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The Identification of Irrigated Crop Types and Estimation of Acreages from Landsat Imagery

A logarithmic-stretch technique was the most economical while an unsupervised-supervised smoothing technique was most accurate for an area in the High Plains of South Dakota.

(Abstract on next page)

INTRODUCTION

PURPOSE

THE PRINCIPAL CONSUMPTIVE use of ground water in the High Plains of South Dakota is cropland irrigation. The quantity of water used for irrigation can be directly estimated from crop-type and crop-acreage determinations (for an example of one method, see Blaney and Criddle (1962)).

The U.S. Soil Conservation Service and U.S. Agricultural Stabilization and Conservation Service maintain yearly records of irrigated crops planted in each county. Because this information is voluntarily reported, county crop records generally are incomplete and may be unverifiable. Therefore, an alternative method of crop-type identification and crop-acreage estimates would be valuable.

The purpose of this study was to evaluate techniques for identifying crop types irrigated by ground water, and for estimating crop acreage in the High Plains of South Dakota, using Landsat imagery (Figure 1). Proven methods could then be applied throughout a larger area of the High Plains to estimate regional use of irrigation water.

LOCATION

The High Plains study area (about 5,290 square miles), located in south-central South Dakota (Figure 1), includes Bennett County and parts of Gregory, Mellette, Shannon, Todd, and Washabaugh Counties. A smaller representative area (about 450 square miles) located in Todd County was used for most data-processing tests because of availability of ground information and seasonal Landsat coverage that was cloud free. The techniques developed from the study of the smaller test area were applied to the entire Landsat image, which encompassed most of the High Plains of South Dakota where irrigation has been developed (Figure 1).

The study area can be characterized topographically as low-relief, rolling uplands with intermittent streams and occasional erosional escarpments and badlands; sand dunes occur along parts of the South Dakota-Nebraska border. The dominant vegetation is prairie grasses, except along bottomlands where riparian plants (such as cottonwoods) dominate, or along escarpments where Ponderosa pines occur.

PREVIOUS INVESTIGATIONS

Numerous investigations have been completed on the feasibility of rangeland and crop identification, and acreage estimation using visual- and computer-

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ABSTRACT: *The purpose of this study was to evaluate the following techniques for identifying irrigated-crop types and estimating crop acreage in the High Plains of South Dakota, using Landsat imagery: (1) Visual interpretation of false-color infrared composite images; (2) density analysis and classifications of single-band images; (3) ratio-cutoff and classifications of logarithmically stretched images based on the band 7/band 5 ratio; and (4) combined unsupervised and supervised classifications of multiple-band images. Smoothing functions were applied to the unsupervised and supervised classifications to decrease the number of mixed-class pixels.*

Visual interpretations of level-sliced classifications of logarithmically stretched images based on the band 7/band 5 ratio, and visual interpretations of smoothed unsupervised and supervised classifications of multiple-band images produced the best identification of crop type and estimates of acreages. Irrigated alfalfa was best identified and mapped using May imagery; irrigated corn and soybeans were best identified and mapped using August imagery.

interpretation techniques applied to Landsat multispectral data (Driscoll and Francis, 1970; Swain, 1972; Phillips, 1973; Draeger, 1977; Bauer *et al.*, 1978; Bauer *et al.*, 1979; Draeger, 1979; Johnson and Loveland, 1979; Poracsky and Williams, 1979; Wall, 1979). Other investigators determined the types of irrigation systems used and estimated the quantity of water used by crops from Landsat-image interpretations (Eucker *et al.*, 1974; Hoffman *et al.*, 1974; Hoffman, 1979). The U.S. Geological Survey is currently developing techniques to estimate irrigation-water use by mapping irrigated cropland, using Landsat imagery (Heimes and Thelin, 1979). Most state-of-the-art techniques involve a combination of digital and manual mapping, multitemporal and multispectral analyses, and supervised or unsupervised computer classification.

METHODS OF STUDY

The principal crops irrigated by water pumped from the High Plains aquifer in South Dakota are alfalfa, corn, and soybeans (U.S. Department of Agriculture, Soil Conservation Service, 1970; 1976; 1978). These crops are grown in the upland areas with winter wheat that is not irrigated.

Some alfalfa, corn, and soybeans are grown adjacent to streams, and are irrigated with surface water or water pumped from shallow, alluvial aquifers. However, this study focused on identifying crop types and estimating acreages that are irrigated by water pumped from the High Plains aquifer. Therefore, only the upland, irrigated cropland was categorized by crop type and evaluated for acreages. Center-pivot irrigation is the method used for greater than 95 percent of the irrigated, upland crop production in the High Plains area of South Dakota (U.S. Department of Agriculture, Soil Conservation Service, 1978).

Cropland can be differentiated from rangeland on Landsat images by cultivation patterns and plant reflectances. Most cropland is identified by square, rectangular, or circular fields. Circular fields, which were targeted in this study, are characteristic of center-pivot irrigation systems (Figure 2 and Plate 1). Vigorous crops are very reflective in the infrared wavelengths and have little reflectance in the green and red wavelengths (light absorption by chloro-

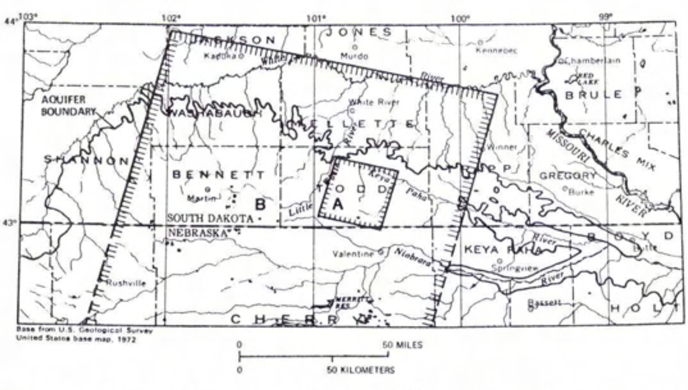

FIG. 1. Location of study area; A is the 512- by 512-pixel test area, and B is the Landsat scene coverage area.

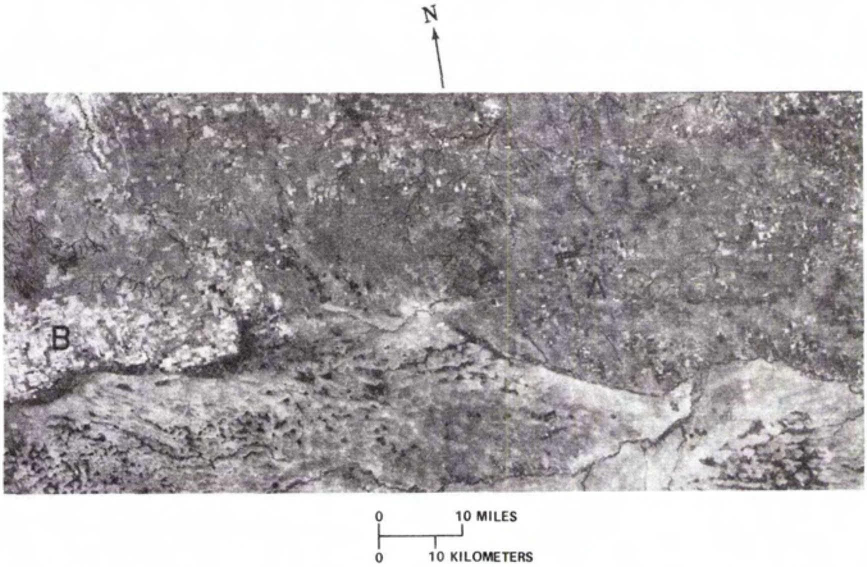

FIG. 2. A part of the black-and-white Landsat band 5 image (E-30153-16503-5) taken on 5 August 1978. Note the circular shape of fields irrigated by center pivots (A) and the rectangular shape of other cropland (B). Vigorous vegetation is dark-toned (A); whereas harvested vegetation has more reflectance.

phyll), as displayed on multiband imagery and photography (Figure 2). These crops characteristically are bright red on false-color-infrared imagery or color-infrared photography (Plate 1). Rangeland, typically, is less reflective in the infrared wavelengths and is a darker red on color-infrared photographs and Landsat images (Plate 1).

Crop-type identification and mapping, using Landsat imagery, can be accomplished best through the evaluation of seasonal variations in plant growth and vigor, and plant reflectance. Crop calendars, determined by the U.S. Department of Agriculture, Soil Conservation Service (1970, 1976, 1978), are essential in determining crop history (planting through harvest).

Bauer *et al.* (1979) and Poracsky and Williams

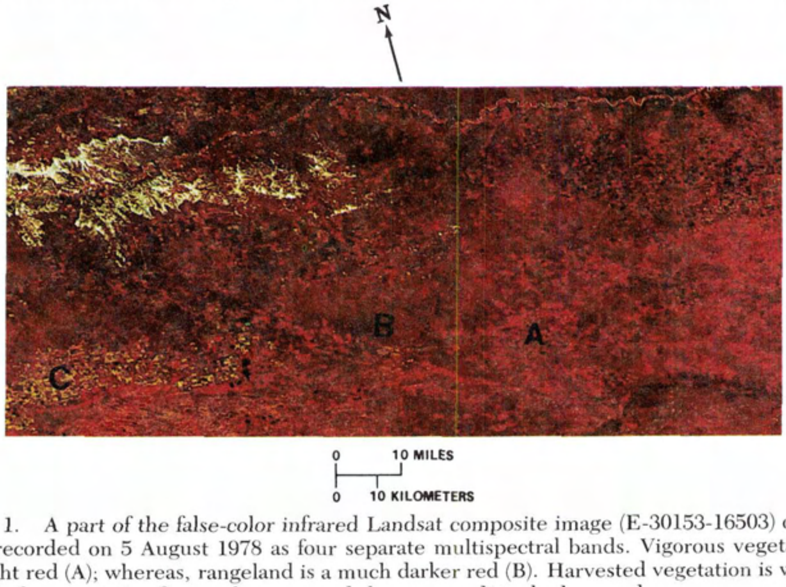

PLATE 1. A part of the false-color infrared Landsat composite image (E-30153-16503) originally recorded on 5 August 1978 as four separate multispectral bands. Vigorous vegetation is bright red (A); whereas, rangeland is a much darker red (B). Harvested vegetation is white to tan, characteristic of sparsely vegetated, barren, or disturbed ground.

(1979) noted that corn and soybeans in the midwestern United States are most accurately identified on Landsat imagery taken during August and early September, and that wheat and alfalfa were most easily identified during May. They concluded that Landsat imagery must be analyzed for a minimum of two dates to identify crop types accurately. Eucker *et al.* (1974) and Hoffman (1979) concluded that additional imagery collected in June, July, and September can increase the accuracy of this identification by 10 to 15 percent. The desire for accuracy needs to be balanced against the costs associated with the purchase and processing of each additional Landsat scene.

For purposes of this study, two 1978 Landsat scenes were chosen (E-21210-16261 taken on 16 May 1978; E-30153-16503 taken on 5 August 1978) for image analysis and interpretation, because they are of high quality, are cloud free, and would maximize crop identification. General advantages for selecting Landsat data for interpretation include multitemporal coverage (monitoring seasonal and yearly changes in vegetation patterns); multispectral-data format (four MSS bands); digital and printed data form; regional scale (large areas can be classified on a single image); and reasonable cost. The general disadvantage of using Landsat data is the limited spatial resolution (250 feet).

Computer-compatible tapes were purchased for each of the two Landsat scenes. Data on each computer-compatable tape were entered into a minicomputer, processed using predeveloped computer programs, and displayed on a video screen. The resultant enhanced data sets were transmitted to a printer/plotter (black-and-white film products) or a film writer (color-film products). The photographic products were processed, and positive enlargements (3× for this study) were produced for visual interpretations. Histograms and pixel-distribution maps were made on the line printer and were visually interpreted. A 512- by 512-pixel test area (about 450 square miles) in Todd County, South Dakota (Figure 1) was selected for analysis because of availabilty of ground information and seasonal Landsat coverage.

Four techniques were evaluated for identifying irrigated crop types: (1) Visual interpretation of false-color infrared composite images; (2) density analysis and classification of single-band images; (3) visual interpretations of ratio-cutoff classifications of logarithmically stretched images based on the band 7/band 5 ratio; and (4) visual interpretations of unsupervised, then supervised, classifications of multiple-band images. Techniques (1) and (2) were evaluated initially because of the potentially favorable cost/benefit ratio. Techniques (3) and (4) necessitated more computer-processing time, and the cost increased accordingly.

A comparison between techniques (3) and (4) also was made, and visual interpretations were compared with computer-generated histogram counts for improvement of acreage estimates. The error criterion used for each technique was an 80-percent accuracy for proper crop-type identification (known acreage versus classified acreage). If the accuracy was less than 80 percent, the method used was considered inadequate for the purposes.

Analysis of Landsat Imagery

Interpretations of False-Color Infrared Composites

Bands 4, 5, and 7 for the May and August scenes were registered spatially by the computer, and false-color infrared composite images were made (Plate 1, for example). These composite images were then visually interpreted for crop-type identification, and acreages were measured with a planimeter.

Vigorous vegetation is bright red (Area A, Plate 1); rangeland is a much darker red (Area B, Plate 1); and harvested vegetation is white to tan and is characteristic of sparsely vegetated, barren, or disturbed ground (Area C, Plate 1).

The total amount of irrigated cropland could be positively identified by circular fields (center-pivot irrigation systems; see Plate 1). This is fortunate, as most of the cropland in this part of the High Plains region has been developed by means of center-pivot irrigation. However, other irrigated and nonirrigated lands were difficult to differentiate spectrally or spatially in many instances, and crop types could not be identified. Therefore, after studying both of the false-color infrared composite images and determining that crop-type identification could not be accomplished with confidence, this technique was abandoned.

Density Analysis and Classification of Single-Band Images

The four single-band Landsat images for each of the two dates were analyzed for crop types, using a density analysis and supervised-classification technique. The investigators used the computer to identify crop types by classifying index pixels (based on tone or density) representing the various crop types using images shown on a television screen. Ground information (collected and plotted on low-altitude photography by the U.S. Soil Conservation Service and the U.S. Agricultural Stabilization and Conservation Service) was used to identify crop types on each image.

This technique can be summarized a follows:

(1) Analyze each individual band for each date separately. Display the image on the television screen for interpretation.
(2) Use the computer to identify pixel groups that represent locations of known crops. The classification program enables the investigator to delimit test sites interactively using ground information. This is accomplished by the investigator referencing the ground truth while using a cursor to approximate the map locations on

the screen. Spectral statistics for each pixel group are determined in this manner.

(3) Perform a maximum-likelihood supervised classification using the training sites and spectral statistics determined by Step 2. Display the classification on the screen or in printed form.

(4) Visually interpret the printed classification for improvement of accuracy (by eliminating or masking out riparian vegetation in bottomlands, for example).

The identification of crop types in each scene was determined by visual observation to be inaccurate, because of spectral-reflectance overlap; more than one crop has the same reflectance. It was concluded that single-band analysis, particularly by using band 7 (infrared) data for both the May and August dates, might be used for isolating acreage irrigated by center pivots and for general estimates of irrigated acreage. However, it was necessary to use more sophisticated computer-image processing and analyses of multiband, multitemporal scenes to delineate specific crop types and acreages.

RATIO-CUTOFF AND SUPERVISED CLASSIFICATION OF LOGARITHMICALLY STRETCHED IMAGES BASED ON BAND 7/BAND 5 RATIO

Simple techniques for developing band ratios were applied to the May and August (1978) Landsat scenes. It was determined that the May and August band 7/band 5 ratio images were most effectively used to delineate crop categories.

Histograms of pixel values versus number of pixels were generated by the computer for the May and August band 7/band 5 ratio images. On the basis of these histograms, a logarithmic base 10 stretch was applied to the ratioed data to increase image contrast and to enhance irrigated croplands on the image. Prints of each logarithmically stretched, ratioed image were generated and visually interpreted (Figures 3 and 4).

The logarithmic stretch was one of two different contrast-stretch methods used (the other, less satisfactory method was a linear stretch). This stretch, which was applied selectively to increase the contrast of small ratio values, best improved the visual appearance of the ratio image (by partly subduing the pixels representing vigorous vegetation and enhancing the pixels representing soils, rock, and rangeland). The result of using this stretch was to produce a print that had more distinct boundaries for physical features; thereafter, a better visual interpretation could be performed.

Crop identifications were determined from the stretched, ratioed image histograms. Crop types then were digitally identified by using a computer program that enables the investigator (on the television screen) to determine the pixel-ratio value for a known ground location. Finally, the number of pixels in each crop-type category were totaled and then multiplied by the pixel area, resulting in the estimated total acreage of a given crop type.

Concurrently, crop-type identification (using ground information as a training set) and acreages (using a planimeter) were computed by visually interpreting the black-and-white positive images of the logarithmically stretched, ratioed scenes (Figures 4 and 5). These then were compared with the results of digital identification. Both results then

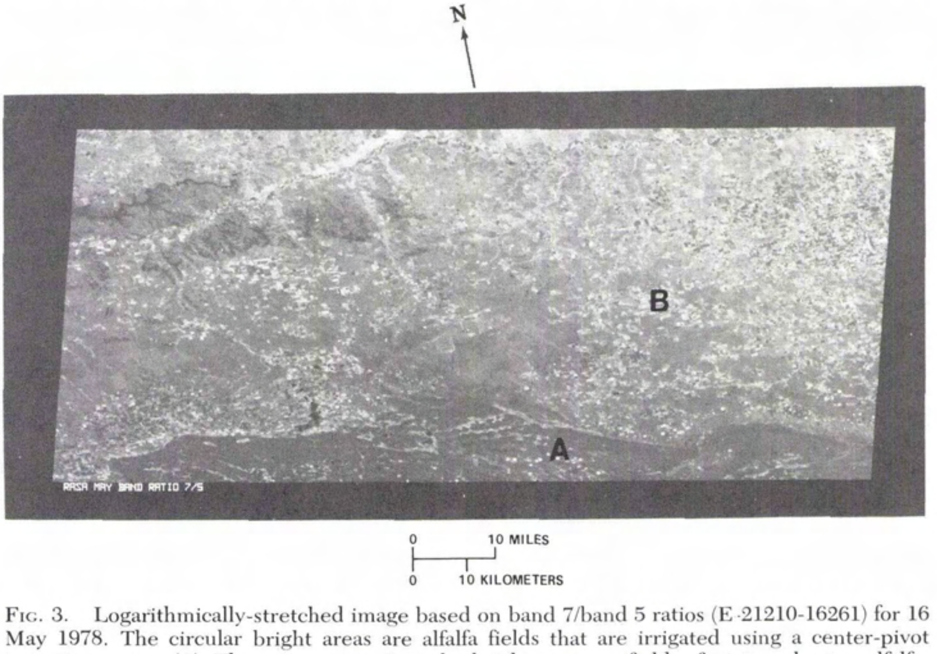

FIG. 3. Logarithmically-stretched image based on band 7/band 5 ratios (E-21210-16261) for 16 May 1978. The circular bright areas are alfalfa fields that are irrigated using a center-pivot irrigation system (A). The square or rectangular bright areas are fields of winter wheat or alfalfa, or natural riparian vegetation (B).

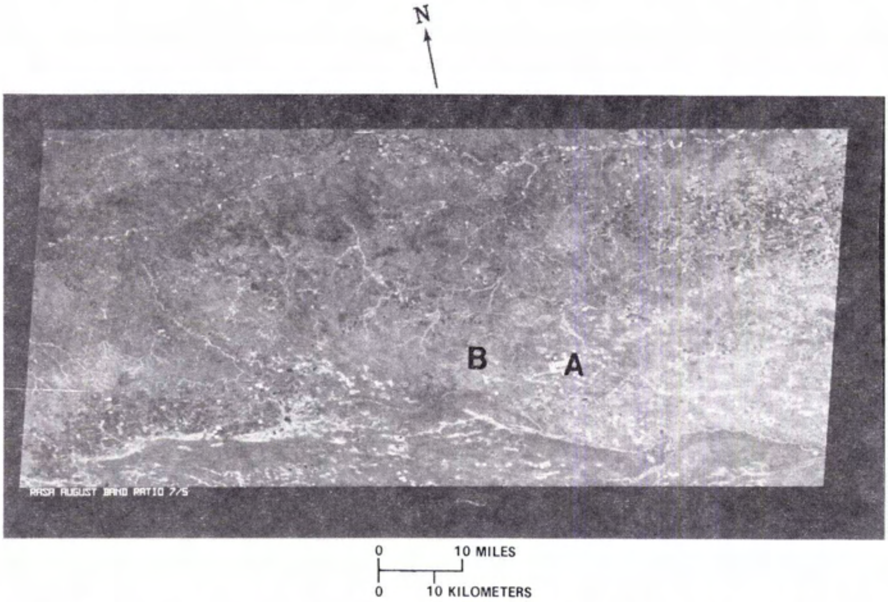

FIG. 4. Logarithmically-stretched imaged based on band 7/band 5 ratios (3-30153-16503) for 5 August 1978. The circular bright areas are fields of corn, alfalfa, or soybeans that are irrigated using a center-pivot irrigation system (A). The square or rectangular bright areas are other irrigated corn alfalfa, or soybean fields (B).

were compared with acreages reported by the U.S. Soil Conservation Service and the U.S. Agricultural Stabilization and Conservation Service and differences determined.

The logarithmic-stretch technique can be summarized as follows:

- Determine a band 7/band 5 ratio on the May and August digital Landsat data.
- Apply a logarithmic stretch to the resulting image to increase contrast and enhance the desired features.
- Interactively determine the specific ratioed pixel values (displayed ratio cutoffs). Classify all pixels using a supervised classification based on these ratio cutoffs.
- Print the logarithmically stretched, classified image as a black-and-white negative photograph and the number of pixels classified in each spectral group as histograms.
- Generate an enlarged black-and-white positive print for visual interpretation. Multiply the total number of pixels classified in each category by the pixel area to estimate total crop-type acreage.
- Visually determine irrigated crop types and acreages from the prints. Compare acreages with those determined by pixel counts.

Reported irrigated-alfalfa acreages were mapped with 95-percent accuracy by visual interpretation of the enhanced and classified May subscene (Figure 3, Table 1). However, acreages computed by histogram separation and digital classification were much less accurate (43-percent error). Alfalfa cropland is easily separated from riparian vegetation using visual pattern analysis, but the computer cannot spectrally differentiate riparian vegetation and alfalfa cropland. Therefore, results of visual interpretation were predictably more accurate than an automated classification.

Irrigated corn acreages were mapped from the enhanced and classified August subscene (Figure 4, Table 1). Acreages computed by digital classification were slightly overestimated (by 4 percent), but were more accurate than those determined by visual interpretation (underestimated by 6 percent).

Irrigated-alfalfa acreages also mapped and estimated from the enhanced and classified August subscene (Figure 4, Table 1). Acreages were overestimated (11 percent) using digital classification and were underestimated (13 percent) using visual interpretations. However, some alfalfa was cut prior to 5 August 1978, and the remaining uncut alfalfa was not representative of the total irrigated cropland.

Irrigated-soybean acreages were the least accurately mapped of all crop types. Soybean fields could be separated reasonably well from other crops (underestimated 23 percent) by visually interpreting the enhanced, classified August subscene (Figure 4). However, the spectral classification of soybeans overlaps riparian vegetation; therefore, soybean-acreage calculations determined by digital classification are very inaccurate (363-percent error; Table 1).

UNSUPERVISED AND SUPERVISED CLASSIFICATION OF MULTIBAND IMAGES

Unsupervised and supervised computer-classification techniques were used to analyze simultaneously all four Landsat bands (4 to 7) of the August scene. The general method was to statistically determine significantly different spectral classes within all of the Landsat data using an unsupervised classification technique (specifically, using a clustering algorithm). Resulting spectral statistics then were used to perform a maximum-likelihod supervised classification (where each pixel was assigned to a spectral class for which the discriminant was at a maximum). The purpose of reclassifying the data, using the spectral statistics generated during the unsupervised classification, was to combine statistically different classes that represented the same physical entity (three different classes of corn, for example).

Fifty-seven spectral classes initially were determined using unsupervised classification methods based on a clustering algorithm. Each spectral class was assigned a letter or numerical label; all labels then were printed out in map form.

The line-printer map was used to identify land-cover classes as an aid in performing a maximum-likelihood classification. Ground information was used to identify the different categories statistically determined by the computer. Using these manual procedures, various spectral classes were combined to form one class. The classes used in this part of the study included corn, soybeans, alfalfa, riparian vegetation, small grains, rangeland, and open water.

Weighted-divergence statistics were generated for each spectral class, according to the methods of Swain and King (1973). Any two classes that had little divergence (indicating similar spectral characteristics) were combined.

Nine sites were selected using ground information. The data then were analyzed interactively and used to refine the spectral statistics for each unsupervised land-cover type. The resulting statistics then were incorporated with the original statistical file determined by weighted-divergence methods and analyses of line-printer listings and evaluated. A maximum-likelihood classification was then computed.

Results of the maximum-likelihood classification were satisfactory for isolating all cover-type categories except soybeans and riparian vegetation (these classes spectrally overlapped). Therefore, the pixels, which were classified as either soybeans or riparian vegetation, were removed from the main data base and reclassified, using unsupervised classification methods. The new soybean and riparian-vegetation classes were used for reclassifying (using known ground information) and then re-entered into the main data base.

A maximum-likelihood classification was repeated; 20 distinct spectral classes were determined. Each spectral class was assigned a cover type that condensed the 20 spectral classes into seven land-cover classes, and every pixel in the classified scene was assigned a value. Each value was assigned a color, and a map in the form of a color negative was prepared. Positives were produced and visually interpreted for crop types and acreages (Plate 2). A histogram also was produced to display the number of pixels in each spectral class. Acreages were determined directly from the histogram.

The classified pixel values then were smoothed using a computer program which evaluates a 3- by 3-pixel cell (nine pixels) and replaces the center pixel with the most prevalent pixel (mode) identified with the cell. This was done to decrease the number of mixed-class or boundary pixels.

The smoothed pixel values were printed in map form as a color negative. Positives were produced and visually interpreted for identifying crop types;

TABLE 1. CROP-TYPE ACREAGES DETERMINED FROM PIXEL COUNTS AND VISUAL INTERPRETATIONS OF BLACK-AND-WHITE POSITIVE PRINTS

[LOGARITHMICALLY STRETCHED, 5 AUGUST 1978 LANDSAT SUBSCENE (512 PIXELS) BASED ON BAND 7/BAND 5 RATIOS WAS INTERPRETED TO ESTIMATE CORN, LATE SUMMER ALFALFA, AND SOYBEAN ACREAGES; LOGARITHMICALLY STRETCHED, 16 MAY 1978 LANDSAT SUBSCENE (512 BY 512 PIXELS) BASED ON BAND 7/BAND 5 RATIOS WAS INTERPRETED FOR TOTAL ALFALFA ACREAGE; ERROR, THE PERCENT ERROR OF ESTIMATED ACRES COMPARED WITH REPORTED ACRES]

Crop type	Reported* acreage	Acreage determined from pixel counts	Error in pixel-count determination (percent)	Acreage determined by visual interpretation	Error in visual interpretation determination (percent)
Corn	6,406	6,686	4	5,997	−6
Uncut, late summer alfalfa	399	444	11	345	−13
Soybeans	3,266	11,850	363	2,512	−23
Total alfalfa	1,316	753	−43	1,382	5

* Reported by the U.S. Soil Conservation Service and the U.S. Agricultural Stabilization and Conservation Service.

acreages were measured using a planimeter (Plate 3). A histogram was produced to display the number of smoothed classified pixels in each group. Acreages also were determined directly from the histogram of smoothed pixels.

The unsupervised and supervised classification technique can be summarized as follows:

(1) Perform an unsupervised classification on May and August digital Landsat data; this enables the investigator, using the computer, to statistically determine distinct spectral classes from the total data base.
(2) Compute weighted-divergence statistics for each spectral class. Spectral classes that have small divergence values and are the same cover type can be combined.
(3) Assign a cover type to each class interactively by using the computer (with cursor), data subsets generated by step 1, and referring to areas of ground truth. These combined spectral classes should correspond closely to those determined statistically by step 2. This step is actually a check for step 2.
(4) Perform a maximum-likelihood classification of the entire study area using the spectral statistics determined quantitatively in step 2 and interactively in step 3.
(5) If some crop types, like soybeans, are difficult to separate from other categories, remove the questionable classes from the main data base and recluster them using unsupervised-classification functions. The new classes need to be checked using ground information and then re-entered into the main data base.
(6) If Step 5 was necessary, repeat step 4.
(7) Perform a smoothing function on the classified data to decrease the number of mixed-class pixels; assign a color to each smoothed class.
(8) Print the classified image as a color-negative photograph.
(9) Generate an enlarged color-positive print to be used for visual interpretation. Determine irrigated crop types and acreages from this color print using a planimeter. The locations of these irrigated fields can be mapped at this point.
(10) Print the number of pixels classified in each spectral group as histograms. Multiply the total number of pixels classified in each category by the pixel area to estimate crop-type acreage. Compare acreages determined by planimeter with those computed by pixel count.

Irrigated-corn acreages were successfully mapped after visual interpretations of the classified August Landsat subscenes (Plates 2 and 3, Table 2). The smoothed classified data showed more distinct crop-type spectral groupings than the non-smoothed data. Therefore, the irrigated-corn spectral groups were more accurately mapped from smooth area (4 to 8 percent difference) (Table 2).

Irrigated-corn acreages determined from histogram pixel counts that were digitally generated (Table 2) were considerably underestimated (nonsmoothed by 29 percent; smoothed by 11 percent). Underestimates of irrigated-corn acreages and large

Table 2. Crop-Type Acreage Determined from Nonsmoothed and Smoothed Pixel Counts and from Visual Interpretation of Nonsmoothed and Smoothed, Classified August Landsat Subscenes (512 by 512 Pixels)
[Error, Percent Difference Between Estimated and Reported Acres]

Crop type	Reported* acreage	Acreage determined from non-smoothed pixel counts	Error in acreage determined from non-smoothed pixel counts (percent)	Acreage determined from smoothed pixel counts	Error in acreage determined from smoothed pixel counts	Acreage visually determined from non-smoothed classified subscenes	Error in acreage visually determined from non-smoothed classified subscenes	Acreage visually determined from smoothed classified subscenes	Error in acreage visually determined from smoothed classified subscenes
Corn	6,406	4,559	−29	5,717	−11	5,918	−8	6,118	−4
Uncut, late summer alfalfa	399	483	21	669	68	399	0	399	0
Soybeans	3,266	6,784	208	3,701	13	4,403	34	4,403	−18

* Reported by the U.S. Soil Conservation Service and the U.S. Agricultural Stabilization and Conservation Service.

overestimates of irrigated-soybean acreages resulted from the large degree of spectral overlap between riparian vegetation and irrigated soybeans, and the small mixed groups of pixels located along the boundaries between irrigated corn and rangeland.

Irrigated-alfalfa acreages were accurately mapped after visual interpretation of both the smoothed and non-smoothed, classified August Landsat subscenes (Table 2, Plates 2 and 3). However, most alfalfa fields were harvested before August. Therefore, irrigated-alfalfa acreages mapped from the August scenes are not representative of total irrigated-alfalfa acreage in the High Plains of South Dakota.

Irrigated-alfalfa acreages determined from histogram pixel counts were greatly overestimated (by 21 percent and 68 percent) in comparison with reported acreage. However, estimated acreages derived from histogram pixel counts probably were accurate. Alfalfa fields that were planted in bottomlands and irrigated with either surface water or ground water derived from shallow alluvial aquifers or subirrigated by water from a shallow water table were correctly identified and counted in the histogram. These additional fields caused the irrigated-alfalfa acreages to be overestimated. A visual interpretation of the classified August Landsat subscene was necessary to separate these two types of irrigated-alfalfa acreages.

Irrigated-soybean acreages were the least accurately mapped after visual interpretation of the computer-classified August Landsat subscenes. Irrigated-soybean acreages determined from the smoothed, classified scene were considerably more accurate (underestimated by 18 percent) than those determined from the nonsmoothed classification (overestimated by 34 percent).

Irrigated-soybean acreages determined from histogram pixel counts ranged from a relatively small overestimate (13 percent) determined from smoothed classification data (Table 2) to very large overestimates (208 percent) determined from nonsmoothed classification data. Riparian vegetation and irrigated-soybean acreages have a large spectral-classification overlap. Furthermore, many soybean fields were planted on bottomlands (Plates 2 and 3). Two possible errors resulted: (1) Either the riparian vegetation was misclassified as soybeans, or (2) soybean fields were planted in the bottomlands that are irrigated by surface water. Therefore, the 13-percent overestimate is misleading.

Discussion

COMPARISON OF TECHNIQUES

Three comparisons were made between the unsupervised-supervised classification and logarithmic-stretch techniques: (1) Visual interpretations of black-and-white prints compared to color prints; (2) acreage computations from histogram pixel counts; and (3) visual interpretations compared to histogram computations. Generally, more complex methods resulted in more accurate results while accruing the most computer time and largest overall costs.

Irrigated corn and alfalfa can be accurately mapped and acreages estimated by visually interpreting the results of either technique. Irrigated soybeans, however, are less accurately mapped using the logarithmic-stretch technique. Visually-interpreted prints generated from the unsupervised-supervised classification technique improved the crop-type identification by 2 percent for corn and 13 percent for alfalfa (Tables 1 and 2). Smoothing aided in increasing interpretations accuracy. The smoothing combined with the unsupervised-supervised-classification technique involved the most computer and computer-operator time and was the most expensive.

Irrigated-corn and irrigated-alfalfa acreages computed from histogram pixel counts were estimated more accurately by the logarithmic-stretch technique (Tables 1 and 2). Irrigated-soybean acreages, however, were better estimated from histograms computed by using smoothing and the unsupervised-supervised classification technique (Tables 1 and 2). However, accuracy of soybean-acreage estimates by the histogram pixel counts was questionable.

Acreage estimates derived from histogram pixel counts generally are questionable and variable. In addition, accuracy of these estimates was consistently less than accuracy of visual interpretations of photographic prints. Therefore, a combination of computer enhancements and classification techniques, and visual interpretation of photographic prints, was necessary for the best irrigated crop-type identification and crop-acreage estimation.

COST ANALYSIS

There were four primary costs involved in conducting this study: (1) Computer-related, image-processing costs; (2) computer-operator costs; (3) data entry and retrieval costs; and (4) visual-interpretation costs (Table 3). A fifth cost, travel to and from the nearest computer-image-processing facility, was computed to show monetary advantages of a processing facility close to the investigator (Table 3).

The computer-operator costs, investigator costs, and travel costs are variable, depending on such factors as necessity and training of computer operator, training of investigator, familiarity of investigator with the type of remote-sensing equipment and computer programs used, difficulty of task being performed, travel distance necessary to attain access to a processing facility, and time spent at the processing facility. Computer and data costs are relatively fixed and will vary with such factors as task difficulty (computer time), study-area size, and the number of negatives and enlarged positives needed for visual interpretation.

Itemizing the costs for each technique used was

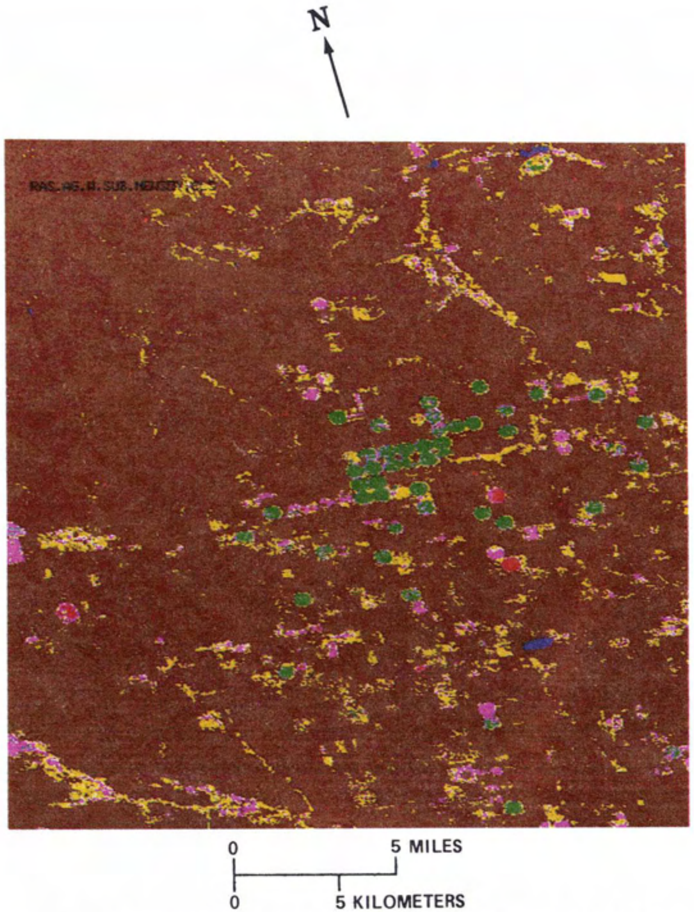

PLATE 2. Color print of the classified 512- by 512 pixel area in Todd County. The following classes can be identified by color: corn, olive, dryland farming, tan; alfalfa, red; rangeland, brown; open water, dark blue; soybeans, violet; and riparian vegetation, yellow.

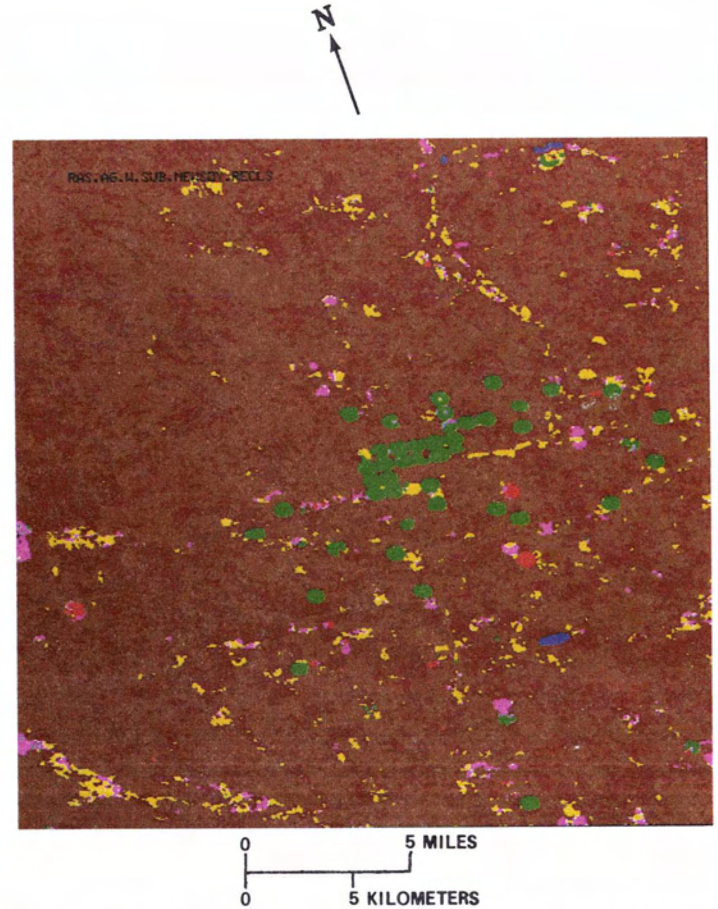

PLATE 3. Color print of the smoothed, classified, 512- by 512-pixel area in Todd County. The following classes can be identified by color: corn, olive; dryland farming, tan; alfalfa, red; rangeland, brown; open water, dark blue; soybeans, violet; and riparian vegetation, yellow.

TABLE 3. GENERAL PROJECT COSTS INCURRED FOR THE REMOTE-SENSING ANALYSIS OF LANDSAT DATA
[COSTS ARE FIGURED IN 1981 DOLLARS; CPU, COMPUTER-PROCESSING UNITS; SRU, SYSTEM-RESOURCE UNITS]

Item	Description	(Costs rounded off)
Computer costs: CPU time	73,506 seconds at $0.005 per second	$368
SRU time	4,922 minutes at $10.00 per hour	820
Computer-operator costs	100 hours at $6.50 per hour	650
Data costs:		
a. Computer-compatible tapes	2 sets at $200.00 each	400
b. Photographic negatives and positives:		
1. Black-and-white processing	2 at $11.00 each	22
2. Color processing	2 at $15.00 each	30
c. Overlay material: (mylar, and so forth)		50
Investigator costs	300 hours at $13.00 per hour	3,900
Travel costs: (to and from the nearest processing facility)		
a. Transportation	Rapid City, South Dakota, to Denver, Colorado	101
b. Meals and lodging	5 days at $57.00 per day	285
	Total	$6,626

not possible because the computer time was billed as a total amount. An estimate of time for each technique is (1) determining ratios, logarithmically stretching, and classifying the images (estimated cost is about $2,300 for two scenes)—one-third computer, computer-operator, and investigator costs; (2) unsupervised-supervised classifying and statistically analyzing the images (estimated cost is about $3,300 for two scenes)—one-half the computer, computer-operator, and investigator costs; (3) start up, general investigation, visual interpretation of false-color, infrared composite images, and single-band classification of images (estimated cost is about $1,400 for two scenes)—one-sixth the computer, computer-operator, and investigator costs.

SUMMARY AND CONCLUSIONS

Computer-image processing and analysis and visual interpretations of Landsat imagery were used to identify crop types and to estimate crop acreages in the High Plains of South Dakota. Landsat imagery for 1978 was used because of the availability of yearly and cyclic (9- to 18-day) coverage, multispectral format (four multispectral scanner bands), digital and printed data form, regional scale, reasonable cost, and availability of cloud-free data.

Four techniques were evaluated: (1) Visual interpretation of false-color infrared composite images; (2) density analysis and classification of single-band images; (3) ratio cutoff and classification of logarithmically stretch images based on the band 7/band 5 ratio; and (4) combined unsupervised and supervised classifications of multiple-band images. In addition, smoothing functions were applied to the unsupervised-supervised classifications to decrease the number of mixed-class pixels. Photographic prints of the digital classifications were usually interpreted to improve crop-type identification and crop-acreage estimates.

Visual interpretations of false-color composite images and single-band density-sliced classifications could not be used to produce accurate enough results for crop-type analysis. Visual interpretations of ratio-cutoff classifications of logarithmically stretched images based on the band 7/band 5 ratio, and manual interpretations of smoothed unsupervised-supervised classifications of multiple-band images produced the best identification of crop type and estimates of crop acreages. The logarithmic-stretch technique was the most economical; the unsupervised-supervised smoothing technique was most accurate.

A multitemporal approach is needed for identifying crop types. Irrigated alfalfa was best identified and mapped using May imagery; irrigated corn and soybeans were best identified and mapped using August imagery.

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