Reprinted from

# Symposium on Machine Processing of Remotely Sensed Data

**June 21 - 23, 1977**

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
77CH1218-7 MPRSD

# A TABLE LOOK-UP PROCEDURE FOR RAPIDLY MAPPING VEGETATION COVER AND CROP DEVELOPMENT

ARTHUR J. RICHARDSON
U. S. Department of Agriculture, Weslaco, Texas

C. L. WIEGAND
ARS-USDA, Weslaco, Texas

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 ($r^2 = 0.974$). Increasing vegetation development, documented by leaf area index measurements, for 1973 grain sorghum fields, was associated with displacement of sorghum MSS digital counts away from the soil background line. 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 threshold region into which no LANDSAT data are expected to fall. We demonstrated that, using a table look-up procedure, based on these 10 decision regions, LANDSAT scenes could be classified into meaningful vegetation density levels, soil brightness levels, and water from the raw satellite data without prior knowledge of local crop and soil conditions. These procedures used deviate from current pattern recognition and remote sensing practice but should lead to faster and more automated machine processing of satellite MSS data for monitoring crop development, and for associating vegetation vigor and yield in large area crop yield prediction efforts. For these purposes, the procedures can be used with ancillary meteorological and crop calendar information as part of a decision tree analysis for rapid classification of vegetation, soil, or water conditions.

## I. INTRODUCTION

Recently, interest has increased for the application of multispectral remote sensing technology to world-wide inventorying of agricultural crops[8]. However, 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 determined that the data space distribution of soil reflectance variation in LANDSAT data is confined to a plane[6]. Our objective was to develop a rapid classification process to improve the operational use of LANDSAT data for monitoring the productivity of range, forest, and crop lands.

## II. EXPERIMENTAL PROCEDURES

In this study, we used the LANDSAT data space as recorded on the computer compatible tapes (CCT) received from the Earth Resource Observation Satellite (EROS) data center at Sioux Falls, South Dakota, to determine Kauth's[6] 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 the overpass dates 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 ancillary LANDSAT data to correct digital data for sun angle effect. A linear correlation analysis between MSS5 and MSS7 was used to define Kauth's plane of soils for our data.

A second data set comprised of sorghum LANDSAT-1 digital data, collected May 27, 1973, and corresponding leaf area index (LAI) measurements, previously reported[11], were compared with results for 1975 to document sorghum development.

A third data set was comprised of the digital data from Hidalgo County, Texas, for LANDSAT overpass dates on April 2, July 10, October 17, and December 10, 1975 (scene I.D.'s given above). These data were classified using the table look-up procedure described in this paper. The acreage of soil, water, plants, cloud, and cloud shadow within the county was determined for each overpass date.

Climatological data for 1975, consisting of mean daily temperature and precipitation, as reported from 12 Lower Rio Grande Valley stations through the National Oceanic and Atmospheric Administration[10], were used to discuss the LANDSAT MSS digital classification tables and maps versus 1975 crop growth conditions.

## III. EXPERIMENTAL RESULTS

### A. KAUTH'S PLANE OF SOIL

We found that LANDSAT MSS digital data from bands 5 and 7 (data set one) followed a highly predictable linear relationship (Figure 1a) for bare soils, clouds, and cloud shadows. This linear relation, which we refer to as the soil background line or Kauth's line of soils, is defined by MSS5 = -0.01 + 2.4 MSS7 and characterized by $r^2$ = 0.974 and Sy•x = ±6 digital counts. The soil background line is a family of overlapping soil brightness levels to which cloud and cloud shadows form the upper and lower extensions, respectively. Thus, we discovered that Kauth's line of soils can be extended to include clouds and cloud shadows. Since the soil background line is based on 6 LANDSAT-1 and -2 overpasses distributed over an eight month period and variable soil types, it is considered generally representative of the line of soils in LANDSAT MSS 5 and 7 data.

Increasing crop development or vigor is manifested by a migration of vegetation points perpendicularly away from the soil background line, as demonstrated in Figure 1b. This figure shows that 10 sorghum fields (data set two), identified by increasing LAI values rounded to 1 digit, deviated to the right of the bare soil background line. Sorghum fields with largest LAI values were displaced farthest from the line. Water, designated by the symbol W, deviated to the left of the soil background line, so it was not confused with either vegetation or soil.

### B. TABLE LOOK-UP PROCEDURE

The LANDSAT data space, determined by bands 5 and 7, has been divided into decision regions corresponding to 10 general categories as shown in Figure 2a. Kauth's line of soil is shown to be an inverted cone with apex at the origin that can be thought of as 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, soil reflectance decreases and the data are compressed toward the apex of the cone at the origin. Similarly, the variations in 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 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 decision boundaries among water, bare soil, and vegetation are referenced to Kauth's plane of soil. 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. For example, the vegetation categories that are meaningful for wheat would not necessarily be those that would be meaningful for corn or sorghum.

These decision boundaries were implemented as a table look-up process where the signature categories of Figure 2a were defined as a table with numbers ranging from 0 to 9, as indicated in Figure 2b. The candidate MSS5 and MSS7 signature pair is used as an address for the table in Figure 2b. The number at that specific address defines the signature category of the candidate signature pair. The process is repeated for each signature pair.

As shown in Figure 2a and 2b, the table look-up automatically takes sun angle effects or degrees of vegetation density into effect through the conical shape of each vegetation density decision region. However, degrees of soil brightness will be affected by sun angle variations along the bare soil line; for example, at low sun elevations, such as for December 10, 1975, (sun elevation above horizon equal 33°) low reflecting soil will be misclassified as shadow unless sun angle corrections are made. Thus, a cosine correction is applied to the digital data before using the table look-up process[3,9].

Since the signatures of water and vegetation are well documented, and the soil plane in LANDSAT MSS data space appears general, it becomes possible to rapidly classify vegetation, soil, water, and cloud conditions for any overpass date and study locations--without any ground truth. Ancillary data about rainfall, evapotranspiration, temperature, and local crop phenology can be incorporated with the described procedure to more precisely describe specific local crop and soil conditions as related to crop yield prospects.

### C. MONITORING VEGETATION, SOIL, AND WATER CONDITIONS

The acreage estimation results of classifying Hidalgo County, Texas (400,000 ha), according to these 10 water, bare soil, and vegetation conditions for four LANDSAT overpass dates (April 2, July 10, October 17, and December 10, 1975) are shown in Table 1 (data set three). Digital count data for July, October, and December were corrected for sun elevation using a cosine correction factor[3,9] that corresponded with the April sun elevation so that all classification results could be compared directly.

Rainfall (Figure 3) between January 1 and July 13, 1975, was below normal, based on 1941 to 1970 climatological data[10], while temperatures were above normal according to readings averaged over 12 Rio Grande Valley reporting stations. Thus, the April and July overpasses represent drought conditions in Hidalgo County. The October and December overpasses represent wet conditions as indicated by high rainfall and slightly lower than normal temperatures after July 13.

The very low hectarage for threshold, which rounds to 0% on each date, shows that virtually all the pixels were classified into one of the other physically meaningful categories (Table 1). For the cloudless July, October, and December scenes, very few pixels (0% when rounded) were classified as clouds, indicating that the decision boundary between highly reflective soil and clouds were correctly placed. For the July, October, and December dates, low reflecting soil was slightly confused with cloud shadow since 1000 to 2000 ha of the county area was classified as cloud shadow on each date, even though they were cloudless scenes. The scene area categorized as water was at a minimum in July just before the drought was broken, in agreement with expected smaller surface area of ponds and lakes during the drought than after the drought (October and December).

The boundaries among spectral categories were identical in the table look-up procedure for all four scene dates. Thus, one can compare the fallow (oı bare) soil and vegetation category classifications for seasonal and rainfall influences (Table 1). The percentage of the pixels for the county that were classified as bare soil and vegetation were in the ratios 38:60, 41:59, 36:63, and 40:59 for the April, July, October, and December scenes, respectively.

Table 2 is essentially a crop calendar indicating the seasonal acreage flucuations for six major crop categories in Hidalgo County: vegetables, cotton, sorghum, corn, sugarcane, and citrus. These data were obtained from Texas Crop and Livestock Reporting Service (TCLRS) publications[12,13,14,15]. This table presents an estimate, based on ground enumerations, of the percent of Hidalgo County devoted to each of these major categories for each month of the year. The estimated rangeland hectarage was reported by Everitt[5]. From this table, the percent of the county covered by bare soil and vegetation were determined in the ratios of 43:57, 29:71, 44:56, and 43:57 for April, July, October, and December LANDSAT overpass dates, respectively.

The computer (Table 1) and ground (Table 2) estimated bare to vegetated ratios for April compared best, 38:60 and 43:57, respectively. The July ground estimated ratio (29:71) favored vegetation more than did the computer ratio (41:59). Early season drought conditions forced an early harvest of dryland sorghum, with reduced yields, but the harvest date of irrigated sorghum should have been advanced only by higher than normal temperatures. In more normal rainfall years, the ground estimated ratio would probably agree better with the computer estimates. The October and December ground estimated ratios (44:56 and 43:57, respectively) favored bare soil more than did the computer estimated ratios (36:63 and 40:59, respectively), probably because the late summer and fall wet conditions resulted in a flush of growth on the rangelands, and regrowth of cotton and sorghum (as well as weeds) that were present on some cropped fields that were too wet to till.

Although there was no valley-wide freeze during the fall of 1975, reported minimum temperatures[10] on November 23, 1975, ranged from -0.6 to 4.5°C. Thereafter, temperatures were too cool for plant development until spring. Thus, by December 10, 1975, the computer estimated more bare soil (40%) than on October 17, 1975 (36%) for Hidalgo County.

D. PLANT, SOIL, AND WATER CLASSIFICATION MAPS

Figures 4 through 7 are line printer classification maps, showing vegetation, soil, and water conditions in Hidalgo County, using the table look-up process previously described. For all four LANDSAT overpass dates the classification map symbols are: shadow (S); water (.); low (-), medium (/), and high (+) reflecting soil; clouds (C); low (space), medium (=), and high (M overprinted W) density vegetation; and threshold (T). These classification maps of the county were 25 X 1 (5X in photographic sense) reductions of the original LANDSAT data. Thus, they have a resolution of 11.7 ha/line printer character.

Low density vegetation is the single largest area on each classification map (blank areas). These areas roughly correspond to where rangeland and citrus are grown in the county; combined percent coverage is 52% according to ground estimates in Table 2. Spectrally, the computer estimates for low density vegetation in April (51%) compares closest with the ground estimate. By July, grain sorghum, a major crop, had reached maturity and was being harvested. Cotton is typically defoliated at the end of July or in August in preparation for harvest.

The high density vegetation, mapped on the October and December classification maps, appeared to be closely associated with areas where sugarcane and vegetables for the fall and winter markets are known to be grown (darkest areas). The combined ground estimates (Table 2) for vegetables and sugarcane for October and December are 4 and 5%, respectively. These figures compare closely with the computer estimates for high density vegetation for October and December of 5 and 4%, respectively. In April, sugarcane regrowth following harvest in winter is sparce so that it is spectrally similar to bare soil. By October when harvest starts, it has developed a dense canopy. Vegetables, like carrots, cabbage, and broccoli planted for winter markets, have developed dense canopies by December and earliest fields are being harvested.

The high percentage of the county area that was in a low vegetative cover class is due to the low vegetation density that the average annual rainfall of about 50 cm can support each year under subtropical temperatures; to rainfall associated with the particular year chosen; to distribution of county land uses among ranching, dryland farming, and irrigated agriculture; and to the spectral criteria chosen to set the vegetation density category boundaries. The low hectarages in the moderate and high density vegetation categories on all dates agree with observation that row crop plants that develop a dense cover maintain it for only a short time before senescing or maturing. Citrus trees are spaced apart so that on the average as much soil background as foliage is sensed by LANDSAT. Nonetheless, we will continue to adjust the vegetation density categories and to study them for particular crops to develop meaningful vegetation density categories as a function of phenological stage.

### E. CROP PHENOLOGICAL CLASSIFICATION STRATEGIES

The table look-up process just described, that can delineate a LANDSAT scene into vegetation density stages, degrees of soil brightness, and water, could lead to completely automated, rather than computer-aided, crop and soil classification strategies as described by Lukes[7]. Lukes proposed a crop phenological classification strategy that involves characterizing agricultural growth cycles (crop calendars) with spectral film density measurements that is similar to the qualitative approach taken by photointerpreters. Photointerpreters classify crops by phenological criteria[2,4] that generally depend on visually matching crop growing patterns to variations in color and tones recorded on film.

Replacement of color and tones on photographs with a more quantitative measure of crop growing patterns would permit automation of phenological crop classification. Lukes used film optical densities rather than visual interpretation of color and tones. An even better approach may be to use LANDSAT spectral measures of vegetation density as provided by the table look-up process along with crop calendar information. In its final form, the look-up table shown in Figure 2a and b will be divided into vegetation density levels appropriate for the time within the growing season. It could also be divided into more vegetation density levels to better distinguish among specific crop and soil conditions, such as between rangeland and citrus and vegetables and sugarcane categories studied in this paper.

Application of these techniques would benefit from digital registration of ancillary data about crop development, rainfall, temperature, and evapotranspiration, with LANDSAT digital data for multidate analysis, using techniques similar to those described by Anuta[1] for digital registration of topographic and satellite digital data. The 4 bands of MSS digital data could be compressed to 1 channel of information about plant density levels, soil brightness levels, and water, using table look-up procedures, before it was registered to the ancillary data for each date. A sequential set of Boolean decision rules could then be formulated in a decision tree mode that could classify the data into specific crop and soil conditions and estimate probable yields based on both spectral and ancillary information. Once all spectral and ancillary data have been collected and stored, then classification, acreage estimations, and yield predictions can proceed, using more completely automated decision rules than is now possible using computer-aided logic processes.

## IV. SUMMARY AND CONCLUSIONS

LANDSAT data space surrounding Kauth's plane of soils for bands 5 and 7 was divided into 10 vegetation, soil, and water decision regions as a table look-up procedure to classify MSS digital data. Our results indicated that without prior information, the table look-up technique would allow any LANDSAT scene to be delineated into vegetative cover categories, degrees of soil brightness, and water. This technique could be used as the front end of a decision tree analysis in which data are directed to the appropriate flow network for further processing based on ancillary data about crop growing patterns, rainfall, temperatures, and evapotranspiration. In addition, the ability to classify clouds and cloud shadows permits ground areas behind clouds or in the shadow of clouds (in nonmountainous areas) to be edited out of data sets before classification procedures are implemented, so as to incorporate these training signatures into classification algorithms. None of the procedures demonstrated in this paper are beyond current remote sensing capabilities, but the overall process entails a significant departure from the mainstream of current pattern recognition and remote sensing practice. Thus, we believe the techniques described yield new capability for improved rapid machine processing of satellite MSS data for global agricultural inventories.

## V. REFERENCES


1. Anuta, P. E. 1976. Digital registration of topographic data and satellite MSS data for augmented spectral analysis. Proc. of the Amer. Soc. of Photogrammetry. 42nd Annual Meeting.

2. Caldwell, R. N. and J. D. Lent. 1969. The inventory of earth resources on enhanced multiband photography. Proc. 6th Intern. Symp. on Remote Sens. of Environ. October 13-16. I:133-143.

3. Deering, D. W., J. W. Rouse, R. H. Haas, and J. A. Schell. 1975. Measuring "forage production" of grazing units from LANDSAT MSS data. Proc. 10th Intl. Symp. on Remote Sens. of Environment, Willow Run Labs., Inst. of Sci. and Tech., The Univ. of Michigan, Ann Arbor, p. 1169-1178.

4. Draeger, W. C., L. R. Pettenger, and A. S. Benson. 1971. The use of small scale aerial photography in a regional agricultural survey. Proc. 7th Intern. Symp. on Remote Sens. of Environ. May 17-21. II:1205-1217.

5. Everitt, J. H., C. L. Wiegand, A. J. Richardson, and A. H. Gerbermann. 1975. Description and LANDSAT-1 remote sensing of the rangeland of Hidalgo County, Texas. J. Rio Grande Valley Hort. Soc. 29:115-125.

6. Kauth, R. J., and G. S. Thomas. 1976. The tasselled cap--A graphic description of the spectral-temporal development on agricultural crops as seen by LANDSAT. Proc. Symp. Machine Proc. of Remote Sens. Data, 6/29-7/2, LARS, Purdue, IEEE Cat. No. 76, Ch. 1103-1 MPRSD.

7. Lukes, G. E. 1975. Projective sampling of multiband/multidate aerial photography for crop classification. Fall Convention of the Amer. Soc. of Photogrammetry. Phoenix, AZ, October 26-31. 20 pp.

8. MacDonald, R. B., F. G. Hall, and R. B. Erb. 1975. The large area crop inventory experiment (LACIE): An assessment after one year of operation. Proc. 10th Intern. Symp. on Remote Sens. of Environ. October 6-10. I:17-37.

9. Potter, J. F., and M. A. Mendlowitz. 1975. On the determination of haze levels for LANDSAT data. Proc. of the 10th Intern. Symp. on Remote Sens. of Environ. II:695-703.

10. Potter, T. D. 1976. Climatological Data--Texas Annual Summary 1975. U.S. Department of Commerce, National Ocenaic and Atmospheric Administration, Environmental Data Service, Vol. 80, No. 13. 31 pp.

11. Richardson, A. J., C. L. Wiegand, H. W. Gausman, J. A. Cuellar, A. H. Gerbermann. 1975. Plant, soil and shadow components of row crops. Photogram. Engin. and Remote Sens. November, 41(11):1401-1407.

12. Walther, W. H., P. M. Williamson, and M. D. Humphrey, Jr. 1975. 1975 Texas Cotton Statistics. Compiled by the Texas Crop and Livestock Reporting Service, Austin, Texas. 21 pp.

13. Walther, W. H., P. M. Williamson, and M. D. Humphrey, Jr. 1975. 1975 Texas Field Crop Statistics. Compiled by the Texas Crop and Livestock Reporting Service, Austin, Texas. 77 pp.

14. Walther, W. H., P. M. Williamson, and M. D. Humphrey, Jr. 1975. 1975 Texas Vegetable Statistics. Compiled by the Texas Crop and Livestock Reporting Service, Austin, Texas. 44 pp.

15. Walther, W. H., P. M. Williamson, and M. D. Humphrey, Jr. 1975. 1975 Texas Fruit and Pecan Statistics. Compiled by the Texas Crop and Livestock Reporting Service, Austin, Texas. 37 pp.

Table 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 | 3 | 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 |

Table 2. The monthly ground area percentages of nine major vegetation and soil conditions in Hidalgo County, Texas obtained from the Texas Crop and Livestock Reporting Service publications. (12, 13, 14, 15).

| Crop and soil categories | Months of year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JAN | FEB | MAR | APR | MAY | JUN | JULY | AUG | SEPT | OCT | NOV | DEC |
| Vegetables | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 |
| Cotton | | | a | a | 2 | 2 | 2 | | | | | |
| Sorghum (wet) | | | a | a | 15 | 15 | 15 | | | | | |
| Sorghum (dry) | | | a | a | 19 | 19 | | | | | | |
| Corn | | a | a | 2 | 2 | 2 | | | | | | |
| Sugarcane | 2 | 2 | 2 | b | b | b | b | 2 | 2 | 2 | 2 | 2 |
| Citrus | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Rangeland | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 |
| Total Vegetation | 56 | 56 | 57 | 57 | 93 | 92 | 71 | 56 | 56 | 56 | 57 | 57 |
| Idle cropland | 44 | 44 | 43 | 43 | 7 | 8 | 29 | 44 | 44 | 44 | 43 | 43 |
| Total County | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

a Crops have been planted but are too immature to distinguish from idle cropland.
b Sugarcane has been cut and regrowth cannot be distinguished from idle cropland.

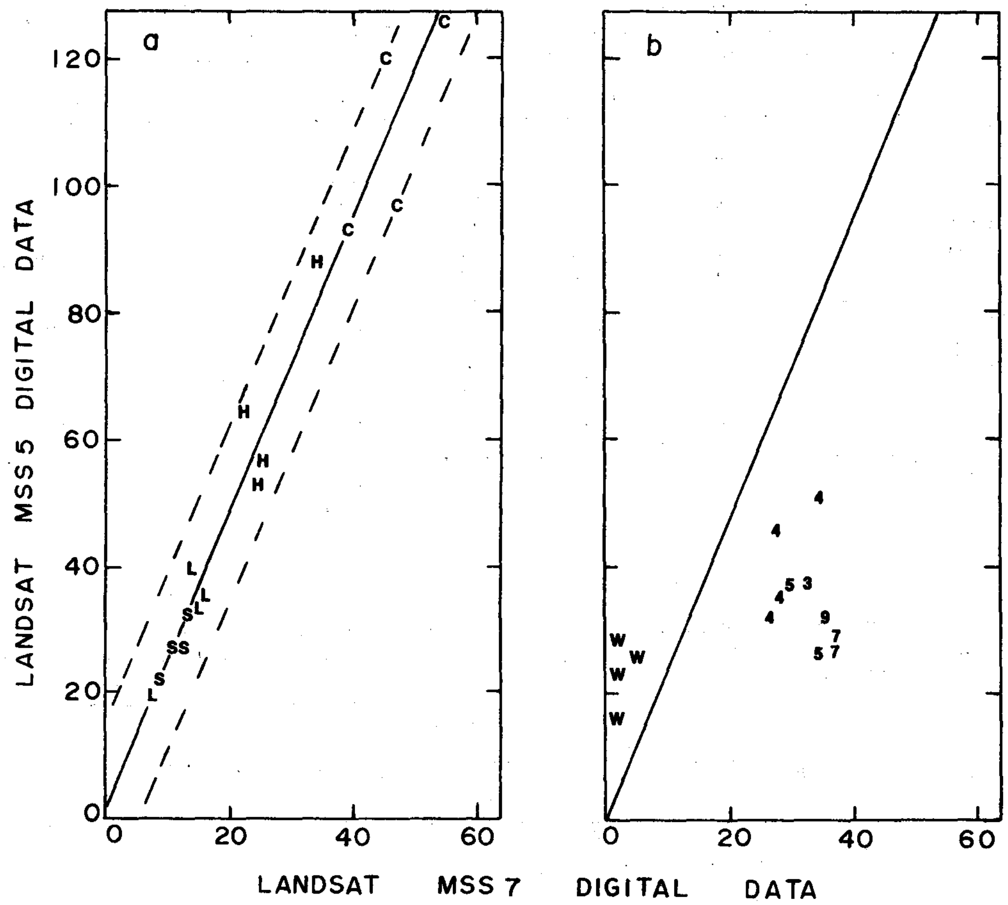


Figure 1. Scatter diagram (a) of digital data from bands 5 and 7 for cloud tops (C), cloud shadows (S), high reflecting soil (H), and low reflecting soil (L). Sun elevation for each category was as follows: April 2 (51°), May 17 (57°), June 4 (58°), July 10 (56°), October 17 (44°), and December 10 (32°), 1975. The regression line (MSS5 - 0.01 + 2.4MSS7) and standard error of estimate ($Sx_1.x_2 = \pm 6$) are plotted as soild and dashed lines, respectively. The coefficient of determination was $r^2 = 0.974$*. Scatter diagram (b) is for digital data from bands 5 and 7 for 10 sorghum fields collected on May 27, 1973. Sorghum fields are defined by their LAI value rounded to one 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 previously.

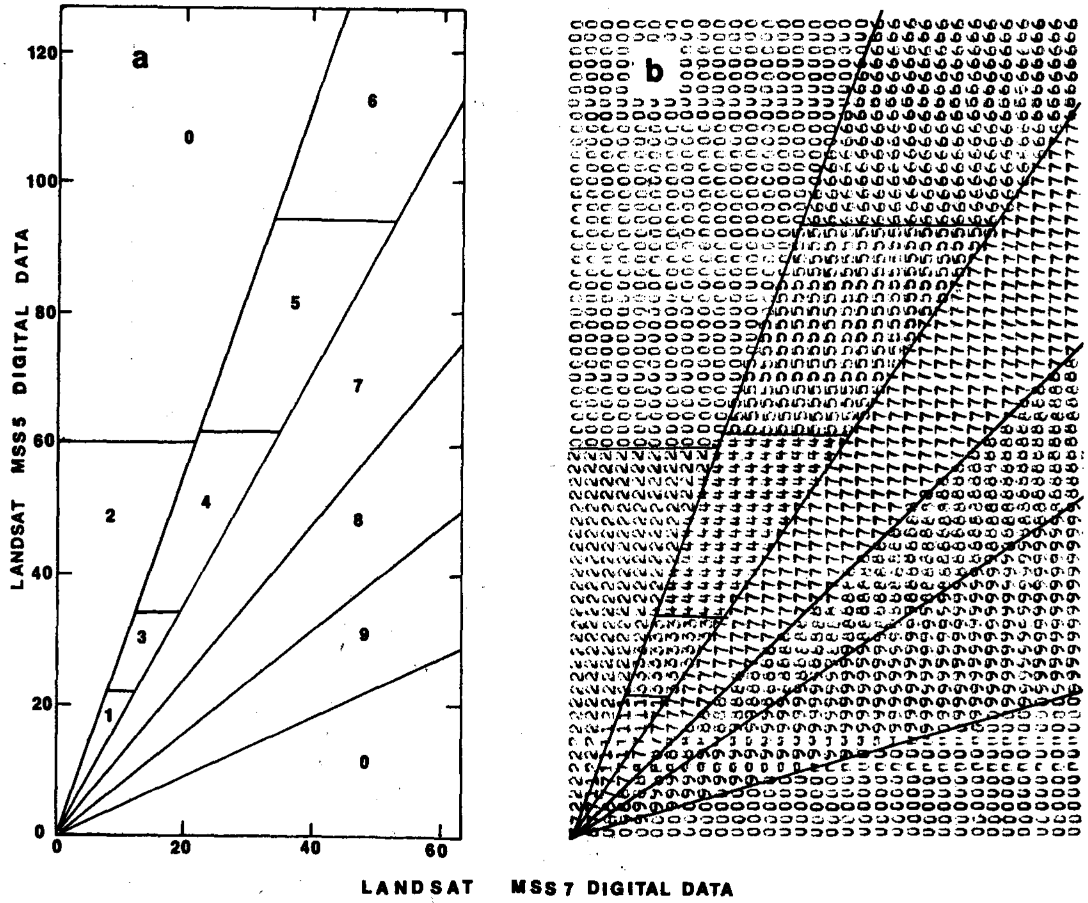


Figure 2. Diagram (a) showing division of LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories as follows: Threshold (0), cloud shadow (1), water (2), low reflecting soil (3), medium reflecting soil (4), high reflecting soil (5), clouds (6), low cover vegetation (7),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

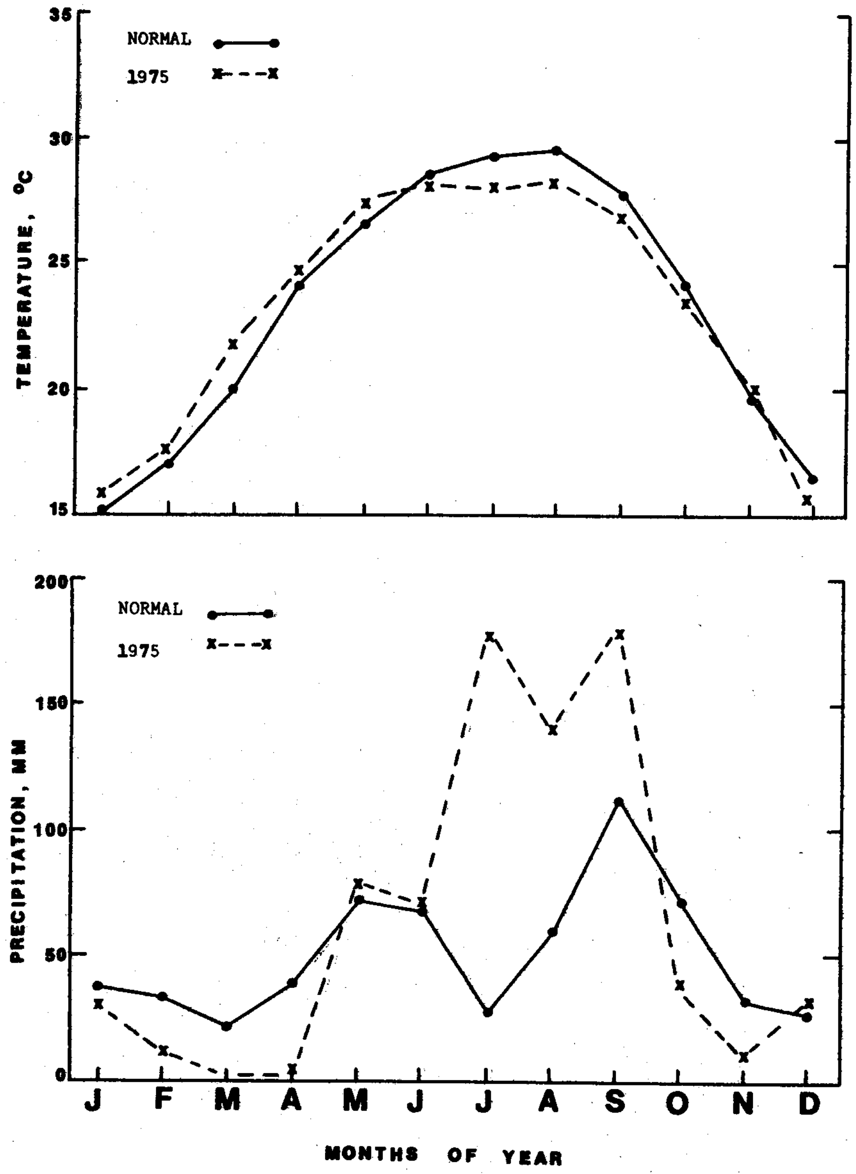


Figure 3. Average temperature (a) and precipitation (b) data reported by 12 Lower Rio Grande Valley stations and recorded by the National Oceanic and Atmospheric Administration. The solid and dashed lines are for normal (average over the 1941 to 1970 period) and 1975 climatic conditions, respectively. Drought conditions existed from 1-1-75 to 7-13-75 with wet conditions prevailing until 12-31-75.

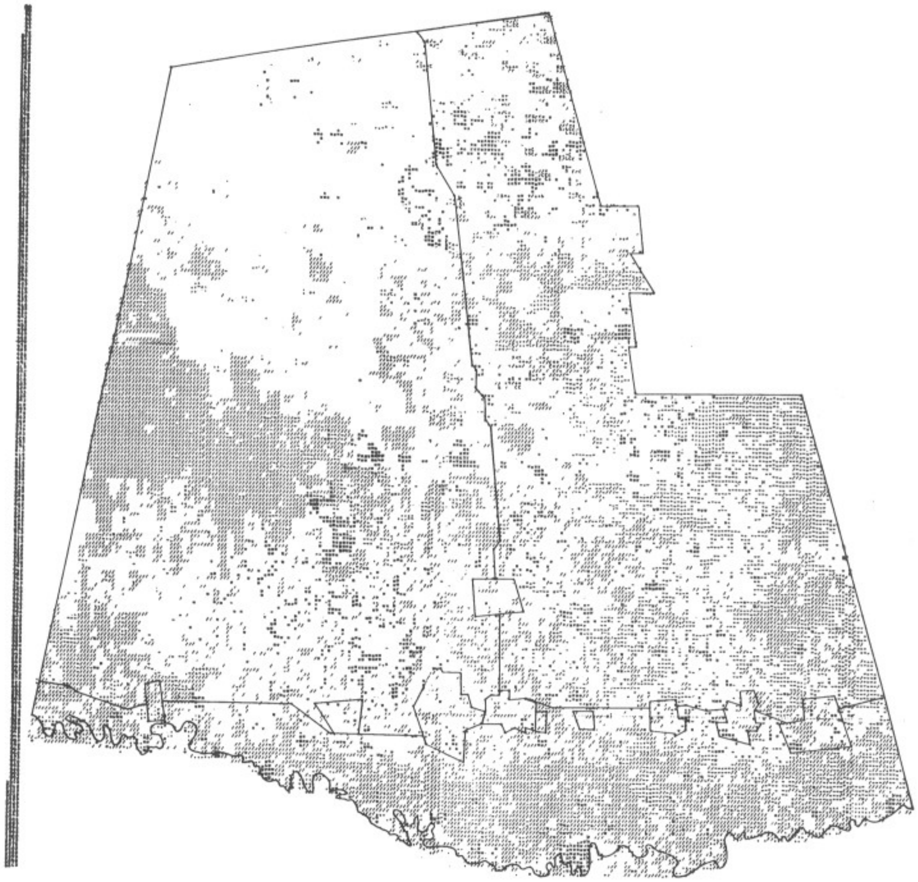

Figure 4. Classification map of Hidalgo County for an April 2, 1975, LANDSAT overpass. The classification map was generated using a table look-up technique that divided LANDSAT data space, defined by bands 5 and 7, into 10 general crop and soil categories: threshold (T); water (.); cloud shadow (S); low (-), medium (/), and high (+) reflecting soil; low (Space), medium (=), and high (M overprinted W) cover vegetation; and cloud (C).

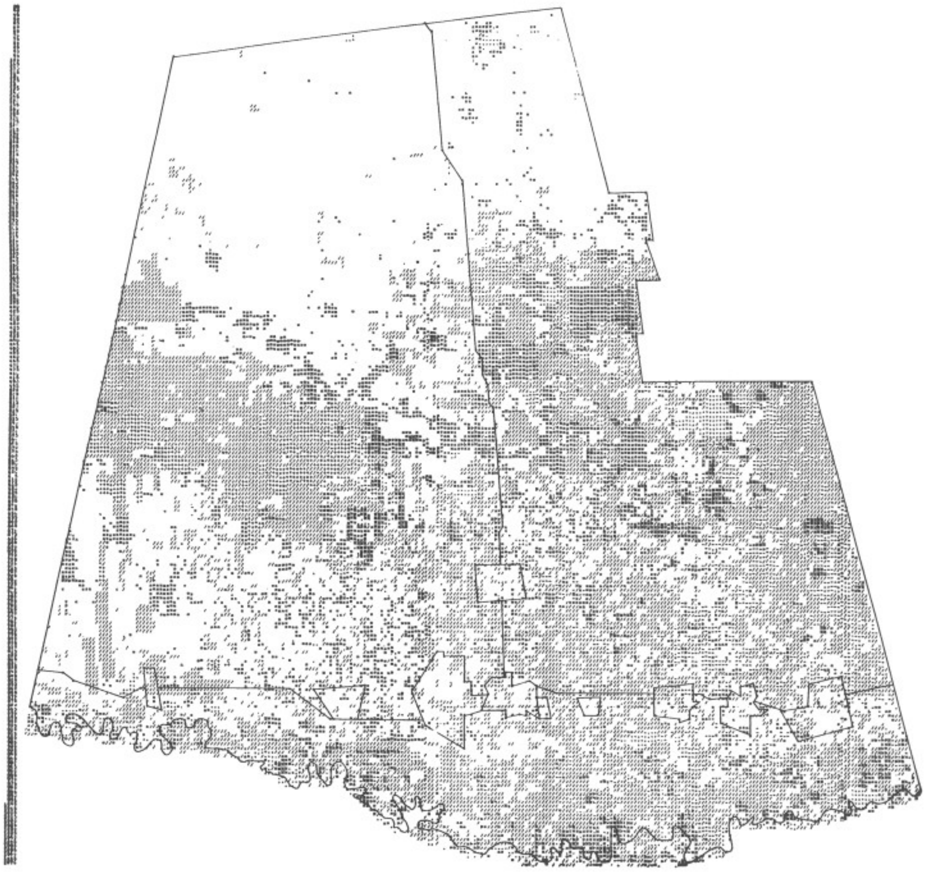

Figure 5. The same symbolism as for Figure 4, but the scene is for a July 10, 1975, LANDSAT overpass.

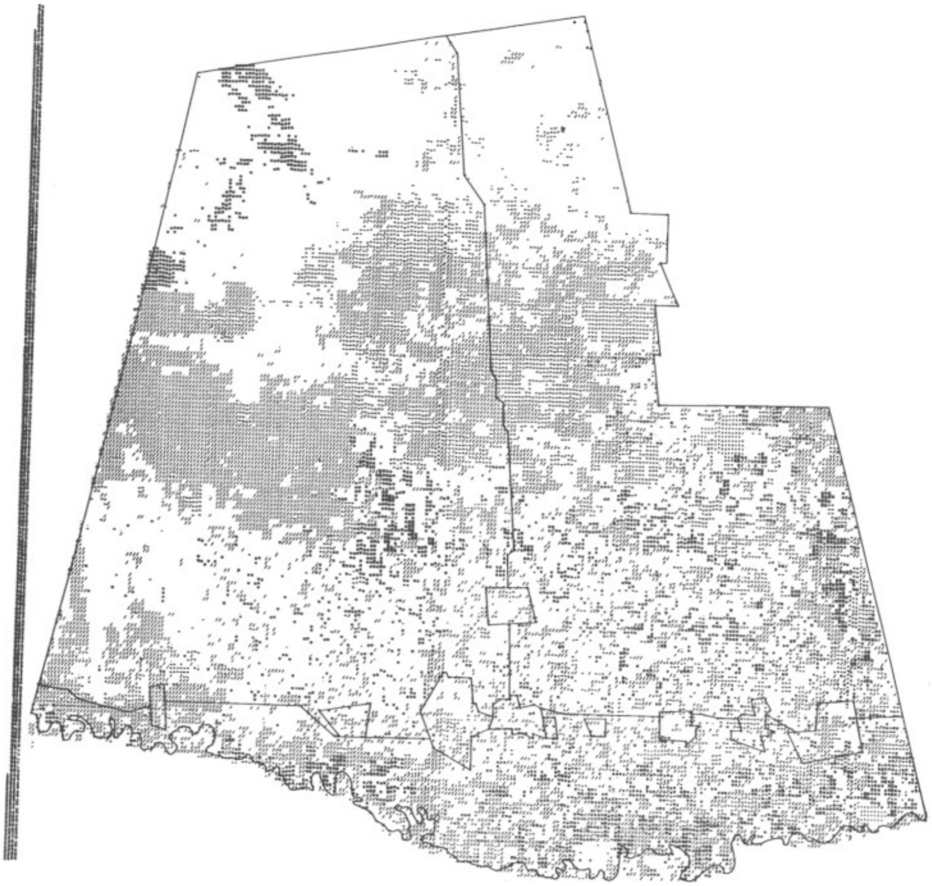

Figure 6. The same symbolism as for Figure 4, but the scene is for an October 17, 1975, LANDSAT overpass.

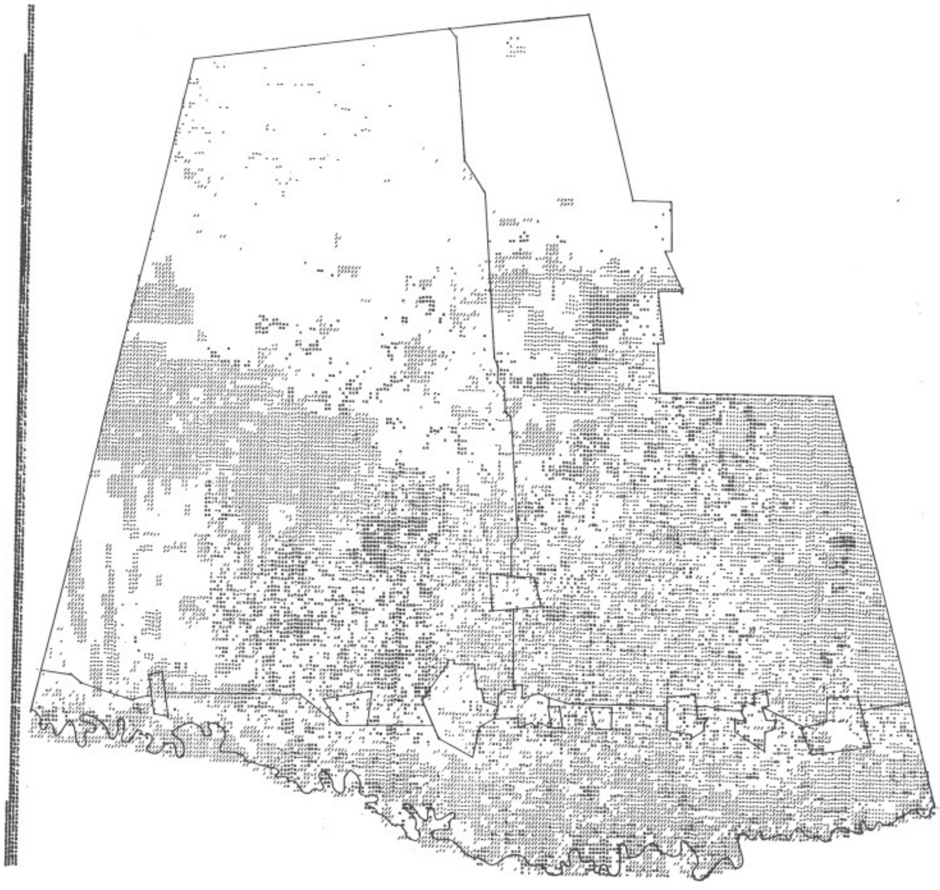

Figure 7. The same symbolism as for Figure 4, but the scene is for a December 10, 1975, LANDSAT overpass.

Arthur J. Richardson is a Research Physicist at the U. S. Department of Agriculture's Soil and Water Conservation Research facilities located in Weslaco, Texas. He has been performing research in agricultural remote sensing for 10 years (1967-1977) at this location. He received his B.S. in secondary education (teaching fields mathematics and physics) from Texas A&I University, Kingsville, Texas, in 1965. He is a member of the American Society of Photogrammetry. He has tested agricultural applications of LANDSAT-1, SKYLAB, and LANDSAT-2 data under NASA contracts.

Dr. Wiegand is Research Leader for Soil & Water Conservation Research, Agricultural Research Service, USDA, Weslaco, Texas and Technical Advisor for remote sensing in ARS. He has been Principal Investigator on LANDSAT-1, EREP, and LANDSAT follow-on investigations. He holds an MS in Agronomy from Texas A&M University and a PhD in Soil Physics from Utah State University.