 17, 1975, LANDSAT overpass. Mature sugarcane is delineated with high cover vegetation symbols while the established citrus orchard continues to be delineated with low to high cover vegetation symbols.

Figure 1. Scatter diagram of digital data (a) from LANDSAT bands 5 and 7 for cloud tops (C), cloud shadows (S), high reflecting soil (H), and low reflecting soil (L). Sun elevation for each category was as follows: April 2 (51°), May 17 (57°), June 4 (58°), July 10 (56°), October 17 (44°), and December 10 (32°), 1975. The regression line (MSS5=0.01+2.4MSS7) and standard error of estimate ($S_{X_1 \cdot X_2}=\pm 6$) are plotted as solid and dashed lines, respectively. The coefficient of determination was $r^2=0.974$*. Scatter diagram of digital data (b) from LANDSAT bands 5 and 7 for 10 sorghum fields collected on May 27, 1973. Sorghum fields are identified by their LAI value rounded to 1 digit. Water (W) from four LANDSAT overpasses, April 2, July 10, October 17, and December 10, 1975, are also plotted. The solid line is the soil background line determined from Figure 1a.


a
b
120
100
80
60
40
20
0
0 20 40 60
0 20 40 60
LANDSAT MSS 5 DIGITAL DATA
LANDSAT MSS 7 DIGITAL DATA

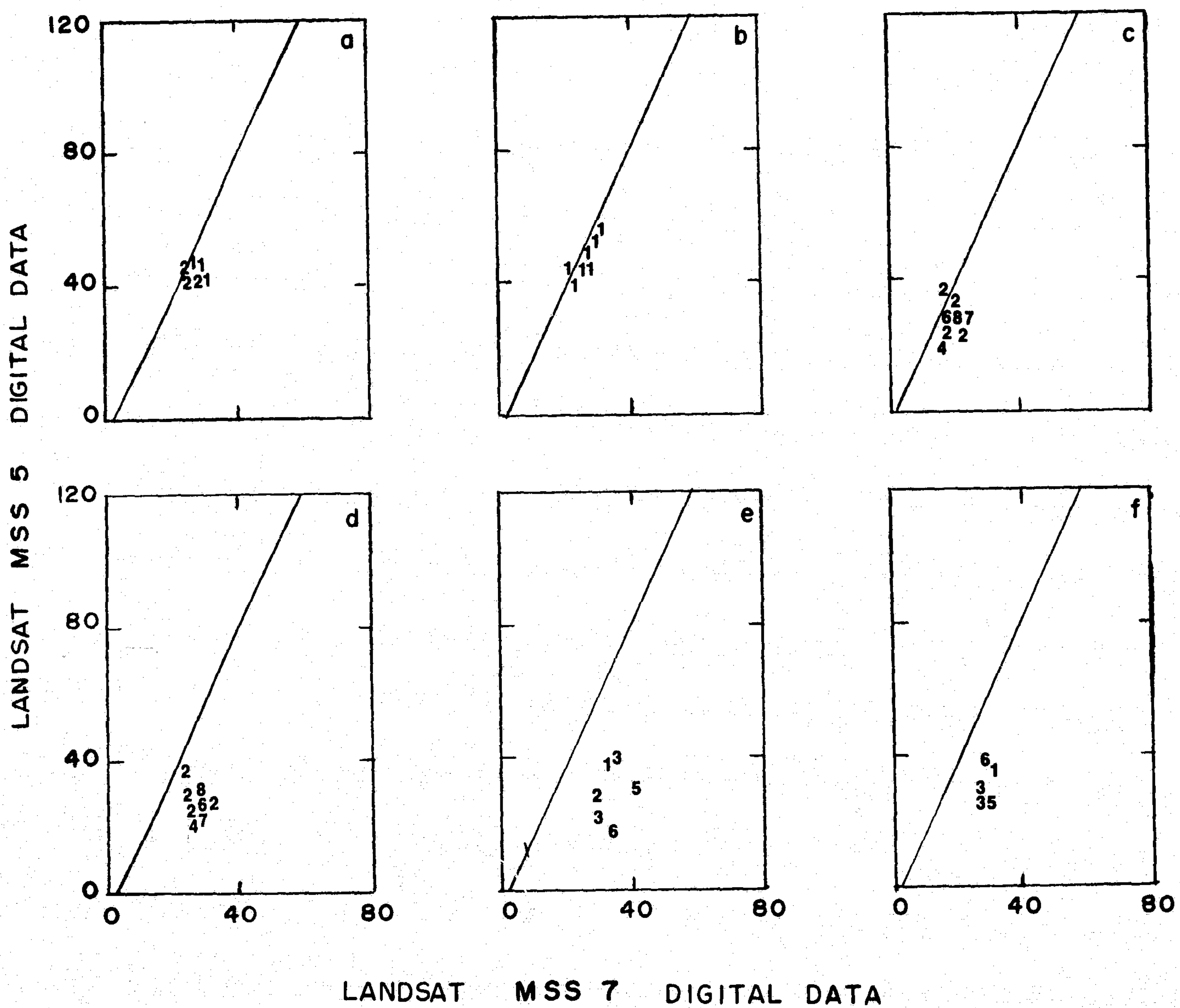


Figure 2. Scatter diagrams of MSS data in LANDSAT bands 5 and 7 for sorghum fields grown under dry cropland conditions (a and b) and irrigated cropland conditions (c through f). Sorghum fields are identified by their LAI value rounded to 1 digit. Each figure is a different combination of MSS and ground truth (GT) data collection dates for 1975 as follows: (a) 5/17 and 5/6, (b) 6/4 and 6/3, (c) 4/2 and 4/24, (d) 5/17 and 4/24, (e) 5/26 and 5/24, and (f) 6/4 and 5/24, respectively.

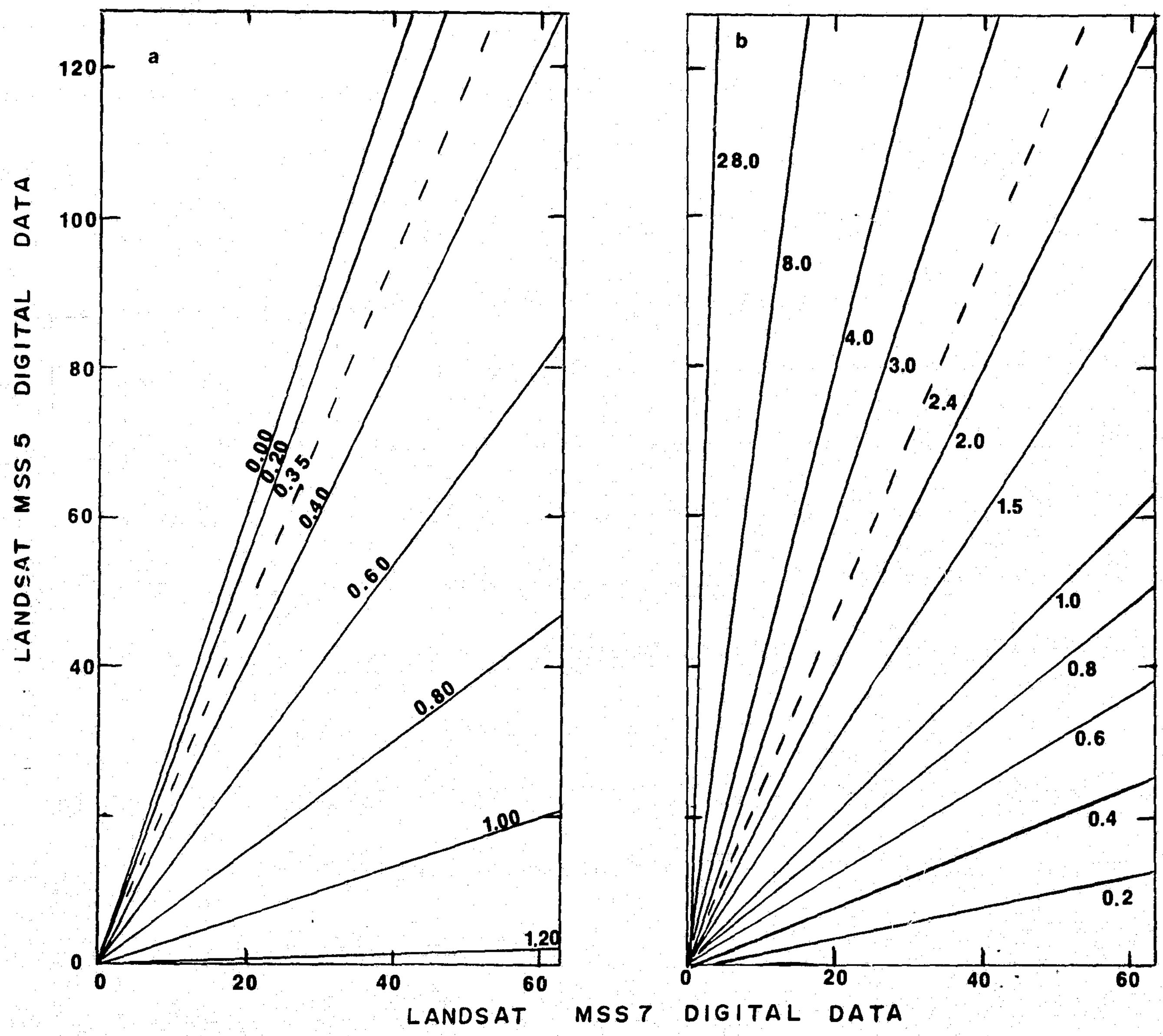


Figure 3. Diagrams showing distribution of (a) the Transformed Vegetation Index (TVI) and (b) Ratio Vegetation Index (RVI) in LANDSAT data space as defined by bands 5 and 7. TVI is defined by:

$$TVI = \sqrt{(MSS7-MSS5)/(MSS7-MSS5)+0.5} \quad \text{and}$$

RVI by RVI=MSS5/MSS7.

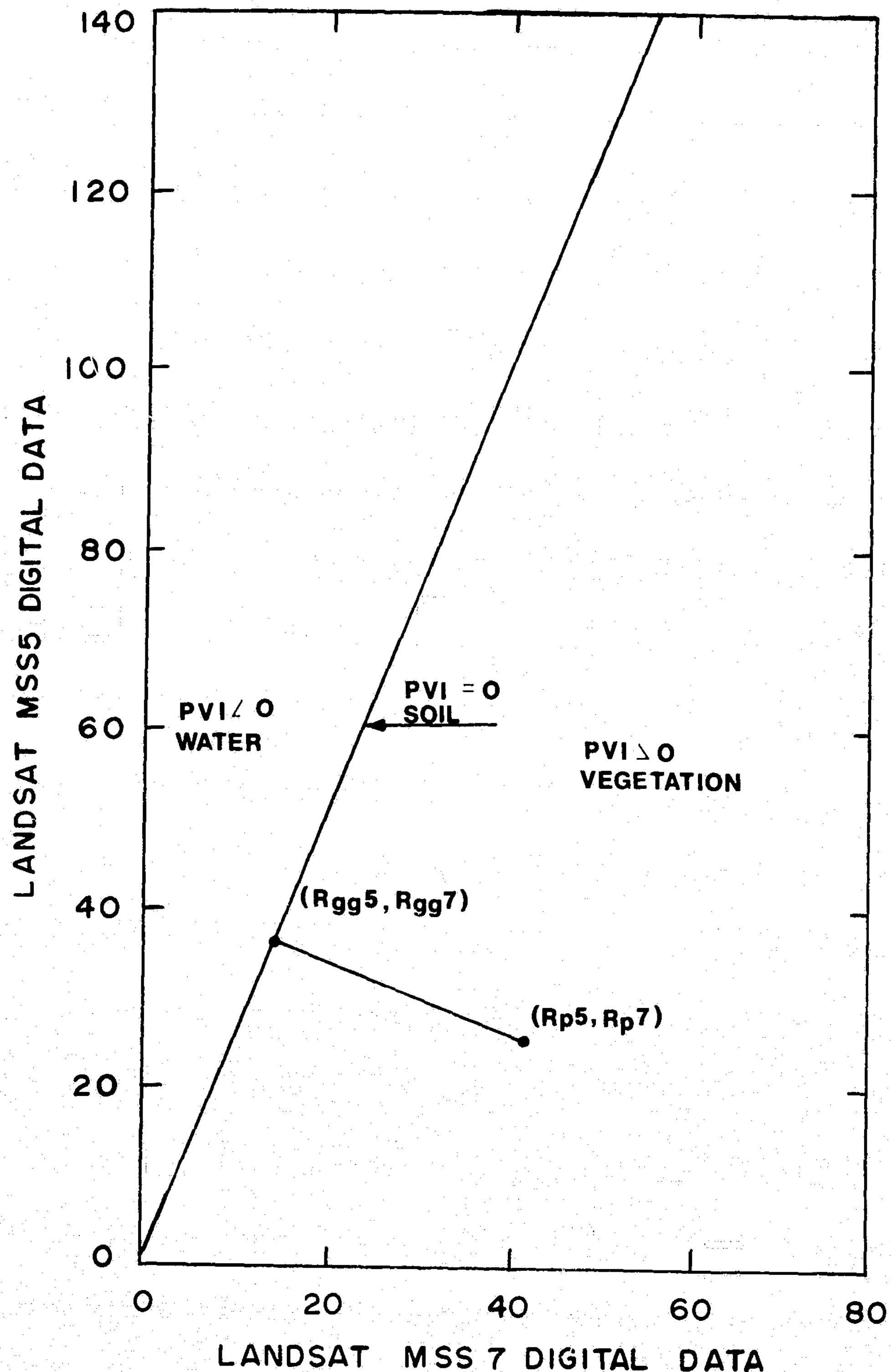


Figure 4. Diagram illustrating principle of the perpendicular vegetation index (PVI) model. A perpendicular from candidate plant coordinates (Rp5, Rp7) intersects the soil background line at coordinates (Rgg5, Rgg7). As shown a PVI<0 (negative) indicates water, a PVI=0 indicates soil, and a PVI>0 (positive) indicates vegetation.

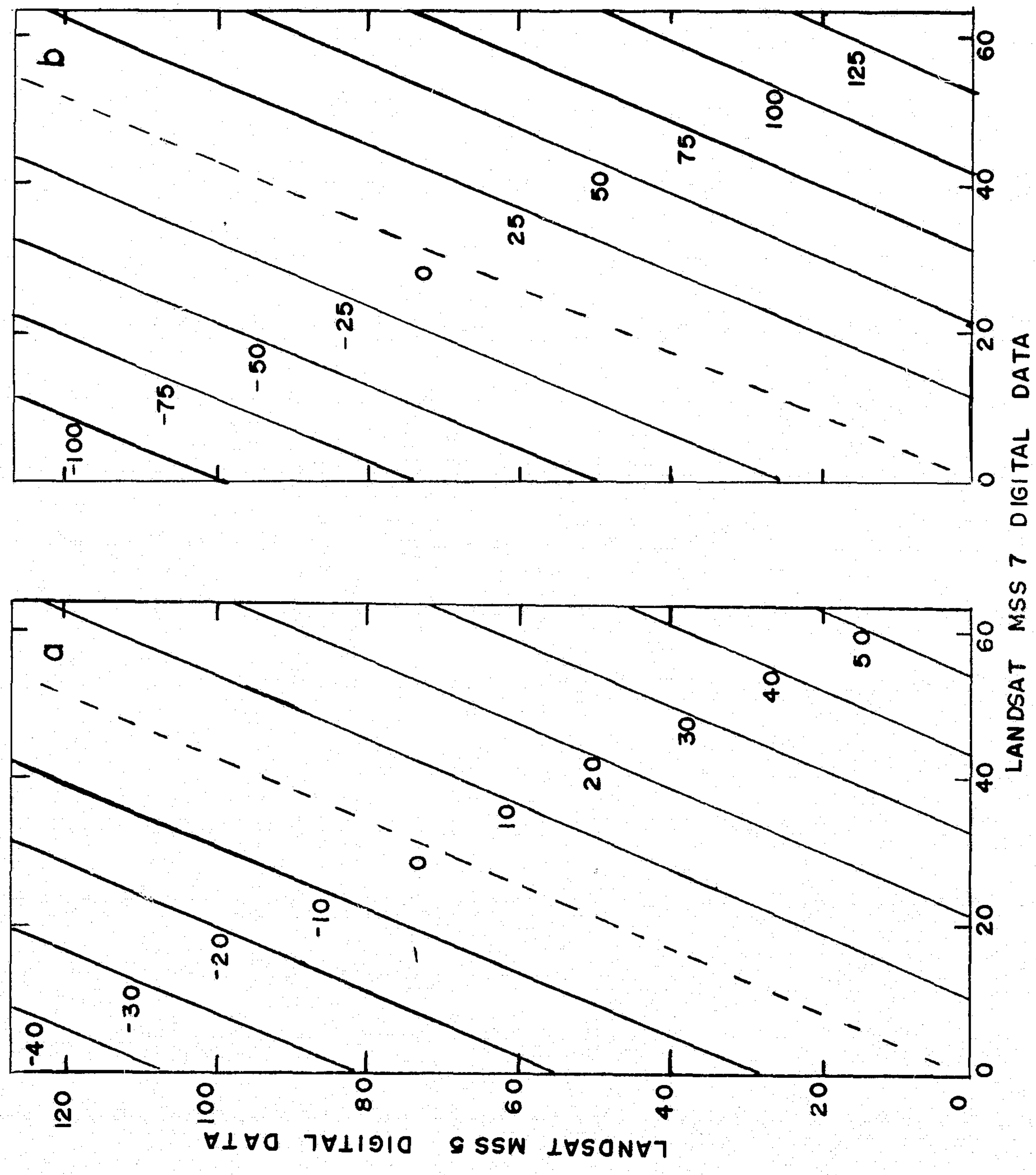


Figure 5. Scatter diagrams showing distribution of (a) the Perpendicular Vegetation Index (PVI) and (b) the Differenced Vegetation Index (DVI) in LANDSAT data space as defined by bands 5 and 7. The PVI is defined by:

$$PVI = \sqrt{(Rgg5 - Rp5)^2 + (Rgg7 - Rg7)^2} \quad \text{and}$$

DVI by DVI=2.4MSS7-MSS5

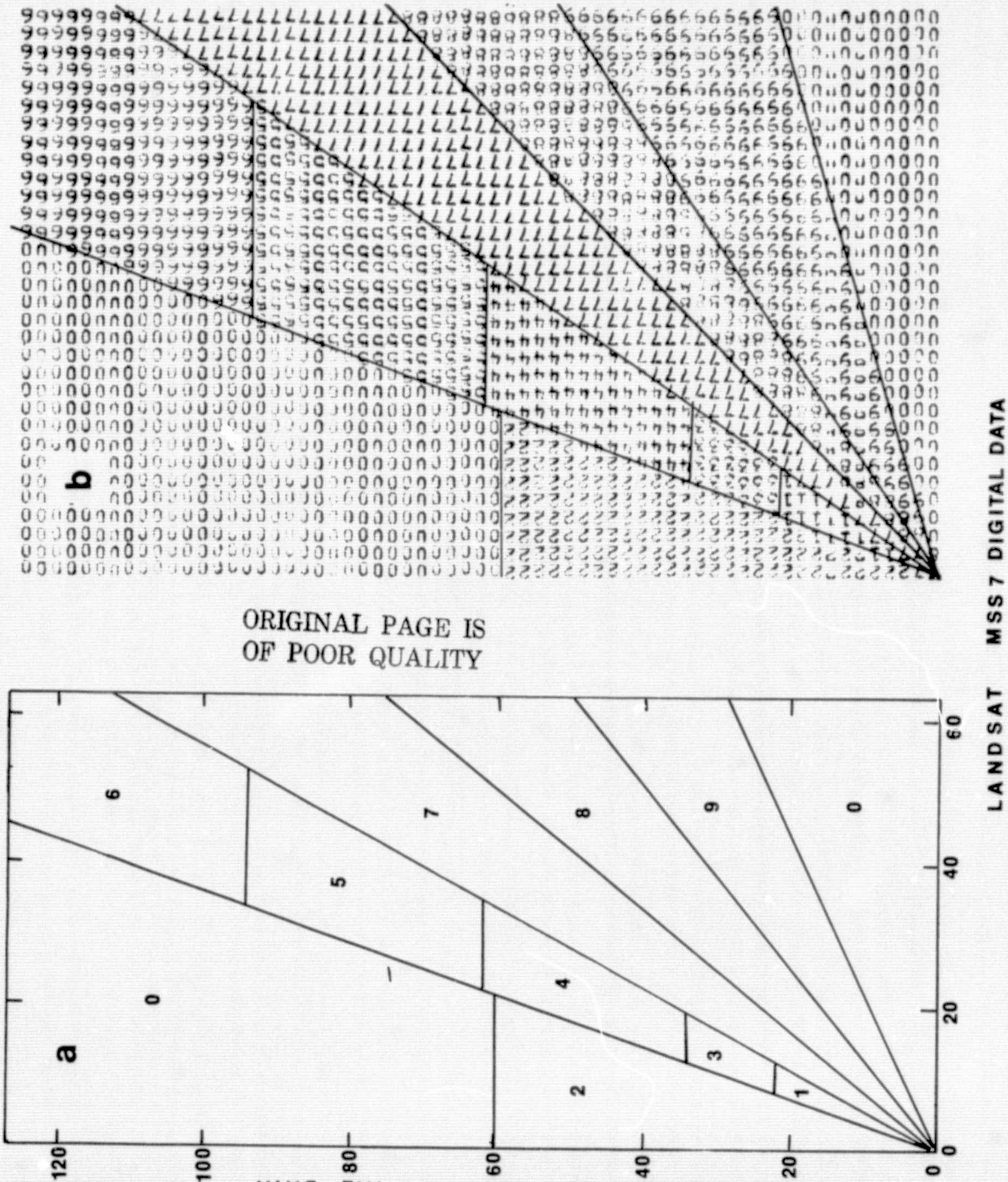


Figure 6. Diagram (a) shows the division of LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories as follows: Threshold (0), cloud shadow (6), water (2), low reflecting soil (3), medium reflecting soil (4), high reflecting soil (5), clouds (6), low vigor vegetation (7), medium vigor vegetation (8), and high vigor vegetation (9). Table lookup matrix (b) was devised to implement the division of LANDSAT data space from Figure 6a.

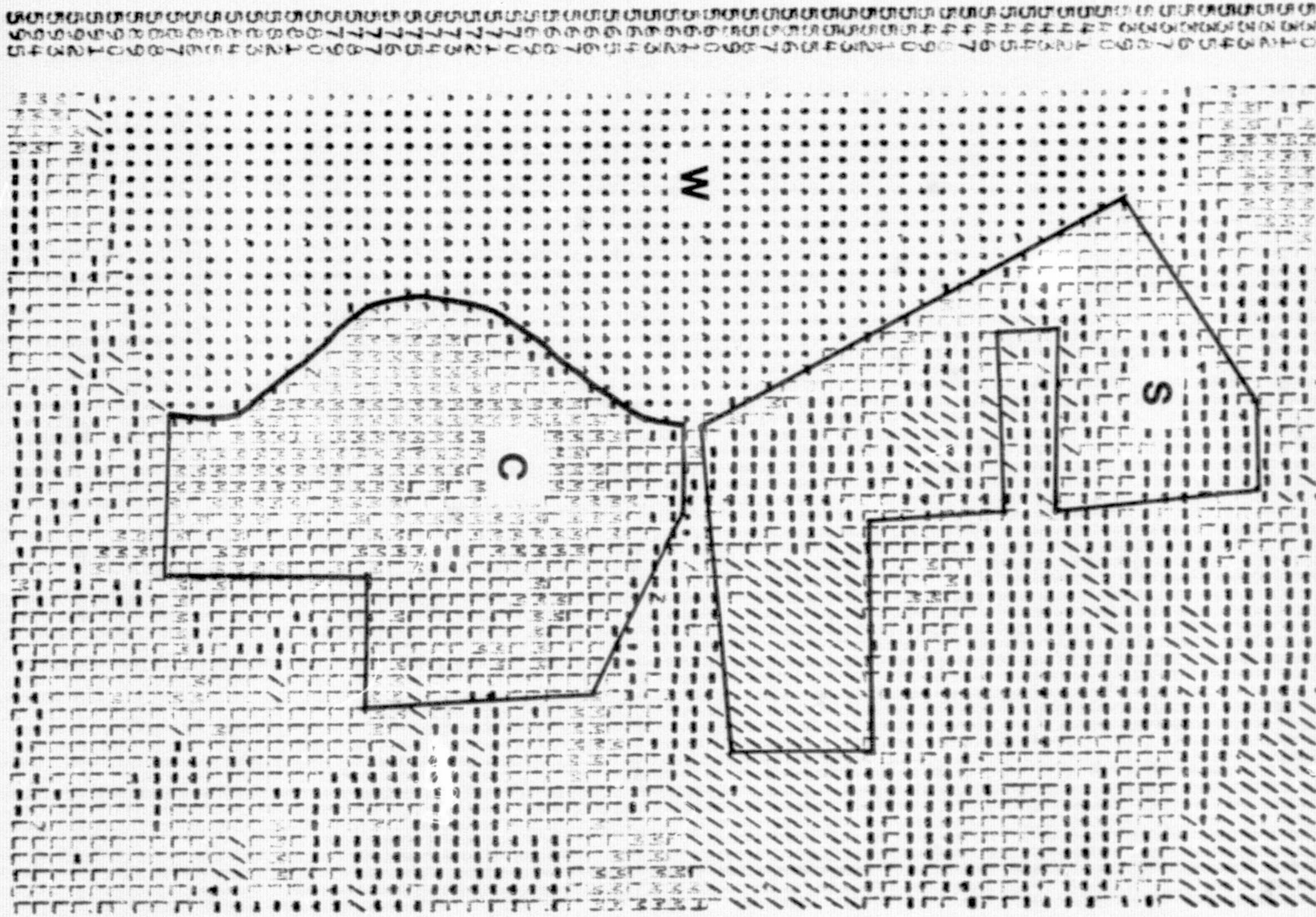


Figure 7. Gray map printout of a water body (Delta Lake), a sugarcane field, and a citrus orchard, in Hidalgo County, Texas. The gray map is based on a table lookup technique that divides LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories; threshold (T), water (•), cloud shadow (Z), low reflecting soil (-), medium reflecting soil (/), high reflecting soil (+), low cover vegetation (L), medium cover vegetation (M), and high cover vegetation (H). This gray map corresponding to an April 2, 1975, LANDSAT overpass delineates immature sugarcane with bare soil and low vegetation cover symbols. An established citrus orchard is delineated with low and medium vegetation cover symbols.

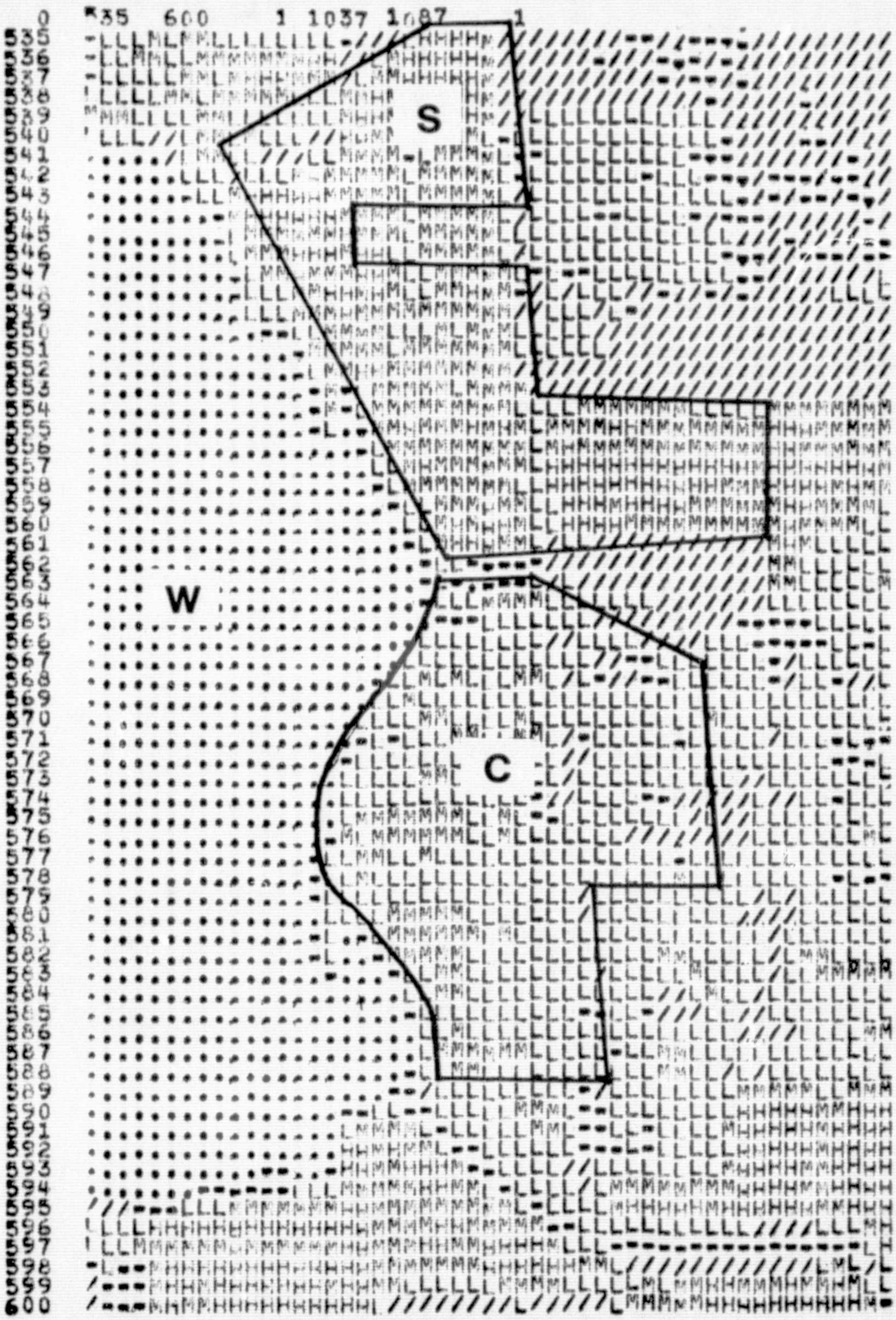


Figure 8. The same symbology as for Figure 7, for a July 10, 1975, LANDSAT overpass. The rapidly growing sugarcane is delineated with low to high cover vegetation symbols, and the established citrus orchard is delineated with low to medium cover vegetation symbols.

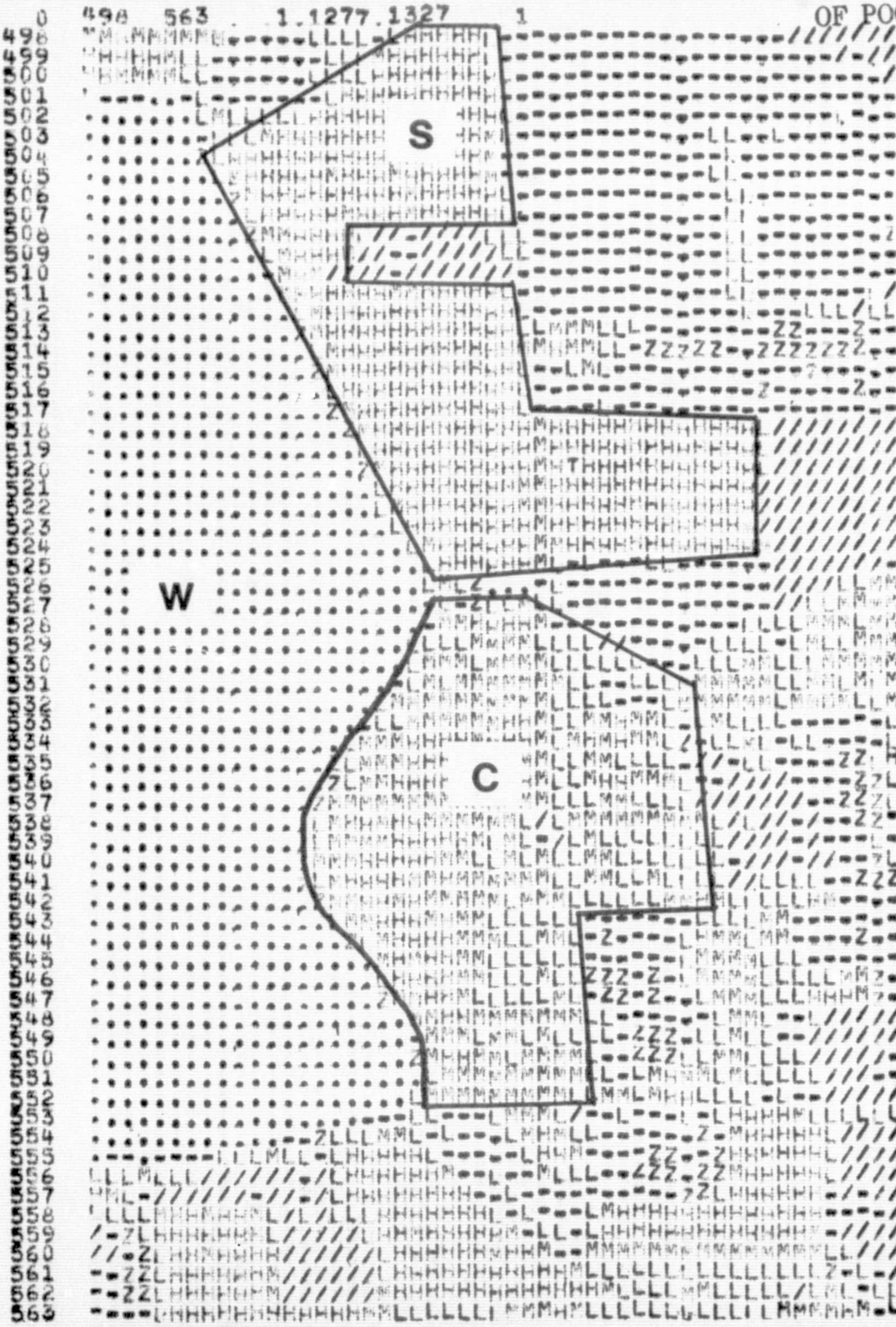
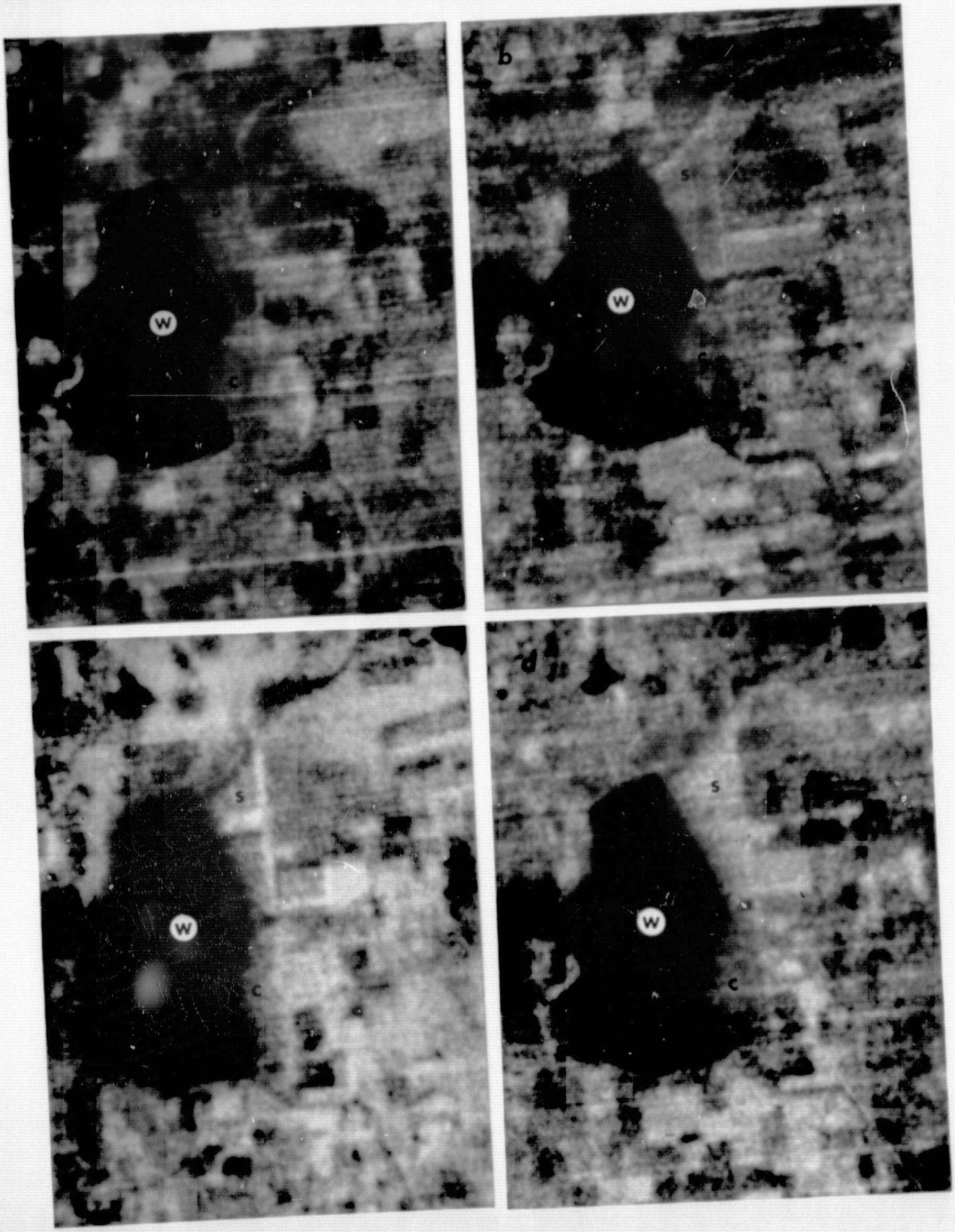


Figure 9. The same symbology as for Figure 7, for an October 17, 1975, LANDSAT overpass. Mature sugarcane is delineated with high cover vegetation symbols while the established citrus orchard continues to be delineated with low to high cover vegetation symbols.



Enlarged LANDSAT color positive print (bands 4, 5, and 7; scale 1:24,000) of a water body (W), a sugarcane field (S), and a citrus orchard (C), in Hidalgo County, Texas. April 2 (a), July 10 (b), October 17 (c), and December 10 (d), 1975, are the overpass dates depicted. Scene ID's are 2070-16203, 5082-16083, 2268-16190, and 2322-16183, respectively.