LANDSAT MONITORING OF IRRIGATED FARMLAND ACREAGE IN CURRY COUNTY, NEW MEXICO

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Abstract

Groundwater depletion is an increasing problem in the High Plains and poses economic difficulties in eastern New Mexico. Farming practices must change to adjust to the supply of irrigation water. A method to improve on the time and labor currently required to measure irrigated acreages would help to better predict the future supply of groundwater. Curry County, New Mexico, was selected as the study area to test the applicability of Landsat satellite digital data in making accurate acreage measurements of irrigated cropland. Due to its digital format, large image area, and repeating coverage, Landsat data have been found to be excellent for large area resource inventories. Three Landsat digital images of the 1981 growing season were classified for Curry County to determine (1) how well Landsat classified irrigated lands in the area, (2) how accurate Landsat acreage measurements could be, and (3) how many Landsat overpass dates would be required to accurately measure irrigated acreage. Results showed that three time periods of Landsat data produced an acreage count which was 94.4% of the official published figure. This report describes the methodology employed and makes recommendations for an operational yearly inventory of New Mexico cropland using satellite data.

Keywords: *acreage measurement, crop calendar, crop phenology, *groundwater depletion, *image processing, *irrigated land, *Landsat satellite, unsupervised classification.

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I. INTRODUCTION AND PROJECT JUSTIFICATION

In the years since the Dust Bowl, one of the most striking changes in the High Plains of the central United States has been the rapid expansion of irrigated cropland. Associated with this rapid growth has been the pattern of diminishing groundwater supplies. Curry County in eastern New Mexico has experienced a continued decline of its groundwater supply. Farms in northern Curry County have recently had to convert to dry farming practices due to the increasing depth to the groundwater supply making irrigated farming uneconomical. The economic importance of irrigated farming to the region and the state demands the best understanding of the hydrologic condition.

Scientific research in recent years has strived to develop hydrologic models which could be used to better understand the current trends of groundwater use and to help predict future groundwater availability. An efficient hydrologic model would have far

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reaching impacts on the future planning of groundwater use in many areas now experiencing, or soon to experience, groundwater shortages.

In a general sense these models contain three variables: (1) water contained in the aquifer at any given time; (2) the amount of water added as recharge; and (3) the amount of water withdrawn during the same time period. Data on the first two variables are generally available through the established analysis of weather and well level measurements. Information on groundwater withdrawal is not always available or as accurate and timely as it could be.

Since the primary use of groundwater in Curry County is for irrigation, an estimation of irrigated cropland acreage could be useful in estimating the volume of groundwater use, and production of a cropland map could indicate areas of concentrated use. Landsat satellite data are particularly useful for an inventory of this type because of the large area contained on one satellite scene and the repeatability of coverage.

Landsat satellite data offer an opportunity to rapidly and accurately measure and map the surface area of irrigated lands for large areas at a low cost per unit area. The original data and resulting classifications are in digital form and geometrically correctable for map generation or integrating with other map data. These data can also be used in hydrologic models. Although Landsat data have been studied in other agricultural environments, it was necessary to adapt a methodology for eastern New Mexico. It was necessary also to determine how accurately the satellite data could be applied to the identification of irrigated lands and which season or seasons would be most effective in the classification. The methodology applied within this study can be applied as a point of reference to future multispectral systems as well as a determination as to the effectiveness of the presently available data resource.

The proposal for this study planned on a real time examination of the data during the 1981 growing season. Due to delays in the contract starting date, the project developed late in the 1982 growing season which eliminated any possibility of real time field verification of results. For all data classified, field verification was performed through records of the 1981 growing season and personal contacts with growers.

Curry County was chosen as the study area for its location within the High Plains, (see Figure 1) and because most of the county can be covered in one satellite image. Many counties in the High Plains require more than one satellite scene for complete coverage. The choice of Curry County required fewer total scenes to purchase and less computing time, reducing the cost of the study. It is an excellent study area moreover because of its range of land uses which include irrigated agriculture, dry farm agriculture, and grazing.

The application of Landsat satellite data to the inventory of irrigated lands proved to be most effective. The amount of irrigated lands determined by the computer classified satellite data was 94.4% of that determined by the normal ground-based field reporting method.

II. LANDSAT SYSTEM

A. Orbital Parameters

The concept behind the design of the Landsat satellites is to provide multispectral data of the earth's surface on a global scale and at regular intervals. Four Landsat satellites have been launched

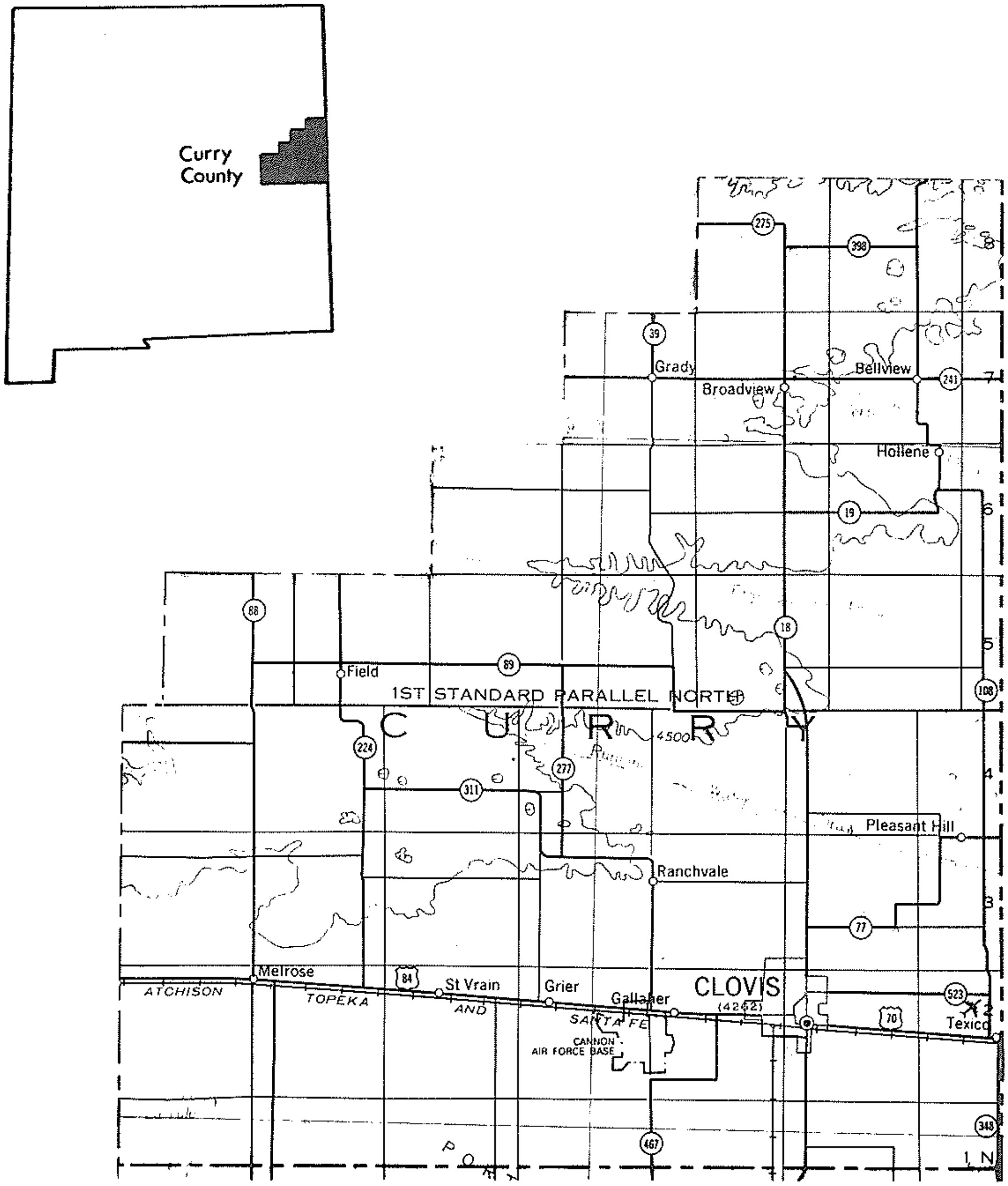


Figure 1. Map of Curry County, New Mexico, 1:500,000

since 1972, with only Landsats 2 and 4 providing resource imagery at the time of this report. The special nature of Landsat 4 and its sensors will be discussed in a later section.

Landsats 1, 2, and 3 circled the earth in polar orbits every 103 minutes at an altitude of 920 kilometers (570 miles). Each made 14 orbits per day and passed over the entire earth's surface every 18 days. The orbit was oriented so that each day's orbital swath fell adjacent to and west of the previous day's image (Figure 2).

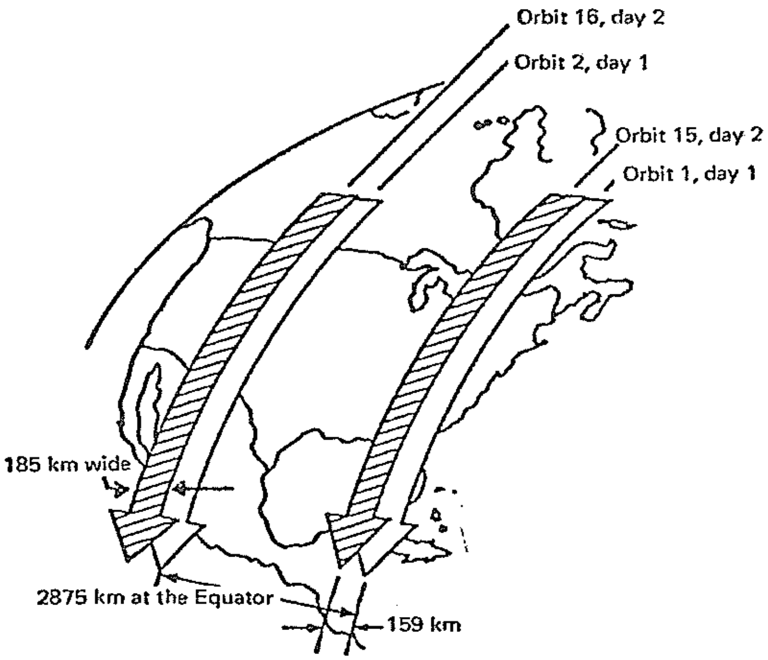


Figure 2. Landsat Orbital Coverage

The orbits of Landsat 1 and 2 were timed so that Landsat 2 repeated the orbital track of Landsat 1 with a delay of nine days. Together, the two satellites provided complete ground coverage every nine days. When Landsat 1 ceased to function, Landsat 3 was placed in a similar orbital path, thus preserving the nine day coverage pattern with Landsat 2. The orbits were configured so that each satellite crossed the equator at the same local time every orbit, approximately 9:30 a.m.

B. Multispectral Scanner

A schematic drawing of the MSS is shown in Figure 3. The MSS has an oscillating mirror that scans the earth's surface from west to east. Radiation coming from the surface of the Earth and its atmosphere is reflected by the mirror into telescope optics, and focused on fiber optic bundles located in the focal plane of the telescope. Radiation is conducted by the fiber-optic light pipes to filters that permit only certain wavelengths of radiation to strike detectors. The voltage produced by each detector is related to the amount of radiation that reaches the detector. The voltage produced by the detectors is an analog signal which is converted to spectral values (from 0 - 63) by a multiplexer. The numbers represent brightness values related to the radiance of an area on the earth's surface in one wavelength band.

The MSS mirror scans the earth's surface from west to east in about 33 milliseconds. Six lines of data are scanned at one time (Figure 4), and each line is about 185 km long on the ground. Twenty-four detectors are used on the MSS to record the six lines of data in four wavelength bands.

During each scan, the voltage produced by each detector is sampled every 9.95 microseconds. For one detector, approximately

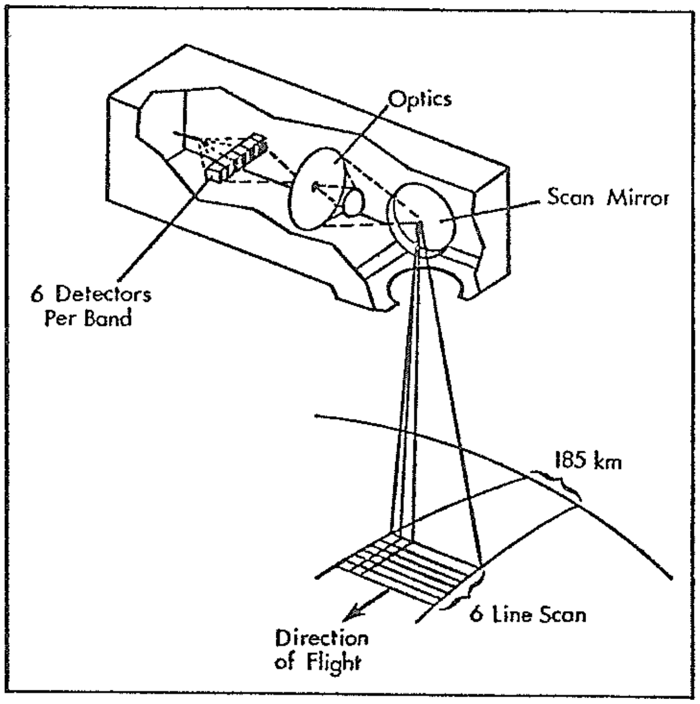


Figure 3. Schematic Drawing of the MSS

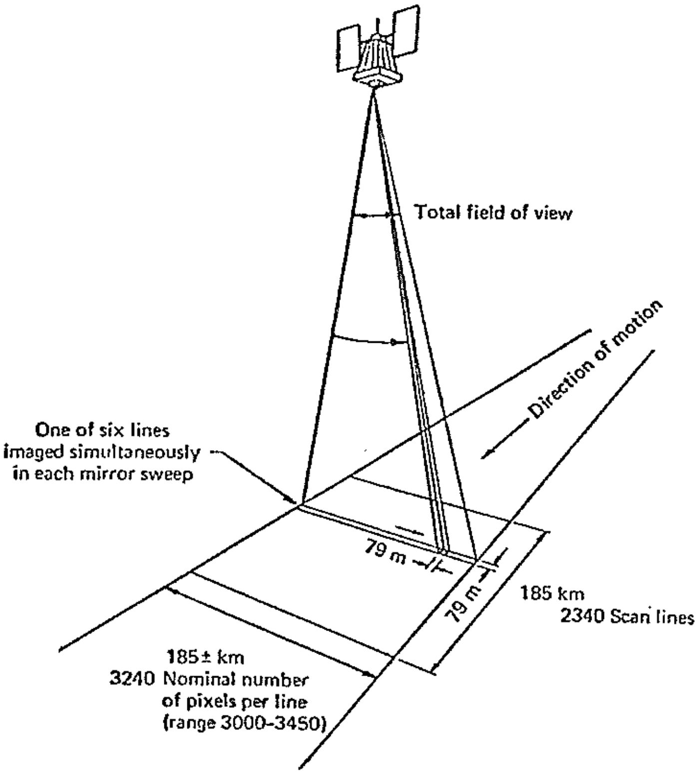


Figure 4. Landsat MSS Operating Configuration

3,300 samples are taken along a 185.2 km line. Thus, the instantaneous field of view (IFOV) of 79m by 79m moves about 56m on the ground between each sample (Figure 5). The individual radiation measurements must be arranged on an image in a manner that preserves spatial relationships. Thus, the measurements are assigned dimensions of 56m by 79m so that geometric distortions are not introduced. The 56m by 79m area is called a Landsat picture element or pixel. Although the measurement of landscape brightness is made from a 6,241 square meter area, the data are formatted as if the measurement were made from a 4,424 square meter area. Note the overlap of the areas from which brightness measurements were made for adjacent pixels (Figure 5). As multispectral data are collected by the MSS, they are either relayed

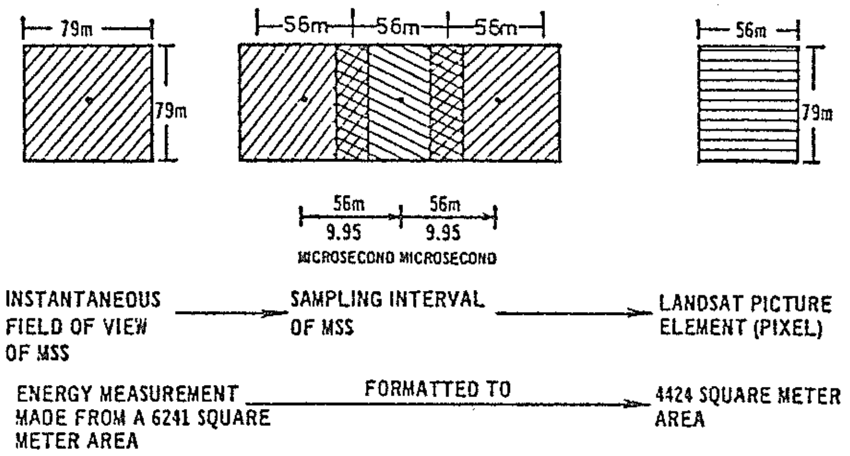


Figure 5. Formation of the MSS Picture Element

in real time to a ground station or are recorded for playback in the future. Landsat data recorded after February, 1979, are further reformatted into square pixels approximately 60m x 60m.

III. IMAGE PROCESSING SYSTEM

In 1979 TAC acquired a computer system for the analysis of digital remote sensing data. Called TDIPS (TAC Digital Image Processing System), the system possesses a wide range of capabilities designed to analyze digital data from aerial and satellite scanners and maps. The components of the system are:

PDP 11/34A Processor by Digital Equipment Company, 256K bytes memory

ELAS Image Processing Software

Two RL01 and two RL02 Disk Drives containing a total of 31.2 megabytes

TME11-EA Magnetic Tape Drive, 45 IPS and 800 BPI

Grinnell 256 x 512 3-color image display

Two VT100AA terminals

One ADM 3 terminal

Printronix Matrix Line Printer

36" X 48" digitizer tablet by Summagraphics

Anderson-Jacobsen Modem, 300/1200 Baud

The Earth Resources Laboratory Applications Software (ELAS) is a geobased information system designed for analyzing and processing digital image data. ELAS was developed mainly to process remotely sensed scanner data, especially the multispectral data acquired by the various NASA Landsat satellites. In addition to Landsat multispectral data, the ELAS system will support the processing of other data such as aircraft-acquired scanner data, digitized topographic data, and numerous other ancillary data, such as soil types and rainfall information, that can be stored in digitized form. As an integrated image processing and data base maintenance system, ELAS offers the user of remotely sensed data a wide range of easy-to-use capabilities in the area of land cover analysis.

IV. THE UNSUPERVISED CLASSIFIER

Using NASA's ELAS software, TAC's computer image processing system employs an unsupervised maximum likelihood classification algorithm to classify land cover types. Unsupervised classifications involve algorithms that examine a large number of unknown pixels and divide them into classes based on natural groupings present in the image values. The basic premise is that values within a single cover type should be close together in the measurement space, whereas data from different classes should be comparatively well separated.

The classes that result from unsupervised classification are spectral classes. Because they are based on natural groupings of the image values, the identity of the spectral classes will not be immediately known. The analyst must compare classified data to some form of reference data (such as air photos or maps) to determine the identity and informational value of the spectral classes.

The unsupervised method can be illustrated with a two channel data set. Natural groupings in the data can be visually identified by plotting a scatter diagram. For example, in Figure 6 pixel values acquired over an agricultural area have been plotted. Three groupings are apparent in the scatter diagram. After comparing the classified image data to ground reference data, we might find that one cluster corresponds to wheat, one to barley, and one to soybeans (indicated by W, B, and S in Figure 6.

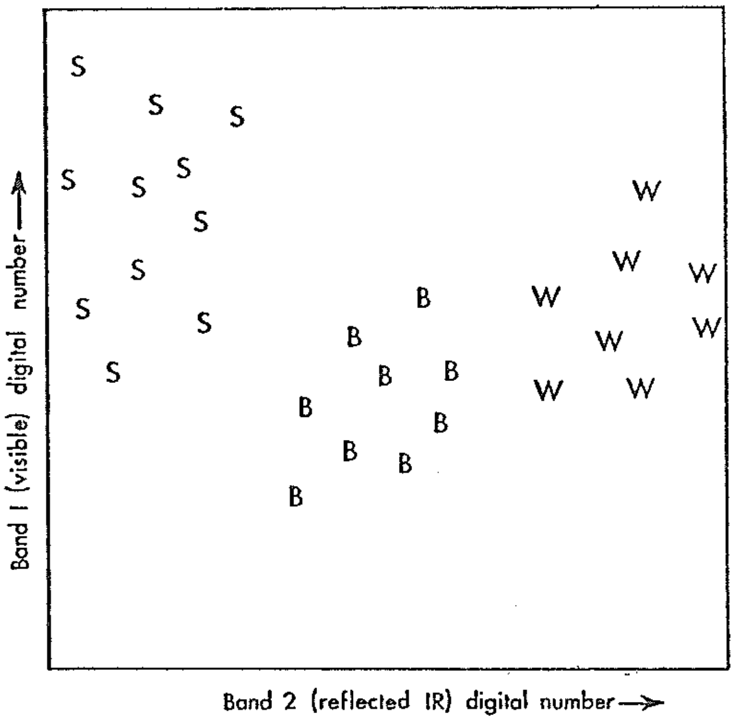


Figure 6. Example of a Two Channel Plot

For image data of more than two channels, it is difficult to plot image values to visually identify natural spectral groupings. Fortunately, statistical techniques are available that can be used to automatically group an n-dimensional set of observations into their natural spectral classes. Such a procedure is termed cluster analysis. The result of applying a cluster analysis is simply the identification of spectrally distinct classes in the image data. After the data are clustered, the analyst must use reference data, such as maps and images, to associate the spectral classes with the cover types of interest.

Table 1 illustrates several possible outcomes of associating spectral classes with information classes for data from a typical

Table 1. Possible Classification Results

Result #1

Spectral Class	Identity of Spectral Class	Desired Class Result
1	Water	Water
2	Agriculture	Agriculture
3	Timber	Timber
4	Urban	Urban

Result #2

Spectral Class	Identity of Spectral Class	Desired Class Result
1	Turbid Water	Water
2	Clear Water	
3	Wheat	Wheat
4	Barley	Barley
5	Spruce	Timber
6	Fir	
7	Urban	Urban

Result #3

Spectral Class	Identity of Spectral Class	Desired Class Result
1	Turbid Water	Water
2	Clear Water	
3	Wheat	
4	Barley	Agriculture
5	Range Grass	Range Grass
6	Urban	Urban

Landsat scene. The ideal outcome would be Result #1, in which each spectral class is found to be associated uniquely with a feature type of interest to the user. This outcome will occur only when the features in the scene have highly distinctive spectral characteristics.

A more likely result is presented in Result #2. Here, more than one spectral class is attributable to several information categories desired by the user. These "sub-classes" may be of little informational utility (turbid versus clear water) or they may provide useful distinctions such as spruce versus fir if the project objective is to categorize timber types. In either case, the spectral classes may be aggregated after classification into the smaller set of categories desired by the user.

Result #3 represents a more troublesome result in which the analyst finds that serveral classes relate to more than one information category. For example, spectral class #5 is found to correspond to agriculture in some locations and range grass in others. This means that these information categories are spectrally similar and cannot be differentiated in a given data set.

V. METHODOLOGY

A. Raw Data Examination

The first step in computer processsing of remotely sensed data is to identify where on the raw data tape the study area is located. This is done by analyzing a hard copy photo of the scanner image or, if a photo is not available, by analyzing large portions of the raw data until the study area is located. Once identified, the raw data for the area are stored on disk as a subscene. The individual channels of data are then displayed on a CRT monitor to check their quality. A number of corrections can be applied to the data to eliminate scanner noise or striping. These corrections are always done before the data are classified. A false color composite (FCC) can also be made by simultaneously displaying three channels of data, each through a different color gun in the CRT. By using different combinations of channels and colors, it is possible to highlight or emphasize certain ground features.

Landsat data tapes covering three time periods in the 1981 growing season were used on this project. Table 2 is a list of the computer compatible tapes (CCT's) used. It normally requires two Landsat tapes to obtain complete coverage of Curry County. However, due to a mechanical malfunction with the Landsat 2 scanner, the second May tape contained no data over Curry County. This resulted in a small data gap in the southeast corner of the county for the month of May. This gap will be pointed out in a later section. For the June scene note that one data tape came from late June and one from early July. Since the bulk of the data for the county in this time period came from the June tape, this scene will hereafter be referred to as the June scene. For the September scene it was possible to obtain two successive days of coverage.

B. Training Data Collection

In order to classify the raw data it is necessary for the computer to search the file for spectrally homogeneous blocks of data with which to train itself. There are several parameters which can be adjusted so that the search program will arrive at a roughly predetermined number of classes. For this project it was felt that

Table 2. Landsat CCT's Used Over Curry County

Scene Name	Scene Dates	Scene ID #'s
May	5-18-81	22308-16495
June	6-22-81	22343-16432
	7-11-81	22362-16484
September	9-20-81	22433-16420
	9-21-81	22434-16475

approximately 30 classes would be a large enough number to adequately classify the agricultural classes, and at the same time be a small enough number to handle efficiently.

The search program begins by examining 3 x 3 blocks of pixels looking for spectrally homogeneous blocks. As these blocks are found, a series of statistics is compiled on them such as their mean, standard deviation, and coefficients of variation. The program is designed to compile statistics on a maximum of 60 classes. If the program finds statistics for 60 classes before reaching the end of the file, it looks back through the data and merges the two classes that are most statistically similar, thus freeing space to add one more class. The search process then continues in this manner until the entire file has been searched and 60 classes have been statistically identified.

When the entire raw data file has been searched and statistics on 60 classes obtained, the computer operator applies a clustering algorithm to the training data. This algorithm clusters together those class statistics that are the most similar. By adjusting several parameters and rerunning the algorithm several times, the operator can modify the clustering until the desired number of classes results. As stated previously, the objective for this project was to identify approximately 30 classes.

The final step in the training data collection process was the generation of a two channel plot. The two channel plot allows the operator to plot the means of all classes in the statistics file for any two Landsat channels. Figure 7 shows a two channel plot made from an ELAS statistics file of Landsat MSS data. Each letter and number on the plot represents the spectral means of one of the classes. The double column on the left is used to correlate the number of the class with its plot symbol. It is immediately evident that the classes on this plot are clustered into four distinct groups. Circles and labels have been provided to identify each group. The whole purpose of the plot is to provide the operator with a preliminary name for each class depending on where the class is located on the plot. For example, bare soil usually occupies the diagonal at the upper right because soil is usually bright on all channels and water is usually at the lower left because it tends to be dark on most channels. Urban and vegetation classes are usually found in the lower center of the plot. It should be pointed out that most plots do not produce as clean a cluster pattern as that found in Figure 7.

C. Image Classification

When the training data process has been completed, the raw data file can be classified using a maximum likelihood unsupervised

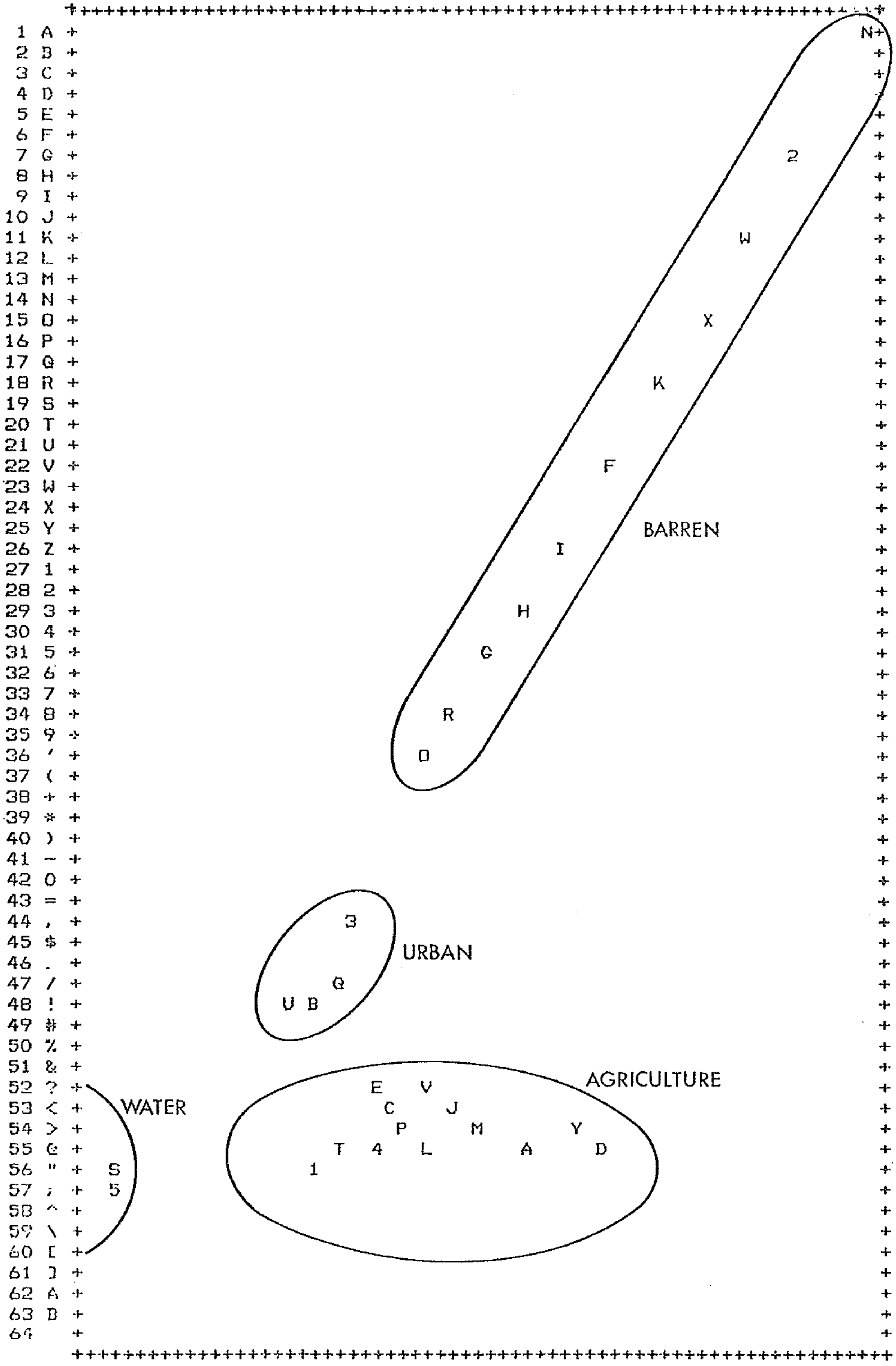


Figure 7. Landsat MSS Two Channel Plot

classifier. An unsupervised classification simply means that the computer has compiled its own training statistics without help from the operator. The term "maximum likelihood" means that the computer compares the spectral values of each pixel in the raw data file to each of the statistically-defined classes in the statistics file. The computer then calculates the probability that a pixel belongs to each class in the statistics file and assigns the pixel to the class to which it is statistically closest. This calculation is performed for every pixel in the raw data file. When the classification is completed, it can be displayed on the television screen and analyzed. A color table is then loaded onto the classification. This color table is created by the computer whereby each class is assigned a color based on the class location on the two channel plot. The operator can then highlight each class in a distinctive color to view its precise distribution and location.

D. Geographic Referencing

In order to obtain a final map product showing irrigated lands from all three Landsat dates, it is necessary to geographically reference, or georef, the three classifications to a common base map. The first step in this process is to locate quality base maps of the county at a useful scale which also contained the Universal Transverse Mercator (UTM) metric grid. The maps chosen for this study were the U. S. Geological Survey 1:100,000 scale series maps entitled "The Caprock " and "Clovis." These maps were attached to a digitizing tablet and a process called initialization was performed. In this process, three known grid intersections were identified, digitized, and their grid coordinates entered into the computer. These points are usually selected so that they form a triangle which includes the entire map. With these three known points the computer is able to calculate the coordinates of any other points on the map. The next step is to digitize several other known grid intersections and display their computer-calculated coordinates on a terminal. The grid values are compared to the calculated values to see how closely they match. Through experience it is desired that the quality of maps being used should produce initialization values equal to or better than the dimensions of one Landsat pixel (60m x 60m). An error of ±60 meters in either the X or Y coordinate direction was considered acceptable. Any errors greater than this are considered to be unacceptable meaning that the map would have to be reinitialized, usually with three different points. In the case of this project, each map was initialized within an error of ±25 meters.

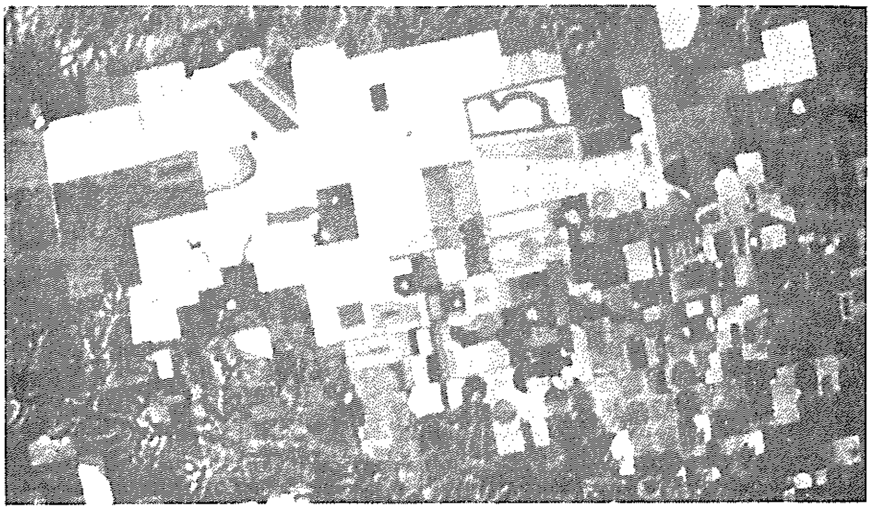
After initializing, it is necessary to identify features which can be found on the base maps and on all three of the raw data files. These features, called control points, usually consist of road intersections and corners of distinctive fields which can be identified as township and range section corners. Once a feature has been selected on the map it is digitized and its UTM coordinates recorded. The raw data for each date are then displayed and the same control point identified. A moveable target, or cursor, on the TV screen is then placed precisely on the point and the Landsat scanline and column for the coincident pixel are retrieved. The point has to be clearly visible on all three dates of Landsat imagery or it can not be used. The end result of this procedure was a list of points for each of the three Landsat images, each point having a pair of UTM and Landsat coordinates. A total of 30 matching points were found for each date. Table 3 is an example of control point coordinates taken from a portion of the September coordinate list.

Table 3. Partial Listing of September Control Points

	UTM Coordinate		Landsat Coordinate	
Point #	Easting	Northing	Scanline	Element
1	627971	3854040	467	216
2	642436	3854213	422	467
3	628168	3841177	689	258
4	637775	3841282	660	424
5	639575	3831670	821	484
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
30	665934	3797060	1343	1043

At this point the UTM and Landsat coordinate pairs for the May data were typed into the computer which then tried to build an equation to fit the Landsat coordinates to the UTM coordinates. In the first attempt the computer may have been able to make a fit of only 600 meters accuracy. The individual accuracy of fit for each point is displayed on the terminal. The worst point is removed and the equation run again. Each time a point is eliminated the accuracy of fit improves until the operator is satisfied with the fit. A fit of 60 meters or less is usually desired; the final result for the May data was 56 meters. At the end of the calculation for the May data there were 25 points remaining, five having been rejected. At the beginning of the calculation of the equation for the June data only the 25 equivalent points retained in the May data were entered and none rejected thereafter. The same strategy was used for the September data. The equation results for these two latter dates were 46 and 28 meters, respectively. What the error numbers of 56, 46, and 28 actually represent are the average amount of error of fit in meters for each pixel of corrected Landsat data if they were overlain onto the initialized base map. This means that the mathematical fit of each georef point used in this study was less than one Landsat pixel.

Up to this point no actual geographic referencing had taken place; only the three equations had been calculated. Each equation was then applied to its corresponding classified image and each pixel was repositioned to its corrected grid position. Each classification was rotated roughly 9° to the east so that north was positioned at the top and any attitudinal or directional distortions caused by the satellite or its orbit were corrected. The result of the entire process is shown in Figure 8a and 8b. Figure 8a is a false color composite of the September raw data over central Curry County. Because an infrared channel was used, the irrigated cropland is shown in red, dryfarm crops in green, fallow in white and light blue, and native grasslands in purple and gray. Note on this uncorrected image that the data seem to be rotated slightly to the left and north would appear to be in the upper left corner. Figure 8b is a classified version of the raw data in 8a which has been georefed. Note how the data have been rotated to the east so that edges of



a. Uncorrected Raw Data False Color Composite

b. Geographically Corrected Classification

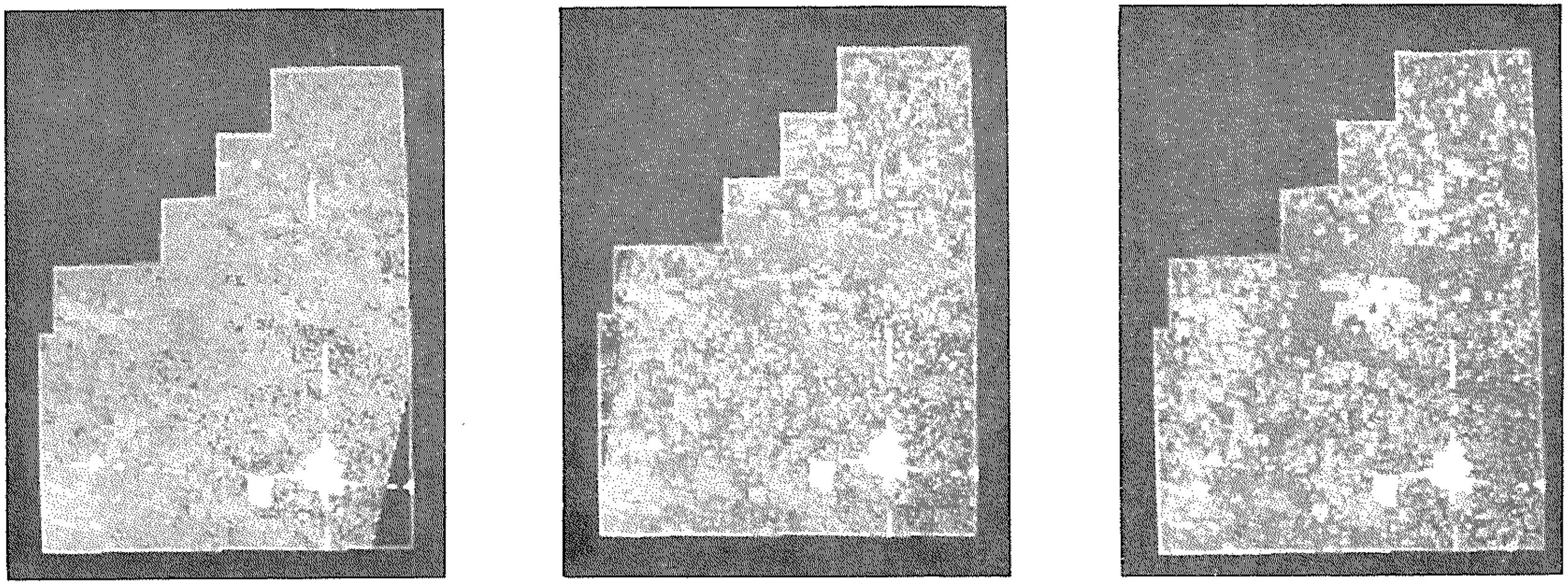
Figure 8. Result of the Geographic Referencing Process

fields run in north-south and east-west directions. North is directly to the top. In 8b the irrigated fields are shown in green, dryfarm in pink, fallow in light tan, and native grassland in gray. Note also that the georefed image is slightly smaller than the raw data false color composite. This is because the geographic correction was calculated to a scale of 1:100,000, and the displayed image scale is slightly different from the display scale of the uncorrected raw image. In this project only the classified images were geographically referenced.

VI. ANALYSIS OF CLASSIFICATIONS

The first step in analyzing the classifications was to digitize the boundary of the county. This digitized line was then merged with each classification and all areas outside of the county line were eliminated. Figures 9a, b, and c show the resulting classifications for May, June, and September, respectively. The areas of Clovis, Cannon Air Force Base, several small municipalities, and several roads were digitized and merged with the classifications and displayed in white for reference. The roads appear dashed due to a four time reduction of the classifications.

Using the two channel plots and the method described in previous sections, each class in the three classifications was examined for its location both on the image and on the plot. In this way the irrigated classes were systematically separated from the nonirrigated classes. In those cases where the identity of a class was uncertain, the raw data were examined in detail to help define the class name.



a. May Classification b. June Classification c. September Classification

Figure 9. County Classifications for May, June, and September

Figures 10, 11, and 12 show the two channel plots for May, June, and September, Respectively. Circles and labels have been applied to show the resulting class groupings.

When the irrigated classes for each date had been identified, a file was created for each classification showing only the irrigated classes. In Figure 13a, b, and c the irrigated classes are shown in yellow for May, June, and September, respectively, as they appeared on the TV screen. To obtain an image which displayed all irrigated lands for the 1981 growing season, the three images in Figure 13 were combined to produce the image shown in Figure 14. The computer was then directed to compute an acreage count for all of the irrigated classes for the year and the result was 138,881 acres. At this point the New Mexico Agricultural Statistics for 1981, published by New Mexico State University, was consulted for the official irrigated acreage for Curry County compiled by conventional means. This figure was 147,180 acres. Comparing the figures, the Landsat classifications resulted in an acreage count which was 94.4% of the official figure. The percentage would probably have been somewhat higher if data had not been missing from the southeast corner of the May classification (see Figure 9a and 13a) and there were scattered clouds over a portion of the June classification which may have obscurred some irrigated fields. It is doubtful, however, if these data losses would make a significant impact on the total acreage count.

The next question to be addressed was whether three dates of Landsat imagery were necessary to obtain an acceptable acreage count, or whether some combination of fewer images could provide an equally

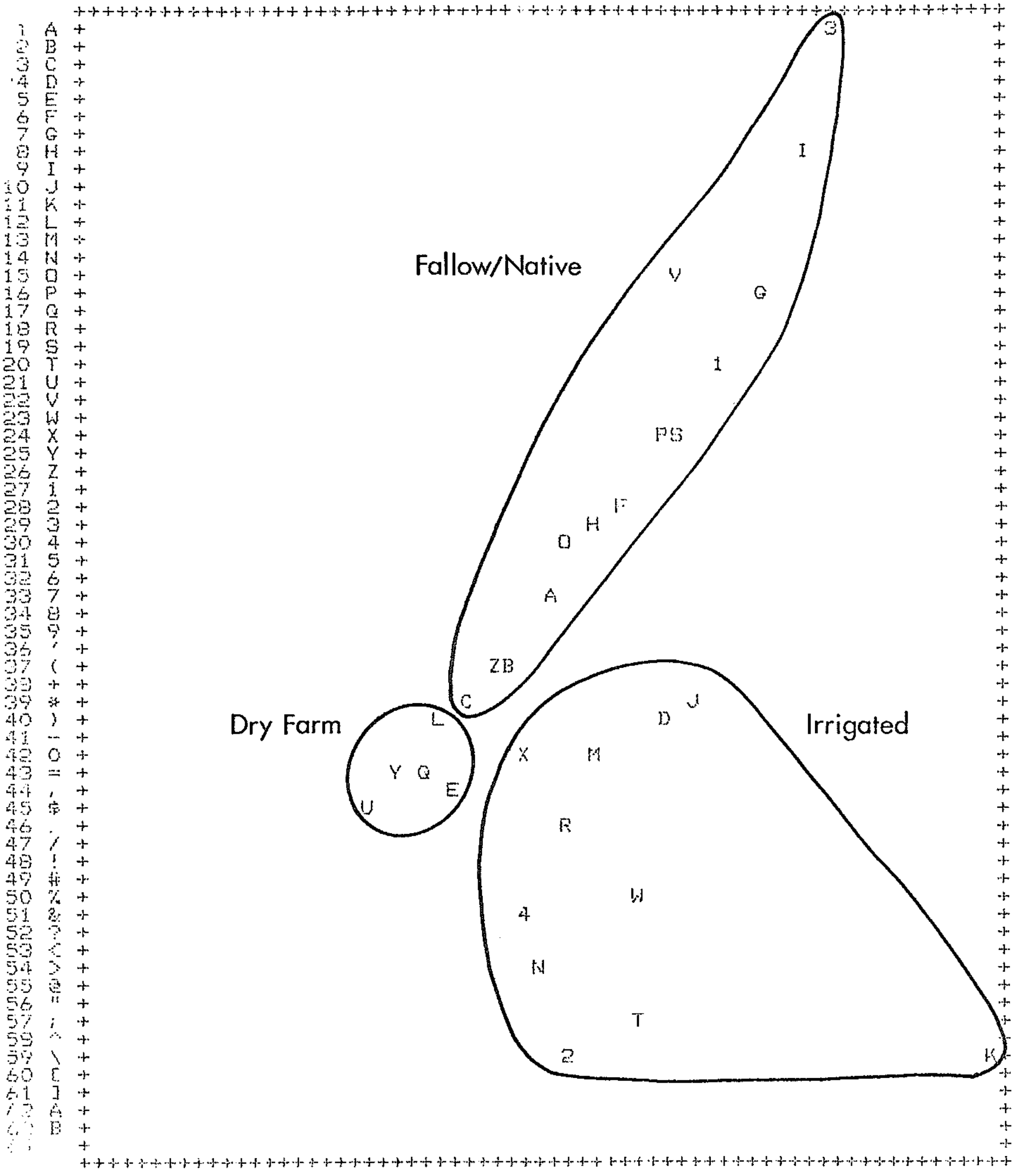


Figure 10. Two Channel Plot for May

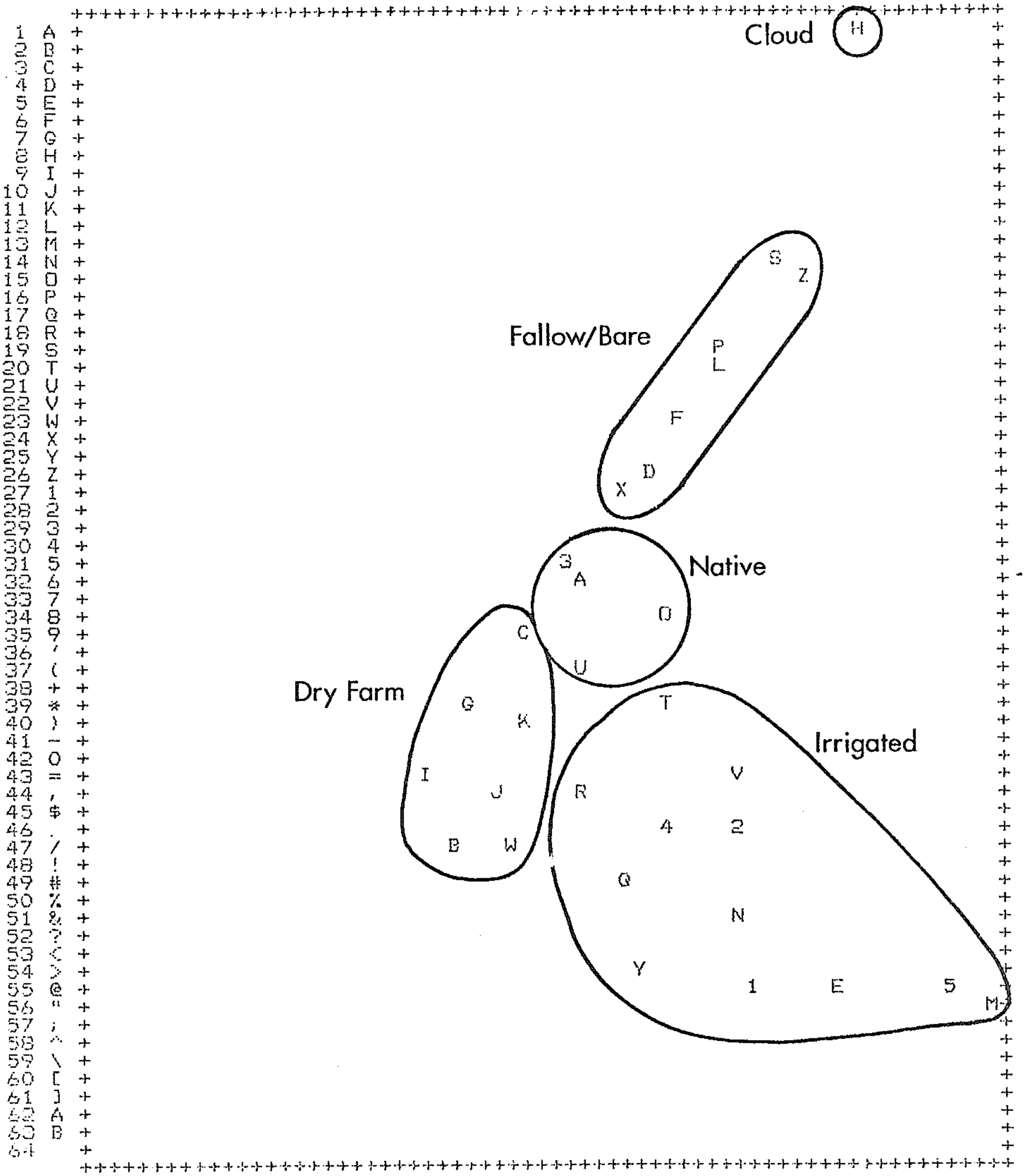


Figure 11. Two Channel Plot for June

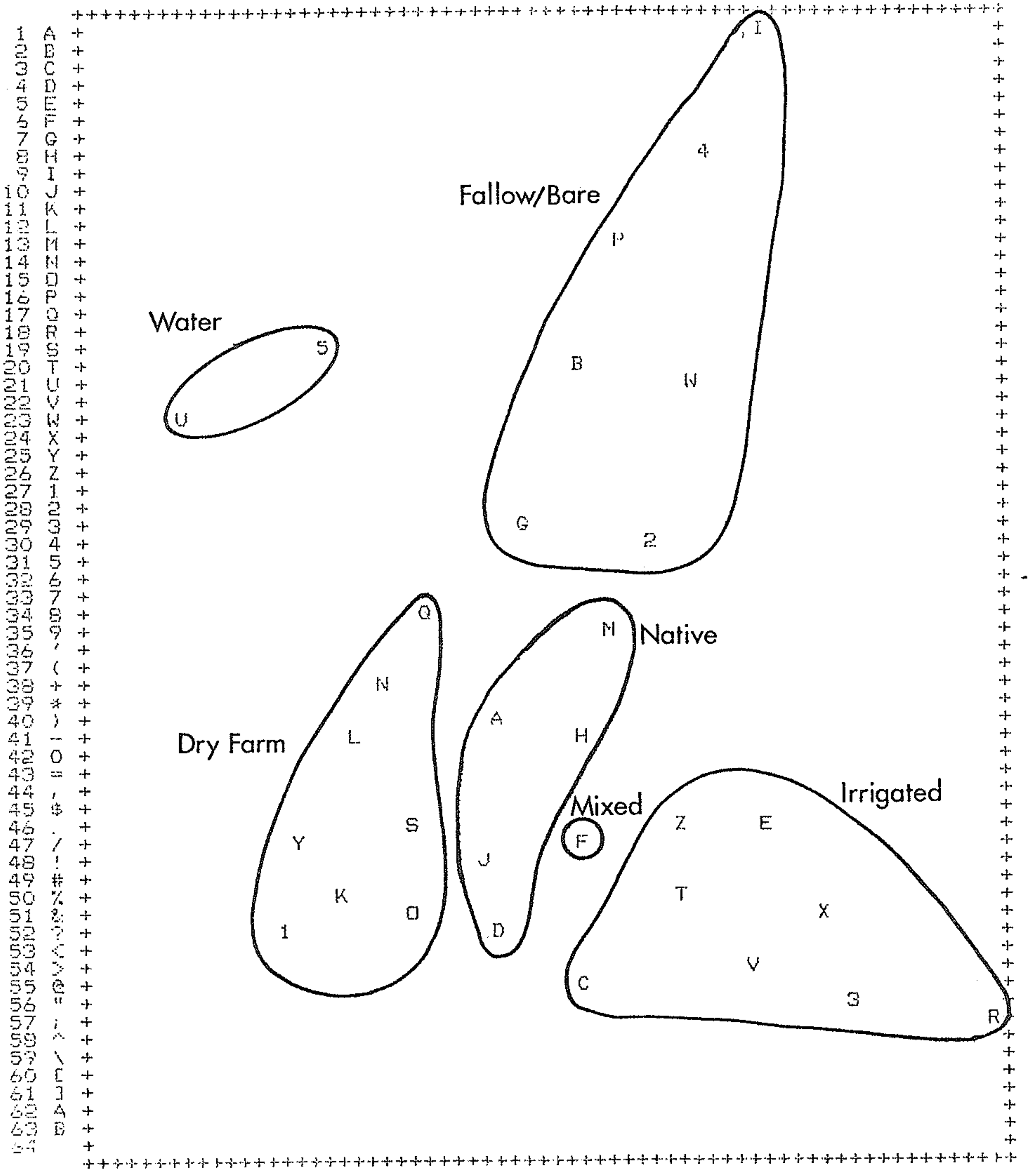
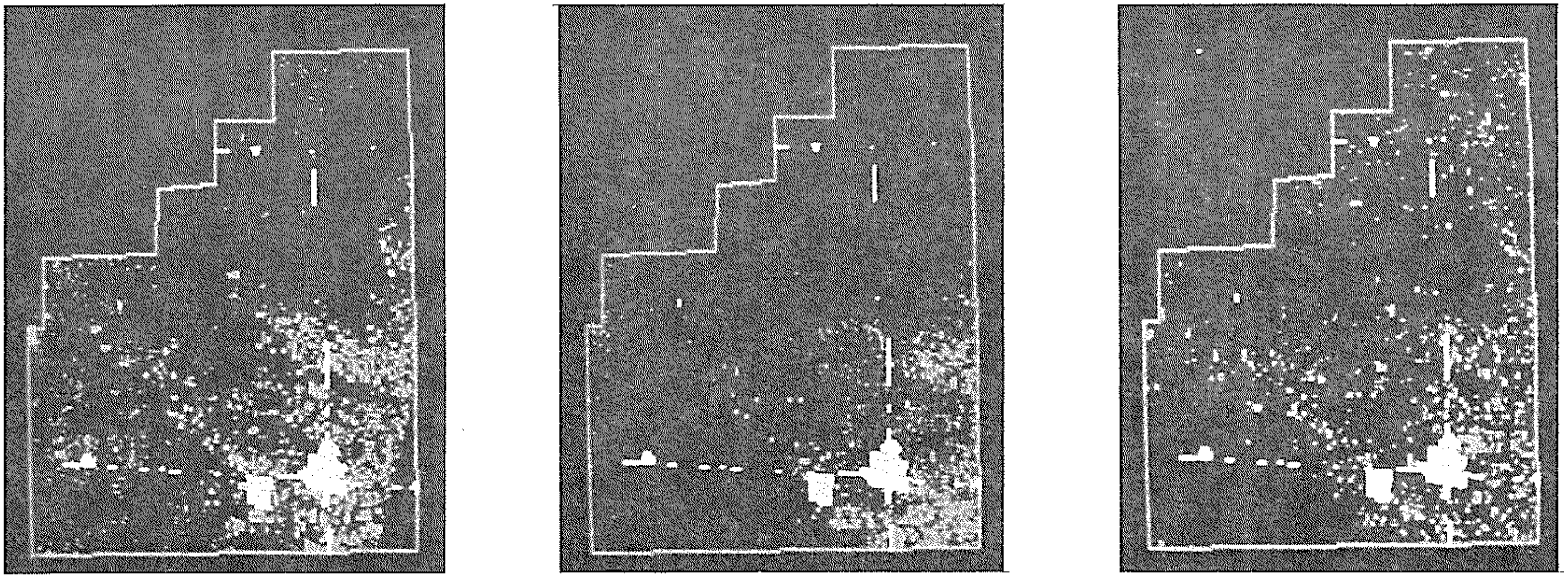


Figure 12. Two Channel Plot for September



a. May Classification b. June Classification c. September Classification

Figure 13. Irrigated Classes for May, June, and September

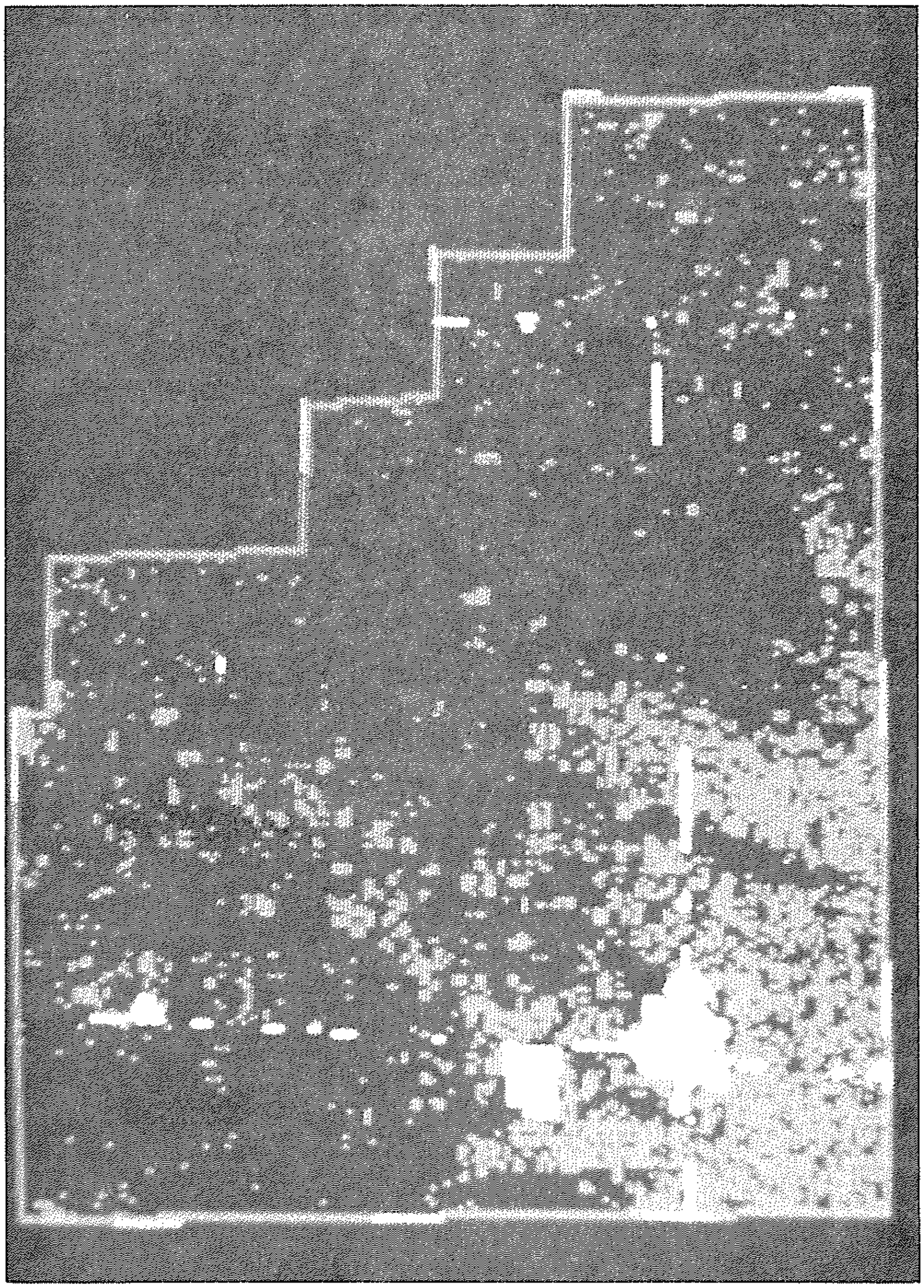


Figure 14. All Irrigated Classes Combined for 1981

accurate result. Table 4 shows a tabulation of acreages for various combinations of the Landsat classifications. Looking at the right-hand column, which is the percent of irrigated acreage measured by image processing compared to the official published figure, it is clear that no single date, or pair of dates, approaches the accuracy achieved by all three dates combined. The incorporation of a fourth date of Landsat imagery would possibly improve the accuracy by several percentage points, but it is doubtful whether the increase would justify the cost of data acquisition and processing time.

Table 4. Tabulation of Landsat/Computer Generated Acreage Figures
(Published Figure - 147,180 Irrigated Acres)

	Classification Date	Computer Acreage	Percent Published Figure
1.	May	73,998	50.3
2.	June	41,172	28.0
3.	September	45,491	30.9
4.	May + June	105,078	71.4
5.	May + Sept.	111,636	75.8
6.	June + Sept.	80,555	54.7
7.	All Dates Combined	138,881	94.4

Note in Table 4 that when the acreage for May (line 1 - 73,998) is added to the acreage for June (line 2 - 41,172) the total is 115,170, which is different from the figure derived by the computer in line 4.

The reason for this is that some fields were irrigated on both dates. Simply adding the figures for the two months would result in counting some fields twice. The computer, on the other hand, counts those fields only once. This holds true for all combinations of dates.

The final step in the project was to generate a printed map of all irrigated lands in the county for 1981 at a scale of 1:100,000. Figure 15 shows the map reduced approximately 3.5 times.

VII. CONCLUSIONS

A number of expected and and unexpected results emerged from this investiation. The first of these was the successful application of satellite data. The 94.4% accuracy of the Landsat classifications indicates that Landsat data can aid water resource planners in making acreage measurements of irrigated lands and, ultimately, in monitoring groundwater withdrawal. It can also be argued that, for the eastern plains of New Mexico three dates of Landsat imagery in a roughly spring, mid-summer, and late summer sequence provide sufficient data for accurate yearly totals of irrigated acreage.

Another point to be realized is the cost savings that could be derived from large area inventories. Although this project was intentionally restricted to Curry County, the data available on a single Landsat tape extend well beyond the county boundary and the methodology and classification applied could be expanded to a much larger area in the High Plains. Without further study it is not yet clear whether the same level of classification accuracy could be obtained from another physiographic region (such as southwest New Mexico), but the technique could readily be extended to other parts of the New Mexico High Plains. The cost per unit area of an area

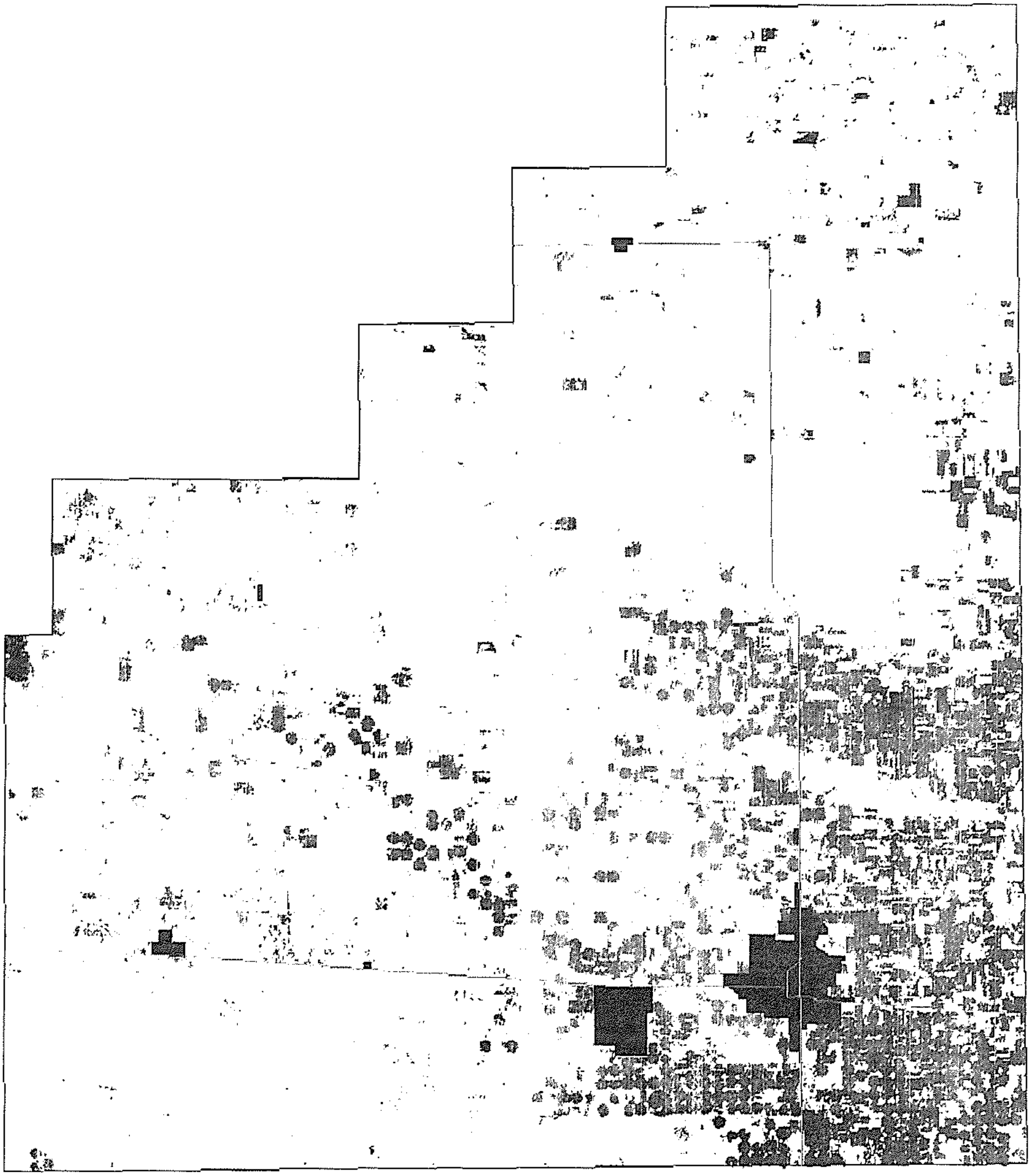


Figure 15. Printout of All Irrigated Classes for 1981

three times the size of Curry County would also be lower than classifying just Curry County. Experience has shown that computer time to classify an area does not increase at the same rate as the increase in the area under study. The methodology developed for the Landsat MSS data could also be applied to future satellite systems such as the Landsat 4 thematic mapper.

Another conclusion that can be drawn from general observations during this research is that the dryer the climate, the easier it is to classify irrigated lands. The reason for this statement is that in a dry climate, such as New Mexico has, native grasslands and pastures are usually not irrigated and their spectral response is much different from irrigated cropland. This spectral difference is very easy for a satellite sensor to detect. There should be little confusion between irrigated cropland and background, or native vegetation in any classification. On the other hand, in more humid areas such as Iowa or Missouri, increased rainfall tends to make pastures and grasslands as green as their surroundings, introducing the possibility for misclassifying pixels. The above statement would also be true for classifications performed on both wet and dry years for the same area. The general conclusion from these observations is that New Mexico offers an excellent opportunity for unambiguous and accurate Landsat classifications.

There are other benefits to be obtained from a Landsat classification other than just irrigated lands measurement. Although the focus of this project was on irrigated lands, there were good indications that dry farmlands could have been identified and mapped equally as well. The two channel plots of each of the three classifications in Figures 10, 11, and 12 indicate an apparent spectral separation of dry farmlands from other general categories.

Another conclusion of this research was the value of digitizing the county boundaries, cities, and roads in Curry County. The value of this goes beyond that of simple reference and orientation, however. Since the classifications are digital in nature and geographically referenced, it is valuable to view the data as information which could be integrated into a geographic information system. For example, it would have been possible to merge these classifications with other digitized data such as depth to groundwater, annual precipitation, soils, landownership, or other environmental attributes. Once done, the variables can be analyzed for relationships and possible trends. Once the basic data base has been installed, Landsat classifications can be added at regular intervals and variables such as depth to groundwater can be easily updated to help in formulating predictions for long term trends. Although minimal use was made of this capability on the Curry County project, the technique provides excellent opportunities to deal with multivariate data sets in different formats. The data sets could be in the form of points (such as well log data), lines (such as roads and rights-of-way), or in polygons (such as soils and landownership). All the data could be merged and used in predictive modeling.

VIII. RECOMMENDATIONS

The results of this research could be successfully applied to a number of future hydrologically related activities, leading to information which may or may not have been dealt with before in New Mexico. The most significant of these are: (1) the implementation of the research results and methodology in a large area program for all of the New Mexico High Plains or statewide; (2) the development of a crop calendar/phenology data base for the various agricultural regions of the state; (3) a geographically based agriculture/hydrology information system; and (4) an evaluation of the new thematic mapper scanner for agricultural purposes in general and the monitoring of irrigated lands in particular. These activities are examined below in more detail.

1) A large area application of the research methodology described in this report would provide an important indicator to the locations and concentrations of irrigated lands in the High Plains. These data could be used simply for acreage estimates, as presently acquired data are used, or for detecting changes in agricultural land use on a yearly basis. This type of satellite information in map form could serve as valuable input when correlated with well depth data, high water depletion sites, and related data impacting on groundwater use and distribution.

2) This study has shown that, at least for eastern New Mexico, three dates of Landsat imagery are sufficient to accurately inventory irrigated lands. For most areas of the state this would probably hold true. However, regional variations in climate and cropping practices may dictate that only two satellite overpasses are needed for a certain area, or possibly as many as four. In order to perform yearly crop inventories over the entire state and to ascertain the number of satellite scenes needed for the various regions in the state it will be necessary to compile crop calendars and phenologies for those crops under study. These calendars and phenologies will help to

segment the state into agricultural regions and will be an aid in performing the Landsat classifications. For example, the growth cycle for corn in Curry County in a given growing season will probably be quite different from corn grown in the San Juan Basin because the precipitation and temperature regimes are quite different, the amount and source of irrigation water differs, and the variety of corn and the methods under which corn is grown will vary. To properly select and interpret Landsat data it will be necessary to know what these variations are. Much of the crop data already exists and most of the work would involve compiling data from numerous sources and modifying it to meet the objectives of the project.

3) A computer information system for agriculture/hydrology which is geographically based would be the ideal technique to merge and organize all of the data types mentioned thus far. Such an information system could serve as the central repository for old and new data and could be drawn upon for data integration and generation of new water planning information. The system could contain all Landsat classifications, crop calendars and phenologies in both map and tabular form, and virtually any other data set of hydrologic and agricultural consequences. The information could be kept by county, agricultural region, or statewide; much like the Natural Resource Information System of the New Mexico Natural Resource Department which has been in existence for several years.

4) New satellite sensors offer increasingly improved capabilities for agricultural resource surveys. The most recent sensor to contribute data is the thematic mapper (TM) carried on Landsat 4. The TM offers the potential of increased accuracy for inventory and change

detection. The methodologies described in this research can easily encompass the TM system. A description of the thematic mapper and its capabilities are included in the following section.

IX. THEMATIC MAPPER

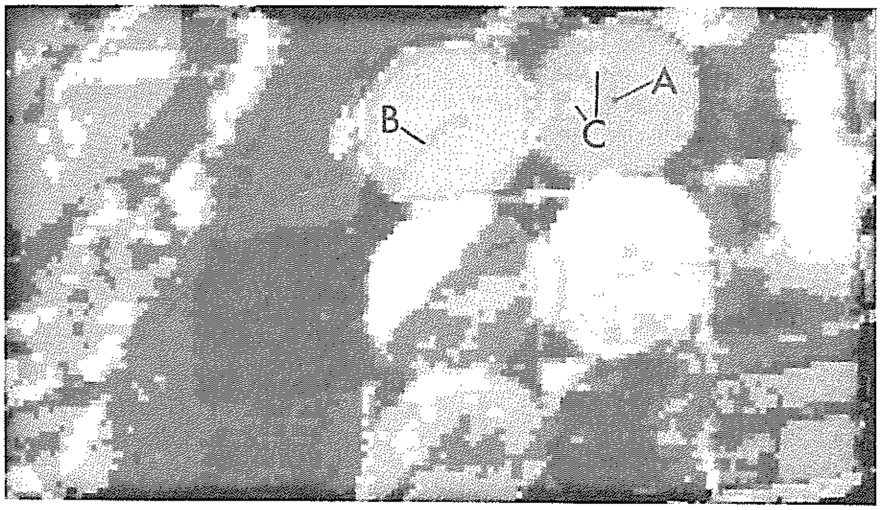
Landsat 4 is the newest generation of earth resources satellites. It was launched in the fall of 1982 and should be operational in 1983. Landsat 4 has an orbital altitude of 704 kilometers and will maintain a 16 day repeat cycle. The two onboard sensors provide ground coverage of about 185 x 170 kilometers per scene.

The MSS on Landsat 4 senses data in the same four bands as the present MSS on Landsat 3, and has the same resolution (57 x 79 meters). A second sensor called the thematic mapper (TM) operates over 7 bands and has a resolution of 30 meters. Band 6, the thermal wavelength, has a resolution of 120 meters. The TM is a high resolution, multispectral sensor designed to significantly increase the capabilities of the Landsat spacecraft in differentiating between various types of agricultural crops and expanding capabilities for mineral exploration.

Figure 16 shows examples of the type of information that will be obtained from the thematic mapper. Figure 16a is a standard false color composite of Landsat 2 MSS data displayed on the TDIPS TV screen. The features shown include center pivot agriculture near Willard, New Mexico in Torrance County in June of 1981. The picture is displayed in a 1 x 1 format, meaning that each TV display element is showing only one Landsat pixel. No enlargement or reduction has been introduced. Figure 16b is a false color composite of the same

a. Landsat MSS False Color Composite

b. Simulated Thematic Mapper False Color Composite



c. Simulated Thematic Mapper Classification

Figure 16. Comparison of MSS and Thematic Mapper Data

area in September of 1981 recorded by a simulated thematic mapper scanner carried on a Lear jet flown by NASA. These data are also displayed in a 1 x 1 format. The increase in resolution obtainable by the new sensor is immediately evident. On the simulated TM data the edges of fields are more precisely defined, allowing for more accurate acreage measurements, and small details such as roads between fields can be seen. Figure 16c is a three time enlargement of a classification of the data in Figure 16b. The degree of detail present in the classification is shown by the location of the center pivot hub at A and the area being irrigated by the sprinkler arm at B.

The increased resolution and additional spectral wavelengths also allow more information to be obtained within a given field. For example, the spectral difference detected at C could be caused by poor soils, irregular watering patterns, or stress induced by disease or insect damage. These features would be much less distinct or probably not visible at all on conventional Landsat MSS data. Thematic mapper data are expected to be the prime source of earth resource information for the next decade and the quality of initial data received from the satellite has proved to be even superior than the examples shown here.

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