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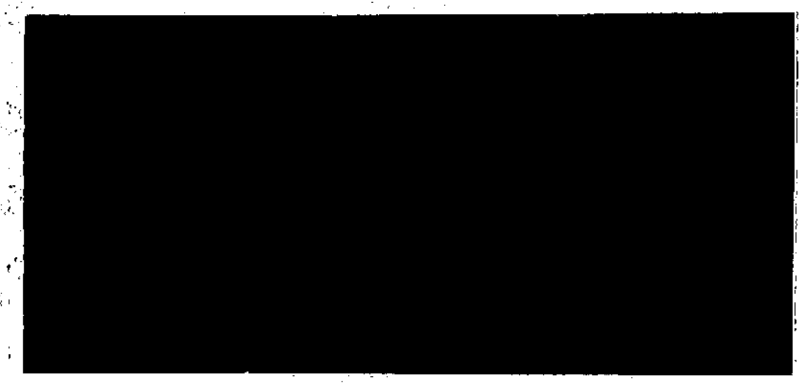

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KANSAS ENVIRONMENTAL AND RESOURCE STUDY: A GREAT PLAINS MODEL

FEBRUARY 1974

Type III Final Report for the Period
August 1, 1972 - February 12, 1974

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Contract No. NAS 5-21822, Task 4



THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2385 Irving Hill Rd.—Campus West Lawrence, Kansas 66044

I

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16. Abstract

Wheat area, yield and production statistics as derived from satellite image analysis, combined with a weather model, are presented for a ten county area in southwest Kansas. The data (representing the 1972-73 crop year) are compared for accuracy against both the SRS August estimate and its final (official) tabulation. The area estimates from imagery for both dryland and irrigated winter wheat were within 5% of the official figures for the same area, and predated them by almost one year. Yield on dryland wheat was estimated by the Thompson weather model to within 0.1% of the observed yield. A combined irrigated and dryland wheat production estimate for the ten county area was completed in July, 1973 and was within 1% of the production reported by SRS in February, 1974.

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# KANSAS ENVIRONMENTAL AND RESOURCE STUDY: A GREAT PLAINS MODEL

Extraction of Agricultural Statistics from
ERTS-1 Data of Kansas

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III

Type III Final Report

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Principal Investigator: Stanley A. Morain

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# PREFACE

This document presents the results of research to ascertain the utility of ERTS data for large area crop inventory. It is supported by two published articles in the March and December Symposia on significant results from ERTS sponsored by Goodard Space Flight Center. Appendices of selected ancillary research are also included along with a handbook for interpreting winter wheat from ERTS-1 data. Some of these appendices have been previously entered into the NTIS document series. The present document is, therefore, a summary of foregoing material and a presentation of the latest results. Further work has been propsed for the ERTS-B program.

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# 1.0 INTRODUCTION

## 1.1 Project History and Justification

Recent events in international politics have had great impact on the economy of U. S. agriculture. The "new" agricultural economics has focused attention on the need for rapid and timely estimates of crop acreage, yield, and general crop condition. Increasing world demand for U. S. agricultural products, coupled with increasing domestic demand, requires the development of means for assessing the status of major crops over large geographic areas at several points in the growing season. Even though present crop reporting methods are reliable for U. S. agriculture, a major shortcoming for efficient planning is the time lag between collection and dissemination of statistics. Techniques that can reduce the time lag in normal crop reporting procedures will undoubtedly have an impact on American agriculture. Similarly, any technique that will improve timeliness and accuracy of information on foreign agricultural production will benefit American agricultural policy makers.

Early reports of remote sensing in agriculture indicated that, within certain limits, crop types could be identified and inventoried. The limits on this capability are directly related to the spectral properties of the crops, the particular combination of crops grown in a given region, the sizes and shapes of the fields in which they are grown, and the pattern of individual crop phenologies. Much effort has been spent in the past decade to reliably identify and inventory U. S. agricultural regions with only modest success beyond the separation of major landscape elements now referred to as "level 1" in USGS circular 671.

In an effort to assess the ERTS-1 system as a means for crop acreage and production inventories this project was designed in such a way as to minimize the confusing relationships listed above, and to concentrate the research effort on wheat. An area was selected in the winter wheat belt of Western Kansas expressly because: 1) field sizes for all major crops tend to be large (40 acres, plus), so there would be no question of detectability on 1:1,000,000 bulk images; 2) the combination of crops is such that distinguishability between them is aided by their crop calendars; and 3) the spectral reflectivity of wheat results in strong and almost unambiguous responses in bands 5 and 7 from the MSS scanner.

## 1.2 Project Structure

The project was organized around a hierarchy of activities to lead logically toward a timely prediction of wheat acreage and total production. Table 1 describes the various phases of effort, including the type of input and output data and processing techniques employed. As a primary task the contract required an assessment of ERTS wheat inventory capability and the preparation of an interpretation handbook (given as Appendix B). We felt this could only be accomplished if our results could be compared to identical crop reporting units from USDA; consequently we focused attention on Finney County. Later we expanded the effort to include ten counties from the Southwest Crop Reporting District of Kansas.

Secondary, but no less important, tasks in the project dealt with the problems of sampling associated with variable cloud cover as observed every 18th day and the question of automatic classification. In addition to these contractual requirements a series of other reports have been prepared regarding various aspects of agriculture observable on ERTS bulk data. These are included as appendices C, D and E. Appendix F converts all text tables into metric units.

# 2.0 PROJECT METHODOLOGY

## 2.1 Primary Tasks

Acreage, and yield per acre, represent the two measuresrequired for a "crude" crop projection for any geographic area. We describe this as a crude projection because it does not consider differences in crop variety, protein content, crop lost during harvesting or refinements on the amount of grain actually delivered to storage bins. Nevertheless, by using ERTS as the data base, projections can be announced several months in advance of current, equally crude, projections announced by the crop reporting service (see Table 6 p. 13).

There are several advantages to visual interpretation from ERTS. First, with experienced interpreters who are familiar with the cultivation of winter wheat, the time involved for a complete enumeration of each county is on the order of one hour per 250 square kilometers. While this is considerably longer than would be required using a computer (assuming it could be trained to identify wheat) it is also much cheaper. Secondly, by visual analysis, we obtain a nearly complete enumeration

TABLE 1

PROJECT STRUCTURE AND FUNCTION

| | Input Data | Processing | Output Data |
|---|---|---|---|
| Phase 1 | 1. Ground truth, including soil maps and road transects and other available data<br>2. Aircraft underflight data including ASCS photography flown in 1971<br>3. ERTS-1 bulk transparencies | 1. Stratify study area into homogeneous land units<br>2. Using all input data learn to recognize wheat fields in each land unit<br>3. Compare measurement techniques | 1. Interpretation rules for wheat in terms of its ERTS tone rendition in each land unit |
| Phase 2 | 1. ERTS-1 bulk tranparencies | 1. Apply rules from output of Phase 1 to estimate acreage over entire study area | 1. Maps of wheat field locations<br>2. Calculation of wheat acreage |
| Phase 3 | 1. ERTS-1 bulk transparencies<br>2. Acreage estimate from phase 2 output<br>3. Weather history (precip. and temp.) | 1. Revise acreage estimate by comparing Winter with Spring images<br>2. Calculate yield/ac using weather model | 1. Calculate production for each county for comparison with USDA SRS figures<br>2. Prepare interpretation handbook and write report |

of the crop and learn how its spectral properties vary geographically and temporally. Thirdly, because we identify and locate each field early in the crop cycle, the need for ground truth and aircraft data diminishes through time and allows us to concentrate those activities in areas where spectral anomalies (disease, stress) begin to appear.

### 2.1.1 Wheat Acreage Estimate

A report on our technique for estimating winter wheat acreage in southwest Kansas was published in the Goddard Symposium on Significant Results using ERTS Imagery (Williams, et. al, 1973). In this document (included as Appendix A in this report), a procedure for visually detecting and enumerating wheat fields on ERTS imagey is described.

Basically the technique requires the interpreter to:

1) delineate county boundaries on the imagery:
2) recognize and delineate agricultural subregions within each county on the basis of differences observed in the imagery (the boundaries of many of these subregions will cut across county boundaries;
3) compare the results of step 2 with soil and landform maps (for those counties where they exist) in order to better estimate the importance of the crop in each land-use region;
4) learn to distinguish the image tones of wheat in fields 80 acres (approx. 32 ha) or larger from those of other important crops in the subregion and convert these into interpretation rules applicable to that subregion, and;
5) visually locate and estimate the acreage of wheat fields in each subregion using the interpretation rules developed in step 4. From the subregion totals a composite acreage is obtained for the entire project area.

By using the above procedure we have found through comparisons with ground truth and aircraft underflight data that 99 per cent of all the wheat fields and 99 per cent of the total acreage can be accurately estimated. Although the interpretation rules are created from grey tones of fields larger than 80 acres, the rules can be applied to all field sizes as small as 10 acres providing there is high tone contrast with their surroundings. An obvious advantage in the Winter Wheat Belt is that, once identified as wheat, the acreage of each field can be accurately estimated because field sizes, by the township and range system of survey, are characteristically 10, 40, 80, 120, 160 or 320 acres (4, 16, 32, 48, 64 or 128 hectares respectively).

Estimates of winter wheat acreage would not be possible without sequential ERTS data. The crop calendar for wheat is unique among those crops commonly grown in the Great Plains. It is planted in September or October depending upon weather conditions. By late November it is the only green crop in the agricultural scene and can be readily detected and enumerated on MSS Band 5 (the chlorophyll absorbtion band). It is significant that these circumstance coincide with the most cloud-free season of the year over this region. With a high probability for at least one cloud and snow-free image, a complete enumeration of wheat planted is virtually a *fait accompli*. In addition, by virtue of slight tonal variations at this time of year, we feel that it will be possible, given more detailed observation, to categorize differences in planting time and general wheat condition.

A second look at wheat is required during March or April in southwest Kansas. We used imagery from this time period to adjust the initial acreage estimate and to assess general wheat condition. This is necessary because a popular practice in western Kansas is to plant wheat as a winter forage and soil protection measure with no intention of later harvesting the crop. In spring the field is turned under to provide green manure and replanted to another crop. Such acreage must be subtracted from the initial estimate. A combination of the red and infrared bands is desired for these early spring observations.

A final ERTS observation is recommended during the harvest season. This is perhaps not as important at present as it could be in the future, after we learn to interpret and adjust estimates for crop loss due to disease, hail damage, etc. Individual fields can be turned under as late as June and still produce a cash crop. An estimate of wheat acreage actually harvested therefore is desirable. It is, of course, true that other crops, in addition to wheat, can be surveyed using the same set of above images. Alfalfa, for example, can be visually distinguished from wheat in May and early June on band 7 (see Appendix E ). At this time of year alfalfa is growing vigorously (bright on band 7) while wheat is drying for harvest (medium tone on bands 5 and 7).

### 2.1.2. Yield/Acre and Production Estimates

The model we have used for estimating average yield per acre was proposed by Thompson (1969). It is based on departure from average weather conditions. According to his results, highest yields in Kansas are associated with above normal precipitation from August through March (normally a total of 325 mm ). Each additional 25 mm at this time of year results in a gain of approximately 0.63 bushels per acre. High yields are also associated with above normal rainfall in April, normal rainfall in May and below normal rainfall in June. As a rule these months receive 88, 120 and 103 mm of moisture respectively. Finally, for optimal yields in Kansas, below normal temperatures during April, May and June are best. With these data, it is possible to calculate an expected yield per acre. A comparison of actual and calculated yields using this model is given in Figure 1.

Weather data suitable for use in the model are published by the U. S. Weather Bureau in its monthly climatological survey of each state. These data are published for each station and the stations are grouped into districts. The southwestern district in Kansas includes the ten counties surveyed in this report and mean weather conditions in that district were used in solving the equation developed by Thompson. The data and the equation are reproduced in Table 2.

## 2.2 Secondary Tasks

### 2.2.1. Automatic Classification

The interpretation rules developed for visual interpretation can be specified in a computer compatible form for rapid wheat acreage surveys. At present the technique is termed semi-automatic because both the pre- and post-processing time involve human activities. In broad outline the procedure requires the interpreter to:

1) specify the coordinates of subareas on the image which match county boundaries or other geographic localities. Care must be taken to specify the location of towns or other non-cropland sites in order to exclude these from later tabulations.

2) create a frequency histogram for the 128 "tones" on the data tape for each area specified in step 1.

3) divide the histogram into 15 levels (roughly equivalent to the 15 gray level steps found on each MSS image).

4) determine the total number of pixels contained within those gray levels that have been determined by visual analysis to closely correspond to wheat. Since each pixels is approximately equal in size to one acre(.4 ha), the number of cells is considered to be roughly equal to the wheat acreage.

FIGURE 1
ACTUAL AND CALCULATED YIELDS AND TREND OF WHEAT YIELD IN KANSAS (FROM THOMPSON, 1969)

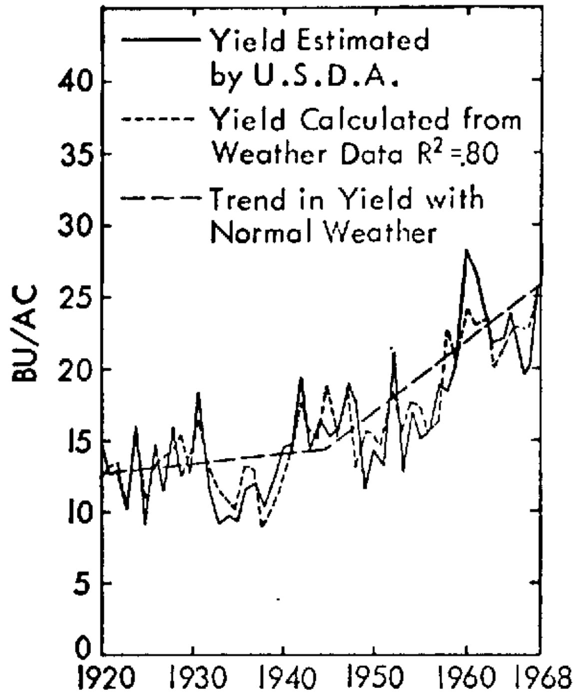



TABLE 2

YIELD/ACRE EQUATION AND APPLICABLE WEATHER DATA FOR THE 1972-73 GROWING SEASON IN SW KANSAS

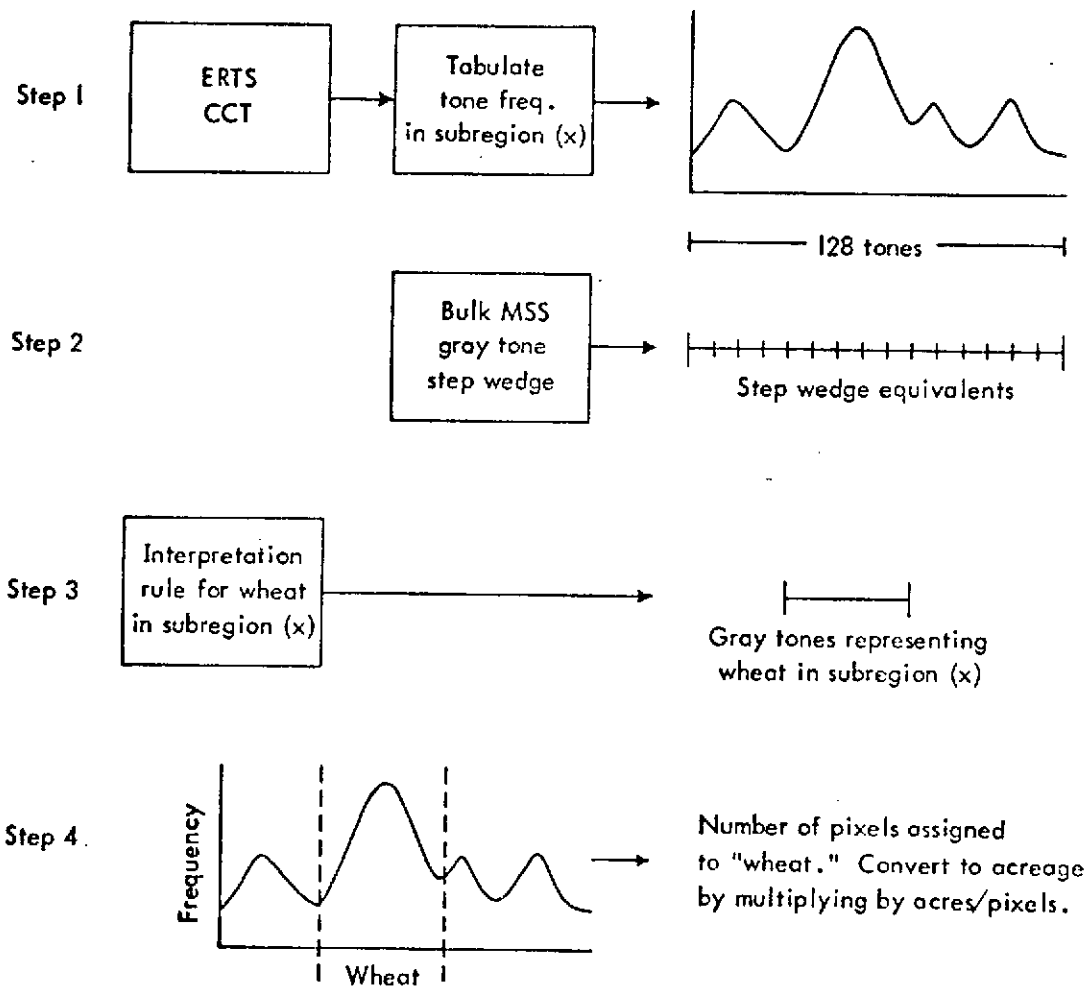
$$y = 12.215 + .066 + .498X_1 + .631X_2 + .223X_3 - .095X_4 + .191X_5 - .223X_6 - .327X_7 - .101X_8 \text{ where:}$$

| Value in 1972-73 | |
|---|---|
| 29.00 | $X_1$ = Technology factor measured in years since 1943 |
| 10.02 | $X_2$ = Departure from total precepitation from Aug. to March |
| .14 | $X_3$ = Departure from average April precipitation |
| -5.30 | $X_4$ = Departure from average April temperature |
| -1.87 | $X_5$ = Departure from average May precipitation |
| -2.90 | $X_6$ = Departure from average May temperature |
| -1.75 | $X_7$ = Departure from average June preciptation |
| - .50 | $X_8$ = Departure from average June temperature |

In diagrammatic form the procedure may be outlined as shown in Figure 2 below.

FIGURE 2

SCHEMATIC DIAGRAM FOR SEMI-AUTOMATIC IDENTIFICATION OF WHEAT



### 2.2.2 Sampling Strategy Around Clouds

Cloud cover may be partial or complete over an area of interest on the date most suited to interpretation. If the cloud cover is complete, imagery acquired on an alternative date must be selected for interpretation. However, if scattered clouds are present, the imagery may still be interpreted. This was done in Meade County, Kansas, where the Fall,1972 wheat planting was estimated at 151,000 acres. Scattered clouds and shadows covered 27.4 percent of the county on Sept. 21, 1972, when the data were acquired.

To accomodate this circumstance, the following techniques were employed:

1) tones were mapped in the cloud free areas by the methods already described;
2) a soil type map was prepared; and
3) a rangeland map was prepared from cloud free imagery.

Wheat acreage was estimated for the cloud free areas using the image tone map and the soil map for each soil type in each township.

The cloud covered areas were then considered. The cloud covered cropland acreage was calculated by subtracting any rangeland from the total cloud covered area. Adjacent cloud free cropland areas with the same soil type were tabulated, ensuring that the cloud free acreage was at least twice the cloud covered acreage. The percentage of land in wheat in the cloud free areas was then calculated and that percentage was applied to the cloud covered acreage to estimate the wheat acreage not directly visible.

To illustrate this method,consider the example of T.33S., R.27W. In this township 16 sections (square miles) were cloud covered. Inspection of the range map showed that five sections were in grassland and 11 sections were cropped. All cropland in this township and in the eastern half of T.33S., R.28W. was in a single soil association. A total of 24 sections of cloud free cropland were present in this area. These 24 sections were estimated to contain 5,930 acres of wheat, 39 percent of the area. Application of this percentage to the cloud covered area provided an estimate of 2,750 acres of wheat in those eleven sections. This technique was applied to each cloud covered area, resulting in the total acreage estimate mentioned earlier.

## 3.0 PROJECT RESULTS

### 3.1 Estimate of Winter Wheat Acreage and Production

Table 3 gives our estimate of wheat acreage for the ten county survey area (approximately 8,071 sq. miles or 21,000 km) and compares it with estimates prepared by the Statistical Reporting Service (SRS) of USDA. The ERTS estimate was prepared in March whereas the data available from SRS represent their May and August estimates of "harvestable" acreage. Final figures from SRS are given in Table 6 which shows that the final tally does not differ significantly from the original ERTS total. The March 73 ERTS acreage estimate is within 5 percent of the SRS official total (Table 6) which did not appear until February 1974.

TABLE 3
COMPARATIVE ESTIMATES OF 1973 WHEAT ACREAGE (AND YIELD IN BU/AC)
FOR TEN COUNTIES IN SW KANSAS
AS COMPILED BY USDA, SRS AND BY ANALYSIS OF ERTS IMAGERY
(See Appendix F Table 1 for data in metric units)

| County | SRS Acreage Est. May 1973 | SRS Acreage Est. Aug. 1973 | SRS Ave. Yield | ERTS Acreage Est. March 1973 | |
|---|---|---|---|---|---|
| Finney | 205,000 | 198,000 | (37) | 239,000 | |
| Grant | 81,000 | 87,000 | (34) | 74,000 | |
| Gray | 157,000 | 162,000 | (36) | 174,000 | |
| Haskell | 104,000 | 109,000 | (43) | 110,000 | |
| Kearney | 117,000 | 119,000 | (31) | 115,000 | |
| Meade | 141,000 | 132,000 | (36) | 151,000 | |
| Morton | 91,000 | 97,000 | (24) | 72,000 | |
| Seward | 83,000 | 80,000 | (36) | 78,000 | |
| Stanton | 135,000 | 132,000 | (24) | 108,000 | |
| Stevens | 85,000 | 87,000 | (31) | 86,000 | |
| Totals | 1,199,000 | 1,202,000 | (33.2 ave.) | 1,207,000 | (34) |

Also shown in Table 3, in parentheses, are the SRS projected average yields per acre, for August, for each of the ten counties. Our estimate for the entire area, as calculated by the Thompson model, is given in parentheses in the row of totals. These values have been combined into a matrix as shown in Table 4. The upper left cell represents the total crude production that would be obtained using the traditional, time-tested techniques and an average of 33.2 bushels/ac. The lower right cell gives the expected production using ERTS imagery and the methodology reported in this paper. The ERTS estimate of total wheat bushels is 2.8 per cent higher than the SRS estimate. It predates the SRS estimate by about two months, and their official, tally by 9 months.

The above results include several points that need amplication. One could argue, first, that if the ERTS acreage estimate is based on a total enumeration of fields instead of a sample, as normally employed by SRS, and that, further if SRS has a more sophisticated technique for calculating average yield per acre than that proposed by Thompson, the combination of these two values might give an even better estimated production. This value is presented in the lower left cell of Table 4 and is approximately 3.1 per cent higher than the SRS tally.

A second argument concerns the complex economics of irrigated wheat and wheat planted as winter forage. Irrigation by center pivot methods is increasing rapidly on the lighter textured soils of the southwest (see Appendix D). In past years many irrigated fields have been planted to wheat as a winter cover crop and replanted in spring to feed grains. However, the recent high price of wheat, combined with the prospect for continued international wheat trading and low domestic reserves has stimulated growers to harvest wheat that would otherwise have been turned under. Yields on irrigated wheat fields in 1973 are estimated on the basis of past performance of 53 bushels/acre. We estimate from ERTS imagery that in 1973 174,000 acres of harvestable wheat were irrigated in the project area. Using these inputs we increased the original production estimate, as shown in Table 5, to 44.344 million bushels, or 17 per cent higher than the August SRS estimate. The final figures by SRS reveal that this refinement is reasonable, at least in terms of acreage. No distinction is made between irrigated and dryland wheat in the SRS August estimate but such distinction is made in the final February data. Our ERTS derived estimate for harvestable irrigated wheat in 1973 is reasonable by comparison to the official tally (Table 6), although we seriously overestimated the yield/ac on irrigated fields.

## TABLE 4
## MATRIX OF TOTAL ESTIMATED PRODUCTION COMPARING SRS AND ERTS DATA

(See Appendix F Table 2 for data in metric units)

Average Yield/Acre

| Harvestable Acreage | SRS (33.2 bu/ac) as of 8/73 | ERTS (34 bu/ac) as of 6/73 |
|---|---|---|
| SRS ($1.202 \times 10^6$) as of 8/73 | $39.906 \times 10^6$bu | $40.848 \times 10^6$bu |
| ERTS ($1.207 \times 10^6$) as of 3/73 | $41.193 \times 10^6$bu | $41.038 \times 10^6$bu |

## TABLE 5
## REVISED PRODUCTION ESTIMATE FROM ERTS TO INCLUDE IRRIGATED ACREAGE

(See Appendix F Table 2 for data in metric units)

| Type | Acres ($\times 10^3$) | Ave. Yield (Bu/Ac) | Total Yield ($\times 10^6$ Bu) |
|---|---|---|---|
| Irrigated | 174 | 53 | 9.222 |
| Dryland | 1,033 | 34 | 35.122 |
| Totals | 1,207 | - | 44.344 |

## TABLE 6
## COMPARISON OF ERTS AND "OFFICIAL" VALUES FOR WHEAT ACREAGE, YIELD PER ACRE, AND PRODUCTION FOR 10 COUNTIES IN SOUTHWEST KANSAS

(See Appendix F Table 2 for data in metric units)

### WHEAT ACREAGE

| Date of Estimate | Source | Value | |
|---|---|---|---|
| March 1973 | ERTS-1 Analysis | $1.207 \times 10^6$ | |
| | | | 95.3% |
| February 1974 | SRS (official, harvested) | $1.266 \times 10^6$ | |
| | | | 94.9% |
| August 1973 | SRS (estimate, harvestable) | $1.202 \times 10^6$ | |

### AVERAGE YIELD/ACRE

| Date of Estimate | Source | Value | |
|---|---|---|---|
| July 1973 | Weather model | 34 bu/ac | |
| | | | 99.9% |
| February 1974 | SRS (official) | 34.01 bu/ac | |
| | | | 97.6% |
| August 1973 | SRS (estimate) | 33.2 bu/ac | |

### TOTAL PRODUCTION

| Date of Estimate | Source | Million Bushels | | |
|---|---|---|---|---|
| July 1973 | ERTS-1 plus weather model | non-irrig. | 35.122 | |
| | | irrig. | 9.222 | |
| | | | 44.344 | |
| | | | | 97.1% |
| February 1974 | SRS (official) | non-irrig. | 35.265 | |
| | | irrig. | 7.799 | |
| | | | 43.064 | |
| | | | | 92.6% |
| August 1973 | SRS (estimate) | undiff. | 39.906 | |

### 3.2 Automatic Interpretation

An estimate from this procedure (see section 2.2.1) for an 840 sq. miles (2,184 sq. km) area in Finney and Gray Counties totaled 165,000 acres. The same area, by visual tabulation, contained 162,000 acres. Although the time required for the semi-automatic approach was about half (10 hrs vs. 5 hrs), the cost was almost four times ($30 vs. $120). At present we do not consider these differences tobe meaningful because of the research environment under which they all were derived. Our two strongest views at this stage are that:

1) we see no way of entirely eliminating the pre-processing, human time required for crop surveys, because there are too many decisions and "bookkeeping" operations involved in a reliable inventory, and;
2) we may require a visual analysis in any case so that we can locate and monitor individual fields for stress, etc.

### 3.3 Other Interpretation Results

In process of fulfilling contractual requirements other interpretations had to be performed. The crux of the procedure itself required the establishment of agricultural regions for Kansas based on their ERTS appearance. Irrigated acreage requirements led logically to a consideration of center pivot irrigation systems. Lastly, it was necessary to distinguish crops other than wheat, especially those most easily confused with wheat. Details on these ancillary interpretations are given in Appendices C, D and E respectively.

## 4.0 APPENDICES

A. Identification of Winter Wheat
B. Interpretation Handbook for Winter Wheat
C. Land-Use Map of Kansas
D. Interpretation of Center Pivot Irrigation
E. Discrimination of Alfalfa
F. Text Tables Converted into Metric Units

## APPENDIX A

# IDENTIFICATION OF WINTER WHEAT FROM ERTS-1 IMAGERY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ABSTRACT: Continuing interpretation of the test area in Finney County, Kansas, has revealed that winter wheat can be successfully identified. This successful identification is based on human recognition of tonal signatures on MSS images. Several different but highly successful interpretation strategies have been employed. These strategies involve the use of both spectral and temporal inputs. Good results have been obtained from a single MSS-5 image acquired at a critical time in the crop cycle (planting). On a test sample of 54,612 acres (22,101 hectares), 89 percent of the acreage was correctly classified as wheat or non-wheat and the estimated wheat acreage (19,516 acres, 7,898 ha.) was 99 percent of the actual acreage of wheat in the sample area.


**********

Continuing interpretation of ERTS-1 MSS images of Finney County, Kansas, has established that hard red winter wheat may be successfully distinguished from all other crops and cropping conditions by a simple human interpretation technique. This technique was initially developed for irrigated wheat, but has proven applicable to non-irrigated wheat as well. On a test sample of 54,612 acres (22,101 hectares) for which surface observations were available, 89 percent of the acreage was correctly classified as wheat or non-wheat. The error terms conformed to the Central Limit Theorem. The estimate of wheat in this test was 19,516 acres (7,898 ha.), 99 percent of the actual amount of wheat (19,674 A., 7,962 ha.) in the sample. This estimate was based on a single band/time-frame image, MSS-5, acquired September 21 and September 22, 1972. The estimate is therefore based on imagery acquired during the planting period.

The sample analyzed for this report represents 6.5 percent of the land area of Finney County and includes all environmental and agricultural types in the county except for the intensive irrigation area in the northwestern part of the county, where wheat is not a significant component of the landscape. Finney County (Figure 1) was originally selected as a test area because of the magnitude and diversity of agriculture in the county. Most of the 1308 square mile (3,388 sq. km.) area is typical of the large field agricultural system of the winter wheat belt of the Great Plains. However, large areas of rangeland exist in the county and extensive and intensive irrigation is widely practiced. The single most important crop in the county is wheat. In 1971, Finney County ranked third among Kansas counties with wheat production of 6,921,000 bushels (188,326 metric tons). In the same year, the county was among the ten most productive counties in Kansas for sorghum for grain, corn for grain, corn for silage, alfalfa hay, and sugar beets while ranking seventh in number of cattle on farms (Kansas State Board of Agriculture, 1972).

Five sample areas were selected in Finney County in such a way that the areas are readily located on ERTS-1 imagery and all environmental and agricultural types in the county have been included. Surface observations of crop type and condition have been obtained for each field in these test areas. Environmental parameters, principally soil type and topography, have been obtained from the standard soil survey map (USDA, Soil Conservation Service, 1965) and available topographic maps.

Four of the five sample areas were used in this analysis (Figure 1). The fifth sample is located in the small field irrigated area of northwestern Finney County and contains a limited amount of wheat. Samples 1 and 2 represent the part of the county with sandy soils. Most of this area is composed of large irrigated fields. Samples 3A and 3B represent the area with nearly level loamy soils. Most of this area is composed of large non-irrigated fields. Sample 4A represents the area of rolling lands with mostly loamy soils. All cultivation in this area is large-field dryland. Sample 4B represents the area of nearly level clayey soils. Most of this area is large-field dryland cultivation.

To obtain ERTS-1 data for analysis of these samples, a simple human image interpretation technique was employed. The gray scale tablet along the bottom of the image was divided into five steps which the three interpreters, Williams, Coiner and Barker, agreed were distinct and detectable in the image context (Figure 2). A map showing field boundaries and field numbers for each sample area had been previously prepared. The interpreter recorded the apparent tone of each field as perceived by comparison to gray scale tablet. All interpretations were replicated, by all three interpreters in most instances. However, Williams performed the data analysis. To avoid possible bias, after he began the analysis for a given sample area, he took no further image data for that area.

The initial wheat detection experiment was designed on a multi-image basis (Williams, et al, 1973). Tonal data had been taken from four images for sample areas 1 and 2. These images were MSS-5 acquired August 16, September 21, and December 2, and MSS-7 acquired December 2. A decision matrix (scattergram) was constructed for the data from sample area 1 and a wheat/non-wheat boundary was drawn through the decision matrix. This boundary resulted in 93 percent separation of wheat fields from non-wheat fields. Due to partially offsetting errors, the estimated number of wheat fields (47) was 98 percent of the actual number. When this decision boundary was applied to the data from sample area 2, 86 percent of the fields were correctly classified and the estimated number of wheat fields (14) equaled the actual number. However, the method (1) did not appear applicable to the data from Sample Area 4, (2) was cumbersome, and (3) seemed unsuitable for application to large areas. Further analysis of the decision matrix revealed that the MSS-7 image had not contributed to the successful discrimination of any field.

This fact led to the concept of monitoring temporal change as a method of identification. The MSS-5 image acquired December 21, 1972, was added to the data set at this time. Although this method of observing tonal change through time also successfully discriminated wheat, the method was plagued by the same shortcomings as the other multi-image approach.

While the temporal change analysis was in progress, further study of the original decision matrix revealed that most of the wheat/non-wheat separation had been due to a single image, MSS-5 acquired September 21, 1972. Part of the county was cloud covered on that date. However, all cloud covered sample areas were clear on September 22. The cloud free coverage for each test area was used for the interpretation.

The hypothesis under which any binary discrimination is achieved is that the two conditions are more or less distinct in the data space (Figure 3). In the case under consideration, the hypothesis is that wheat fields have lighter tones than non-wheat fields. This conclusion may be confirmed by inspection of the graphs in Figure 3. However, the significant degree of overlap in tone level 3 is obvious. This overlap constitutes a serious error if the tone is assigend to either wheat or non-wheat.

Inspection of the data subdivided according to environmental area (Figure 4) reveals that this serious overlap does not exist in the individual areas. Instead, most fields assigned to tone level 3 are wheat in sample areas 1, 2, and 4B, while most fields assigned to tone level 3 are non-wheat in sample areas 3 and 4A. That is, error is spatially distributed as a function of the spatial distribution of environmental variables.

Based on these spatial results, the following optimum rule for wheat incentification in Finney County, Kansas, was devised: on MSS-5 imagery acquired during the wheat planting period in 1972, all fields with light and medium tones (tone levels 1, 2, and 3 on sandy soils and nearly level clays are wheat and all fields with light tones on nearly level to rolling loamy soils are wheat.

This rule was initially developed for and applied to all fields 80 acres (32 ha.) or larger, because these fields were consistently detectable as discrete entities in the image. The four sample areas contained 377 fields 80 acres or greater in size. These 377 fields contained 54,612 acres (22,101 ha.), for an average size of 145 acres (59 ha.). The accuracies (Table 1) of classification and estimation of wheat were identical for both number of fields and acreage. Eighty-nine percent of all fields and acreages were correctly classified as wheat or non-wheat. The estimated number and acreage of wheat fields was 99 percent of the actual number and acreage. Use of a single classification rule for all sample areas results in slightly decreased accuracy of classification and serious errors in the estimation of wheat acreage. For example, if only fields having tones 1 and 2 are assigned to wheat, the accuracy of the classification is 86 percent but wheat acreage is underestimated by 26 percent. On the other hand, if all fields having tones 1, 2 and 3 are assigned to wheat, the classification accuracy drops to 82 percent and wheat acreage is overestimated by 35 percent.

Fields smaller than 80 acres had been omitted from the initial analysis because (1) they were often hard to separate from adjacent fields, and (2) most of the resolution cells contain boundaries and are, therefore, averages of often disparate tones. However, tones were also assigned for smaller fields in areas 1, 2, and 3A. These areas contained 202 large and 78 small fields. The large fields contained 23,896 acres (9,670 ha.). This acreage was classified with 91 percent accuracy and the wheat acreage estimate was 100 percent correct. The 78 small fields contained only 2,925 acres (1184 ha.). Only 74 percent of this acreage was correctly classified and wheat acreage was overestimated by 13 percent. But when this modest acreage was added to that of the large fields, the resulting acreage classification was still 89 percent accurate and the overestimation of wheat acreage was 2 percent.

Although temporal data were not required for the identification of winter wheat, these data may serve two important roles. The estimates of wheat acreage presented here are estimates of acreage planted and are, therefore, significantly larger than the acreage harvested. In the fall of 1970, 192,000 acres (77,702 ha.) were seeded in Finney County. In June 1971, 189,000 acres (76,488 ha.) were harvested. Although this difference was small, the amount of wheat destroyed is quite variable from year to year and must be removed from the original acreage estimate. Furthermore, temporal data may provide information on the state of the crop. For example, tones of wheat fields are highly variable on MSS-5 images acquired in December. This variability is an indication of the degree of fall growth, which varies greatly from one field to another. This tonal variability makes identification of wheat very difficult, but, if a field has already been identified as wheat, the variability provides useful data on the state of the crop in that field.

The results presented here demonstrate that a simple method for winter wheat identification may be developed given an adequate prior knowledge of local environment and crop cycle. The method appears to be applicable to other crops if suitable distinct crop cycle events may be defined. Knowledge of the local environment is critical if the interpretation is to be successfully conducted. Components of the local environment data set can be taken directly from the ERTS-1 imagery (Williams and Coiner, 1973) but other components are best developed at the local level. Furthermore, surface observations for a small number of fields from each environmental area would be a necessity. The necessity for (1) surface observation, (2) knowledge of the local environment, (3) knowledge of local crop cycles, and (4) the modest amount of equipment and training required to perform these interpretations make this method suitable for implementation at the local (county) level.

REFERENCES:

ERTS-1 Imagery

| DATE | FRAME NUMBER | SCALE | QUALITY |
|---|---|---|---|
| 8-16-72 | 1024-16511-5 | 1:1,000,000 | Excellent |
| 9-21-72 | 1060-16512-5 | 1:1,000,000 | Good, partial haze cover |
| 9-22-72 | 1061-16564-5 | 1:3,300,000 | Good |
| 9-22-72 | 1061-16570-5 | 1:3,300,000 | Good |
| 12-2-72 | 1132-16514-5 | 1:1,000,000 | Good |
| 12-2-72 | 1132-16514-7 | 1:1,000,000 | Good |
| 12-21-72 | 1151-16572-5 | 1:1,000,000 | Good |
| 12-21-72 | 1151-16575-5 | 1:1,000,000 | Good |

Reports:

Kansas State Board of Agriculture. 1972. Farm Facts, 1971-1972. Topeka, Kansas: Kansas State Printer.

U.S.D.A., Soil Conservation Service. 1965. Soil Survey, Finney County, Kansas. Washington: Government Printing Office.

Williams, Donald L., and Jerry C. Coiner. 1973. Land Use Map, Finney County, Kansas. Center for Research, Inc. CRINC - DIIR 2264-3.

Williams, Donald L., Bonnie Barker, and Jerry C. Coiner. 1973. Discrimination of winter wheat on irrigated land in southern Finney County, Kansas. Center for Research, Inc. CRINC - DIIR 2264-4

TABLE 1: Contigency table for discrimination of wheat from non-wheat fields $\geq 80$ acres, all test areas, Finney County, Kansas, September 21, 22, 1972.

Rule: Field is wheat (areas 1, 2, 4B) if tone is $\leq 3$
Field is wheat (areas 3, 4A) if tone is $\leq 2$

| | Number of fields assigned | | Acres assigned | |
|---|---|---|---|---|
| | wheat | non-wheat | wheat | non-wheat |
| Actual wheat | 140 | 22 | 16,710 | 2,964 |
| Actual non-wheat | 20 | 195 | 2,806 | 32,132 |

Total = 377 fields
Accuracy of Assignment = 89%
Accuracy of estimation wheat = 99%

Total = 54,612 acres
Accuracy of Assignment = 89%
Accuracy of estimation of wheat acreage = 99%

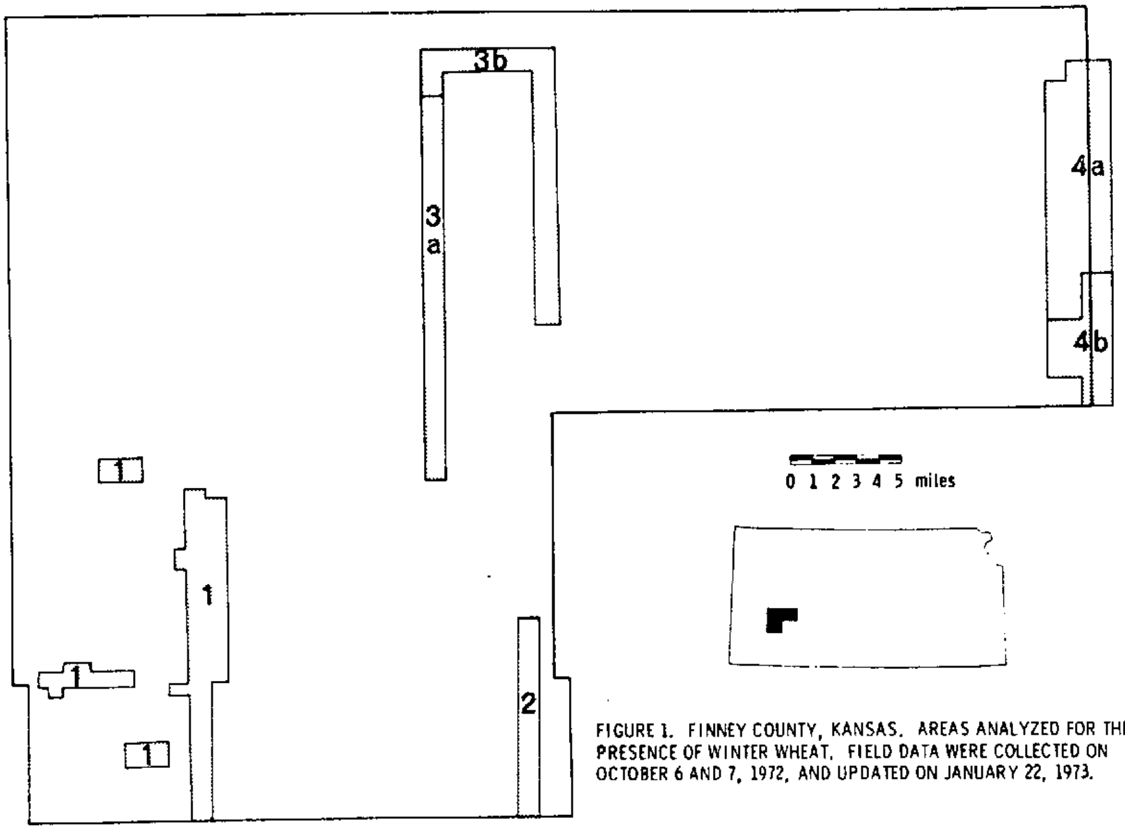
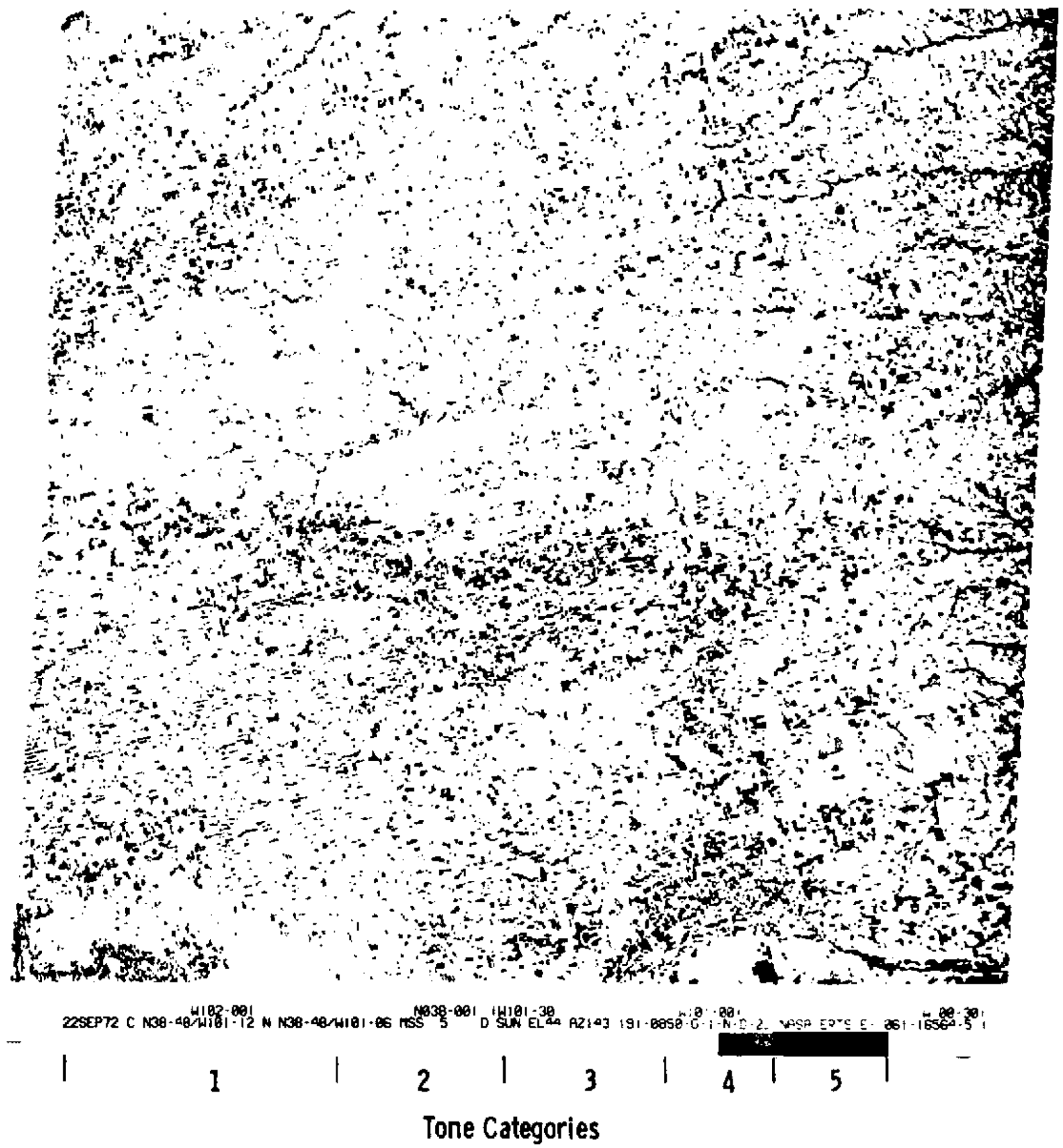



FIGURE 1. FINNEY COUNTY, KANSAS. AREAS ANALYZED FOR THE PRESENCE OF WINTER WHEAT. FIELD DATA WERE COLLECTED ON OCTOBER 6 AND 7, 1972, AND UPDATED ON JANUARY 22, 1973.

Figure 2. ERTS-1 MSS-5 image acquired September 22, 1972. Part of Finney County, Kansas, is in the southeast corner of this image.



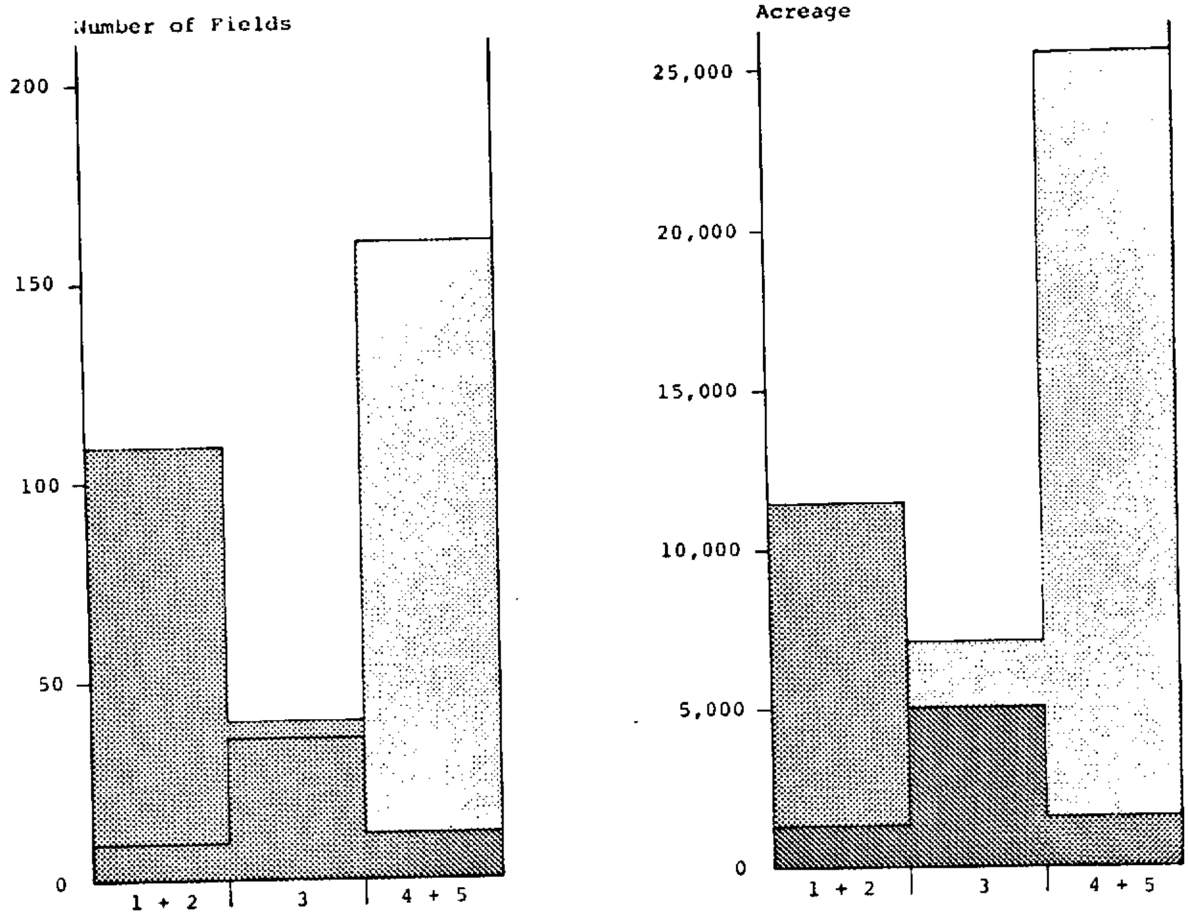



Figure 3. Frequency with which MSS-5 image tones were associated with wheat and non-wheat field conditions in Finney County, Kansas, September 21 and 22, 1972.

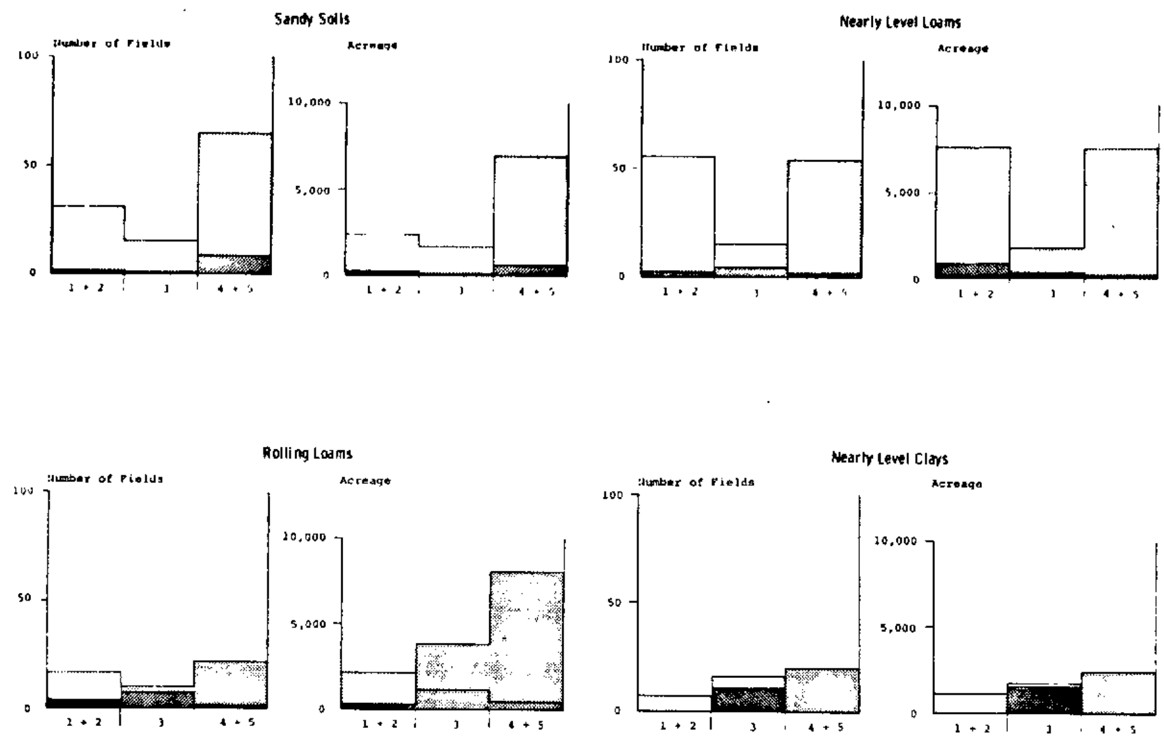



Figure 4. Frequency with which MSS-5 image tones were associated with wheat and non-wheat field conditions in Finney County, Kansas, September 21 and 22, 1972, as a function of soil and landform types.

# APPENDIX B

## INTERPRETATION HANDBOOK FOR WINTER WHEAT

Donald L. Williams

This handbook outlines a step-by-step procedure for human interpretation of ERTS-1 MSS imagery for the estimation of wheat acreage. The procedure relies upon selection of proper images and the employment of simple tone recognition from these images. A single properly selected image is sufficient for the interpretation, although introduction of temporal data greatly improves the final estimate.

The technique relies heavily upon the interpreter's knowledge of the crop cycle and the behavior of non-crop-related phenomena in the landscape. The technique was successfully applied to a variety of landscapes in southwestern Kansas, all within the winter wheat belt. IT SHOULD BE APPLICABLE THROUGHOUT THE WINTER WHEAT BELT. However, it may not be applicable outside this area because fall identification of planting relies on bare soil detection and the almost perfect correlation between bare soil in late September or October and wheat plantings. In moister environments, where winter moisture conservation is less important and dust storm hazards are lower, some fields may be maintained without vegetative cover throughout the winter. Planting period estimates in moister regions would therefore be too large. However, spring estimates would still be reasonably accurate.

This technique is designed to rapidly provide an estimate of wheat acreage over large areas. It is not necessarily accurate for the identification of wheat in any given field. Accuracy of assignment of any individual field should not be expected to exceed 90 percent. Assignment errors cancel to produce the accurate estimates over large areas obtained by this technique.

## SELECTION OF IMAGERY

This interpretation uses MSS-5 images. Although MSS-4 images contain essentially the same information, reduced contrast and sharpness from atmospheric attenuation make images of this band less useful for wheat identification. The infrared band (MSS-6 and 7) provide some supplementary data but are inadequate for the first round of interpretation.

The first image should be selected to coincide with the wheat planting period. This period is normally between September 15 and October 15 in southwestern Kansas. Slightly later date images are acceptable but earlier date images are not because seedbed preparation occurs only immediately before planting and irrigated double cropping will not be detected.

The second image should be late enough in the spring for acreage conversion to have been completed and for adequate sun angles to have developed, but early enough to prevent confusion with spring crops. Images acquired during May satisfy these criteria in southwestern Kansas.

## INTERPRETATION EQUIPMENT

Two interpretation devices are key to this project; a light table with good magnifying optics and a Zoom Transfer Scope (or equivalent instrument). Although the Zoom Transfer Scope (ZTS) may be used alone, some loss of accuracy in tone assignment results. The use of the ZTS is in accurate location and mapping of fields and, therefore, determination of acreage. A small light table with optics magnifying up to 10X permits accurate assignment of image tones.

## INTERPRETATION TECHNIQUE

The steps of the technique for estimating wheat acreage are discussed below and illustrated in figures 1,2 which illustrate the interpretation of one 36 mi$^2$ area, T.22S., R.31W., Finney County, Kansas.

1. Pre-interpretation Phase. Several preparatory steps are required in the pre-interpretation phase. Several land uses may be rather consistently confused with wheat. To ensure exclusion of thes land-use areas, a map showing all rangelan, pasture, hay fields, alfalfa fields, wasteland and urban areas should be prepared at the desired working scale. A scale of 1:63,360 (1 in = 1 mi) was found to be quite satisfactory. This map may be easily prepared from recent USDA aerial photographs by conventional photo interpretation techniques. The map may be up-dated from MSS images acquired at suitable times (midsummer for grasslands and urban areas (MSS-5) and May for alfalfa (MSS-7). Figure 1 shows the map of lands excluded from the

example township. Employment of this map as a plotting base substantially speeds the interpretation since tonal assignments need not be made in the excluded lands. In most southwest Kansas counties these amount to more than 30 percent of the area.

Since reflectance varies as a function of soil and terrain, a map showing these features should also be prepared. Three categories are important in southwestern Kansas; loamy soils, sandy soils, and clay soils. Reference to these classes is necessary during the fall image typing phase. This map may be combined with the excluded lands map but is not illustrated for the sample township, which happens to lie entirely in an area of loamy soils.

2. <u>Preparation of tone map.</u> A cloudfree image (Fig. 2) was obtained September 22, 1972, within the time-frame specified earlier. Five tone classes which were distinct to the interpreter were specified by reference to the gray scale step tablet printed along the bottom of the positive film transparency(Fig. 3). A ZTS was used to transfer field boundaries and tones to a map. The image was then transferred to a light table and the tone assignments were verified.

Perception of tones in the image context vary slightly from one interpreter to another. However, this poses no problem if each interpreter works a specified area and the wheat identification rules are established on the basis of surface observations within each interpreter's area of responsibility. Furthermore, two advantages accrue to permanent assignment of an area to an interpreter. Location of political boundaries is difficult on an ERTS image. As an interpreter works with an area, he becomes familiar with a large number of landmarks (rivers, road curves, peculiarly shaped fields, towns, etc.) which permit him to rapidly and accurately locate areas of interest. Since the interpreter can specialize in an area, he can become extremely familiar with that area, learning the crop cycle, the nature of farming practices , and other aspects of the area which facilitate quality interpretation. An example may be appropriate. On September 20, 1972, a heavy rain fell on part of Kearney and Finney Counties, Kansas. This resulted in general darkening of tone in that area when ERTS imaged the area on September 22. Had the interpreter been unaware of what tones to expect, he might have failed to delimit this darkened area, where a special wheat identification rule was required.

3. <u>Establishment of identification rule.</u> Surface observations were obtained October 9, 1972, for part of this township (Fig. 4). Comparison of tones with the surface observations in this and other areas led to establishment of the following rule. If the field tone is medium gray or lighter ($\leq 3$ on a scale of 1 = lightest, 5 = darkest), the field contains wheat.

4. <u>Estimation of wheat acreage.</u> By application of the rule to all lands in the township not excluded on Fig. 1, a map of wheat was prepared (Fig. 5). A gridded overlay constructed to show 10 acre parcels (graph paper with 8 x 8 divisions to the inch) was then applied to the map and the acreage of each field was estimated and added to a running tabulation. This tabulation resulted in an estimate of 10,295 acres of wheat planted in this township. This figure was then added to the estimates for other townships to obtain the county estimate.

5. <u>Spring update.</u> To update the wheat map, an image (Fig. 6) acquired May 31, 1973 was selected. The steps of preparing a tone map (Fig. 7), establishing an interpretation rule, mapping wheat fields and estimating acreage were repeated. In this case the rule was: If the field tone is medium dark or darker ($\geq 4$ on a scale of 1 = lightest, 5 = darkest), the field contains wheat. The resulting wheat map shows changes in a number of fields but results in an acreage estimate of 10,110 acres of wheat, a decrease of less than 2 percent from the fall planting estimate. Small acreage decreases are to be expected under southwestern Kansas cropping practice and the close conformance of the estimates support the validity of early fall acreage estimates from ERTS.

Operationally, it is not necessary to prepare the complete tone map from the spring imagery. Instead, after the rules have been established in areas with surface observations, the spring image may be projected on the fall wheat map (with wheat symbol-rather than tone-coded) through the ZTS and the interpreter may rapidly compare image and map to make necessary changes on the original map.

6. <u>Production estimation.</u> Once the spring image has been used to refine the acreage and a suitable yield prediction has been obtained, the production of larger units, such as counties, may be estimated.

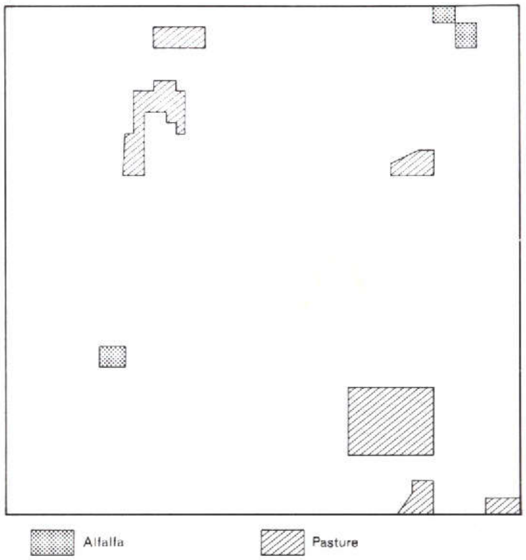
## INTERPRETATION TIME

The following time requirements are based on records maintained while interpreting 220 townships in 10 counties in southwestern Kansas. The times are presented as average time per township. It should be emphasized that some townships are entirely grassland and require almost zero time, while others are almost entirely small irrigated fields which may require three times the average.

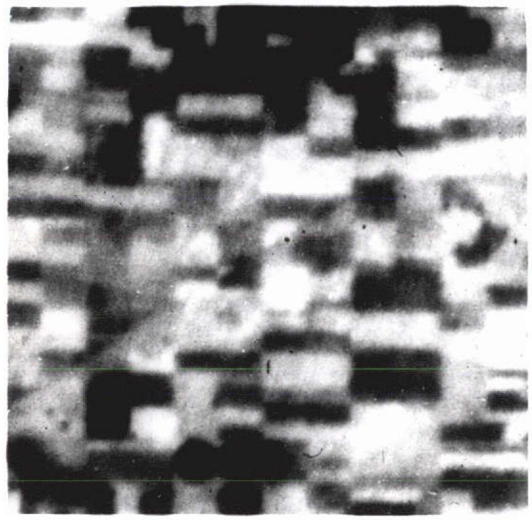
Preparation for the interpretation required approximately 1.0 hour per township. This time was used to prepare the excluded lands and soil maps. About 0.25 hours per year would be required to update the excluded lands map. Although surface observations would not be required in every township, an effective surface observations program would require about 0.5 hours per year for each township in the study area. However, many observations besides those needed for a wheat monitoring program could be obtained in the same amount of field time.

Preparation of the fall tone map requires about 0.4 hours and wheat rule determination and preparation of the wheat map about 0.2 hours. Fall acreage estimation requires about 0.2 hours. Correction of the wheat map in the spring requires about 0.25 hours and recalculation of acreage 0.15 hours. If spring reestimation is not intended, preparation of the fall wheat map is not necessary because the acreage may be estimated directly from the tone map. Thus only 0.6 hours total per township would be required. Under the interpretation strategy outlined above, after the initial preparation, 1.7 hours of interpreter time per year would be required for each township, supplemented by 0.5 hours of field observer time. Thus, approximately 37 hours of interpreter time per year would be required for a typical southwestern Kansas county.

1


Alfalfa
Pasture

2



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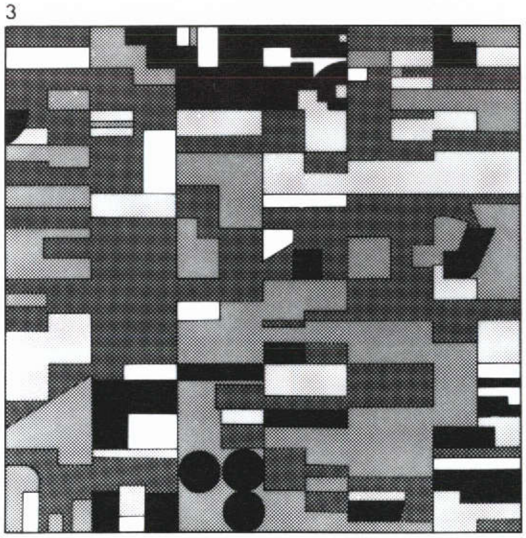
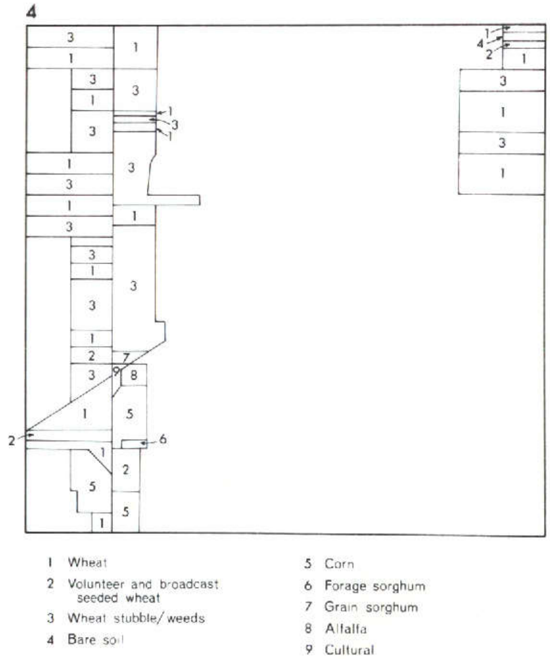
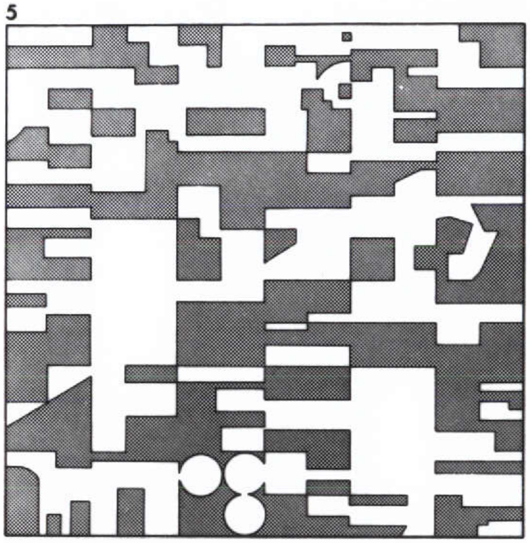


4

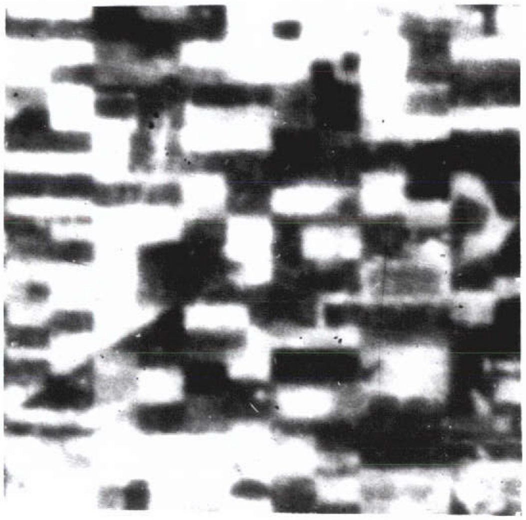

1 Wheat
2 Volunteer and broadcast seeded wheat
3 Wheat stubble/weeds
4 Bare soil
5 Corn
6 Forage sorghum
7 Grain sorghum
8 Alfalfa
9 Cultural

5

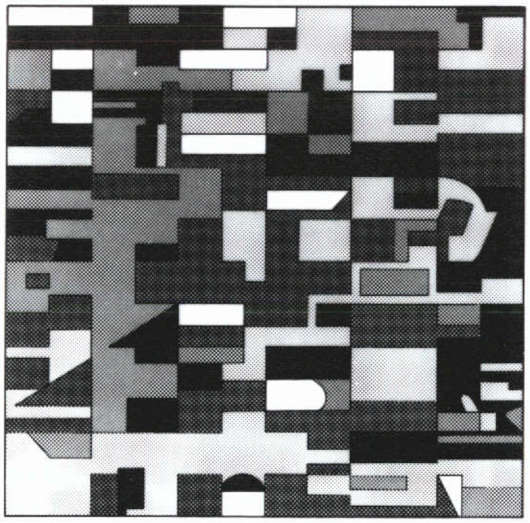


Wheat in September

6



7



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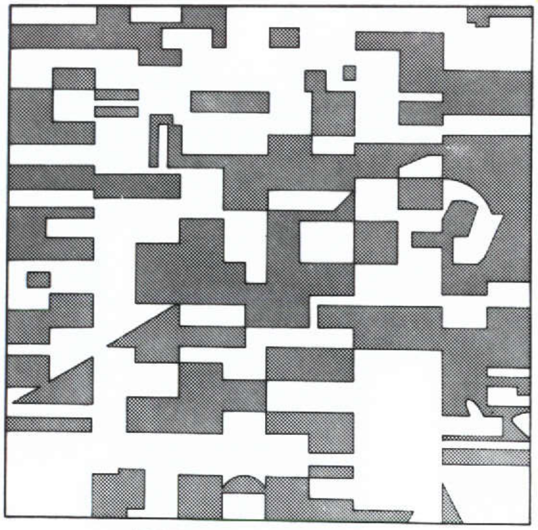


Wheat in May

APPENDIX C

# LAND-USE MAP OF KANSAS

Donald L. Williams

Major patterns of land-use in Kansas, with particular reference to agricultural systems, were mapped from ERTS-1 MSS images by the technique described by Williams and Coiner (1973). The essence of this technique was that boundaries were drawn between areas which exhibited different visual characteristics on the imagery (primarily MSS-5, but some MSS-7 and color composites). These visual characteristics included size and shape of fields, combinations of tones occurring in fields within bounded areas, and lack of field patterns.

The following categories were identified:

1. Grassland
2. Forest
3. Large field flood irrigation
4. Small field flood irrigation
5. Center pivot sprinkler irrigation
6. Large regular field dry cropping
7. Strip cropping
8. Small regular field dry cropping
9. Irregular (generally small) field dry cropping
10. Major towns
11. Reservoirs and lakes
12. Other non-agricultural land (mostly mining)

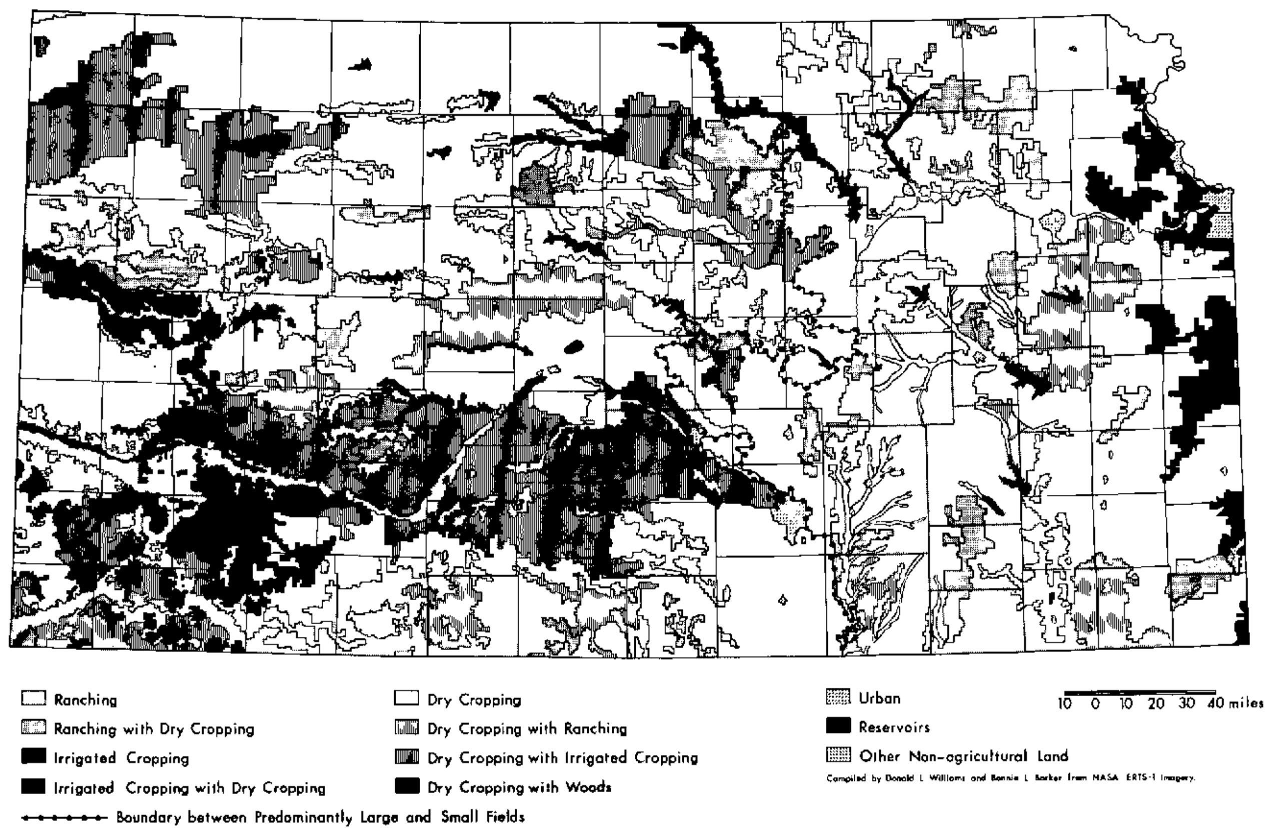
Within each bounded area, the proportions of each of these land uses were visually estimated. The area of each type of land-use was then tabulated for the state (Table 1). Where statistics from other sources were available, these were compared with the tabulated results. The area of grassland was underestimated by 4 percent compared to the 1969 Census of Agriculture estimate. The area of forest differed by less than 1 percent from a 1971 tabulation of the Kansas Forestry Extension Service. Total cropland from the ERTS map included farmsteads, small towns, and roads and railroads and was 6.5 percent above the 1969 figure. Total agricultural land was the sum of cropland and grassland and was 3.7 percent above the 1969 figure.

The original mapping units were then combined according to dominant and subdominant land-use to create the accompanying map (Figure 1).

TABLE 1

AREAS OF MAJOR LAND-USES IN KANSAS, 1973

| Land-Use | | Area ($km^2$) |
|---|---|---|
| Grassland | | 76,000 |
| Forest | | 4,860 |
| Irrigation | | |
| Center pivot sprinkler | 2,510 | |
| Large field flood | 9,630 | |
| Small field flood | 610 | |
| Total | | 12,750 |
| Dry Cropping | | |
| Large regular field | 61,710 | |
| Strip cropping | 16,960 | |
| Small regular field | 30,110 | |
| Irregular field | 7,240 | |
| Total | | 116,020 |
| Total cropland | | 128,770 |
| Urban land | | 1,500 |
| Other nonagricultural land | | 240 |
| Total agricultural land | | 209,630 |
| Total nonagricultural land | | 1,740 |
| Total land | | 211,370 |
| Total water | | 1,660 |
| Total surface area | | 213,030 |


Ranching
Ranching with Dry Cropping
Irrigated Cropping
Irrigated Cropping with Dry Cropping
Dry Cropping
Dry Cropping with Ranching
Dry Cropping with Irrigated Cropping
Dry Cropping with Woods
Urban
Reservoirs
Other Non-agricultural Land
Boundary between Predominantly Large and Small Fields
10 0 10 20 30 40 miles
Compiled by Donald L. Williams and Bonnie L. Barker from NASA ERTS-1 Imagery.

## APPENDIX D

# CENTER PIVOT IRRIGATION IN FINNEY COUNTY, KANSAS: AN ERTS-1 INTERPRETATION PROCEDURE

Donald L. Williams and Bonnie Barker

## ABSTRACT

ERTS-1 images were used to map the distribution of center pivot sprinkler irrigation systems in Finney County, Kansas. This recently developed irrigation system is rapidly increasing in importance throughout the Great Plains of North America. In Finney County, 83 new systems were installed between June 1971 and September 1972. By the latter date 327 systems were in operation irrigating 40,527 acres. Conventional statistics are not available for this irrigation system but ERTS-1 imagery may be effectively used to provide data on the distribution of the system. This paper describes a procedure which may be used to obtain these data.

## INTRODUCTION

Center pivot sprinkler irrigation is a recent innovation in the repertoire of agricultural practices in the Great Plains of North America. The system has already been recognized as creating a unique pattern on aerial photographs (1). Preliminary analysis of ERTS-1 imagery of southwestern Kansas indicated that the same unique pattern is readily interpretable from multispectral images procured at orbital altitudes. Since the diffusion of this innovation is known to be extremely dynamic, mapping of the system was undertaken on a test basis in Finney County, Kansas. Finney County was selected because of the importance of center pivot irrigation in this area and the availability of conventional imagery and surface observations.

Center pivot irrigation is a relatively simple and efficient water application procedure (Figure 1). The system operates in the following manner. Water is delivered through a pipe in the center of the field. A horizontal pipe suspended from steel towers is connected to the central pipe. Sprinklers are then attached at intervals along the horizontal pipe and the volume of each sprinkler individually set so that all parts of the field receive an equal application of water. The steel towers are equipped with wheels

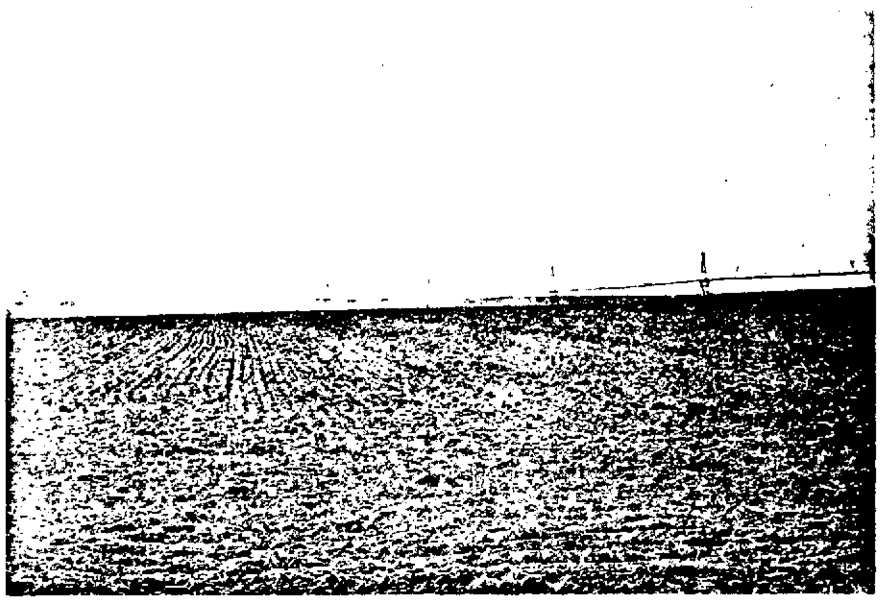


Figure 1. Center pivot sprinkler system in operation, southern Finney County, Kansas, 6 October 1972. Forage corn had been harvested from this field and winter wheat, being grown for winter grazing, had just emerged. This field is on undulating loamy fine sand.

and are mechanically propelled around the central "pivot" pipe. Liquid fertilizer is applied by mixing with the water passing through the central pipe. The system therefore irrigates a circle in an agricultural region where fields are normally rectilinear. The term system, as it is being used here, refers to a pivot sprinkler irrigated field and not to the irrigation equipment itself. One equipment unit is often used in two adjacent fields and transported by tractor between those fields by turning the wheels parallel to the horizontal pipe.

Four sizes of systems are currently being used in Finney County (Table 1). Ninety-five per cent of all systems have the 1320-foot pipe. This system creates a circle with a diameter of one-half mile.

## LOCATION AND USE

Sprinkler irrigation is especially effective on sloping or undulating terrain and porous soils. The horizontal pipes of center pivot systems are quite flexible and operate even over sand dunes with 10 feet or more vertical relief within the field. Since water is applied directly to all parts of the field, high permeability rates do not adversely affect water distribution. In contrast, flood irrigation requires level land (natural or man-made) and sufficiently slow permeability to permit water to flow the length of the field.

In Finney County, 71.4 per cent of all center pivot systems are located on undulating and sandy soils, an increase of 4.2 per cent from 1971 (Table 2). In the past year 57 systems have been installed on soils not considered suitable for any type of cultivation in 1965 (2).

Corn is the crop most extensively produced under center pivot irrigation in Finney County (Table 3). Wheat, grain sorghum, and pasture are also important crops in this land use system. Double cropping is also being practiced to a limited extent. After the forage corn crop is harvested, wheat is planted for winter pasture. In the Spring, the wheat is cultivated to enrich the soil and the field is again planted to corn.

## INTERPRETATION OF ERTS-1 IMAGES

Shape was the sole criterion used in mapping center pivot fields (Figure 2). Tone was not useful because it varied from white to black, depending on the state of the vegetation in the field. The size of the system was determined by the apparent diameter

TABLE 1.

SIZE OF CENTER PIVOT IRRIGATION SYSTEMS
INSTALLED IN FINNEY COUNTY, KANSAS

| Qualitative Size | Length of Horizontal Pipe (feet/meters) | Area Irrigated (Acres) | Area of Corners not Irrigated (Acres) | Apparent Diameter of Circular Field on 9.5 inch ERTS-1 Image (in/mm) |
|---|---|---|---|---|
| Large | 1650/500 | 196 | 54 | 0.039/1.0 |
| Normal | 1320/400 | 126 | 34 | 0.031/0.8 |
| Small | 990/300 | 71 | 19 | 0.024/0.6 |
| Very Small | 660/200 | 31 | 9 | 0.016/0.4 |

TABLE 2.

DISTRIBUTION OF CENTER PIVOT SYSTEMS BY SOIL TYPE, 1972. SOIL TYPES ARE GENERALIZED FROM (2).

| Soil Type | Slope | Percent of Previously Installed Center Pivots | Percent of New Center Pivots | Percent of All Center Pivots |
|---|---|---|---|---|
| Loamy fine sand | Undulating | 28.3 | 51.8 | 34.3 |
| Loam and fine sandy loam | Undulating | 31.2 | 17.6 | 27.7 |
| Loam and silt loam | 0-1% | 23.1 | 12.9 | 20.5 |
| Fine sand | Undulating | 7.7 | 14.1 | 9.3 |
| Saline soils | 0-3% | 4.4 | 2.4 | 3.9 |
| Silt loam | 1-5% | 4.0 | 1.2 | 3.3 |
| Clay soils | 0-1% | 1.2 | 0.0 | 0.9 |

TABLE 3.

USE OF CENTER PIVOT IRRIGATED FIELDS, FINNEY COUNTY, KANSAS. BASED ON FIELD DATA COLLECTED 6 AND 7 OCTOBER 1972, FOR A SAMPLE OF 117 CENTER PIVOT FIELDS.

| Crop | Number of Fields |
|---|---|
| Corn | 57 |
| Wheat | 26 |
| Grain Sorghum | 13 |
| Corn and Wheat, double cropped | 7 |
| Pasture | 6 |
| Volunteer Wheat | 4 |
| Alfalfa | 3 |
| Forage Sorghum | 1 |

Figure 2. ERTS-1 image of southern Finney County, Kansas. The distinctly circular fields are center pivot irrigated. Notice the particular concentration of such fields in the northwestern part of the image. These fields are located in a grassy sand dune area which has been newly opened to cultivation by the advent of this irrigation system. Dark tones on this positive are associated with corn and grain sorghum and light tones with nearly bare ground. This enlargement of part of an MSS-5 image has an approximate scale of 1:330,000. The image (1061-16570-5) was obtained 22 September 1972.

of the circle on the image (Table 1). Actual length of the pipe and area irrigated were measured from the 1971 aerial photographs. The ERTS-1 system corrected red light band images (MSS-5) for three dates (29 July and 21 and 22 September 1972) were used. These images had the greatest agricultural scene contrast and sharpest boundary definition of any acquired bands. Approximately 97 per cent of all circular fields identified were detectable on each MSS-5 image examined. However, each image contributed fields which were not detectable on the other two coverage dates. Infrared images (MSS-7) were supplementally employed in locating reference landmarks in the image. The images were examined under variable (7X to 30X) magnification. As circular fields were identified, their location was recorded on a base map containing the reference landmarks. One of us compiled the map and the other checked the work.

Two interpretation strategies were employed. First, a map was prepared without any prior knowledge of the location of center pivot fields. Second, a map was prepared with knowledge of the location of such fields in 1971. This knowledge had been derived from conventional aerial photographs. Comparisons of change were made with reference to that map which showed 248 pivot sprinkler systems irrigating 30,583 acres. The first ERTS-1 map (Figure 3) shows 270 pivot sprinkler fields with 34,065 acres under irrigation. The net increase of 22 fields and 2772 acres conceals 61 center pivot systems which were present in 1971 but which were not identified on the ERTS image. Of these, 10 were in the small and very small categories. Field checks in October 1972 established that four of the normal-sized fields had not been used in 1972. Therefore, the actual under-estimation was 47 fields, or 19.7 per cent, in the primary size class. By referring to the data collected by a field party on 6 and 7 October 1972, some of the causes for non-identification can be listed as: (1) square field cropping with the sprinkler irrigating the center of the field, (2) irrigated pastures, (3) large weeds in the non-irrigated corners, (4) more than one crop being grown within the irrigated area, (5) overlapping areas of sprinklers, and (6) lack of awareness of the existence of the smaller sized systems. Examination of images of several dates should eliminate most occurrences of the first three problems since the center of the field will be darker than corners if it has been recently irrigated. With increasing experience, the interpreter will be able to reduce errors caused by the last three problems. Although it is possible that some of the newly identified circular fields are not center pivot irrigated, the field party did not find any misidentifications while checking about 60 per cent of these newly identified fields. Therefore, we conclude that, while a small error of overestimation may exist, it is substantially smaller than the established error of underestimation.

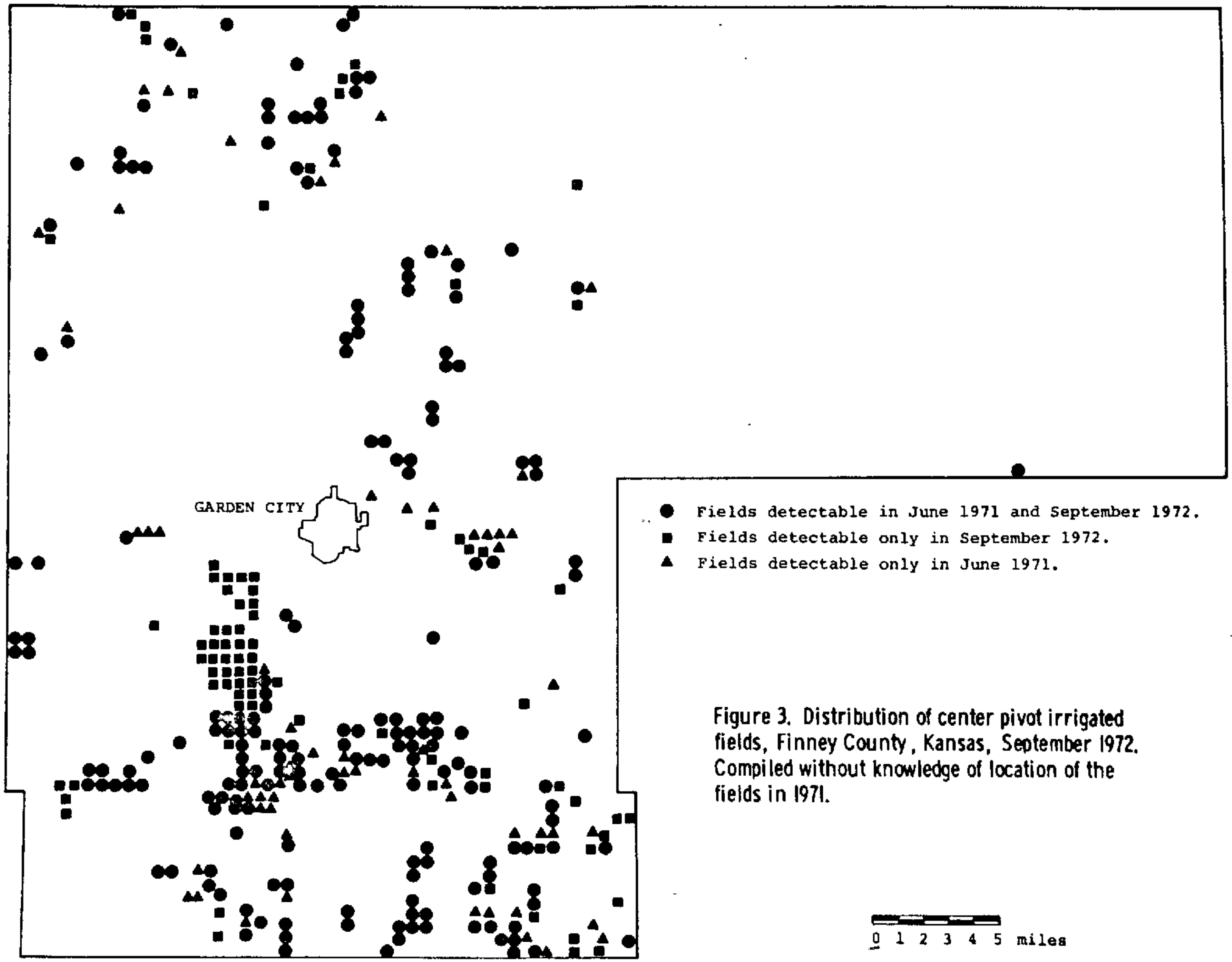



Figure 3. Distribution of center pivot irrigated fields, Finney County, Kansas, September 1972. Compiled without knowledge of location of the fields in 1971.

The second map (Figure 4) was plotted on a base map showing the 1971 locations of fields. The map shows a total of 331 center pivot fields with 41,031 acres under irrigation. This map includes all large, small, and very small fields that were present in 1971. Of the normal-sized fields present in 1971, fourteen were not detected on the ERTS images. Of these, four were not in use and the other ten were being cropped as square fields but irrigated as circular fields. Therefore, 327 center pivot fields with 40,527 acres under irrigation were operational in Finney County in September 1972. This represents an absolute increase of not less than 83 center pivots installed between June 1971 and September 1972. The underestimation term on new systems is the error term associated with detection without prior knowledge. Therefore, the number of new normal-sized systems may be as high as 103. The fact that some underestimation of new systems does occur was verified by the field party, which mapped one new system that has not been detected on the ERTS images.

## CONCLUSIONS

Center pivot irrigation is a rapidly expanding innovation in the Great Plains. ERTS-1 imagery may be effectively used to monitor the location and expansion of this system. The results of this analysis differ sharply from a recent study of center pivots conducted by traditional data collection methods, specifically data collected by letter from county agents (3). In that study, the estimate for Finney County was 200 systems, compared to 327 systems interpreted from ERTS-1 imagery. Accurate statistics on the use of center pivot irrigation are not available through conventional channels because most of the crop production on these fields is not subject to government regulation. Analysis of ERTS-1 images can provide timely and accurate statistics on the use of this irrigation system.

## IMAGERY REFERENCES

| Date | Agency | Mission Number | Frame Number | Scale | Quality |
|---|---|---|---|---|---|
| 9/22/72 | NASA | ERTS-1 | 1061-16570-5 | 1:3,300,000 | Good |
| 9/22/72 | NASA | ERTS-1 | 1061-16564-5 | 1:3,300,000 | Good |
| 9/21/72 | NASA | ERTS-1 | 1060-16512-5 | 1:1,000,000 | Good, partial haze cover |
| 7/29/72 | NASA | ERTS-1 | 1006-16511-5 | 1:1,000,000 | Good, partial cloud cover |
| 7/7/71 | USDA | CDA-2MM | 1-9, 16-26 | 1:64,000 | Good |
| 6/24/71 | USDA | CDA-1MM | 9-180, 199-209 | 1:64,000 | Good |

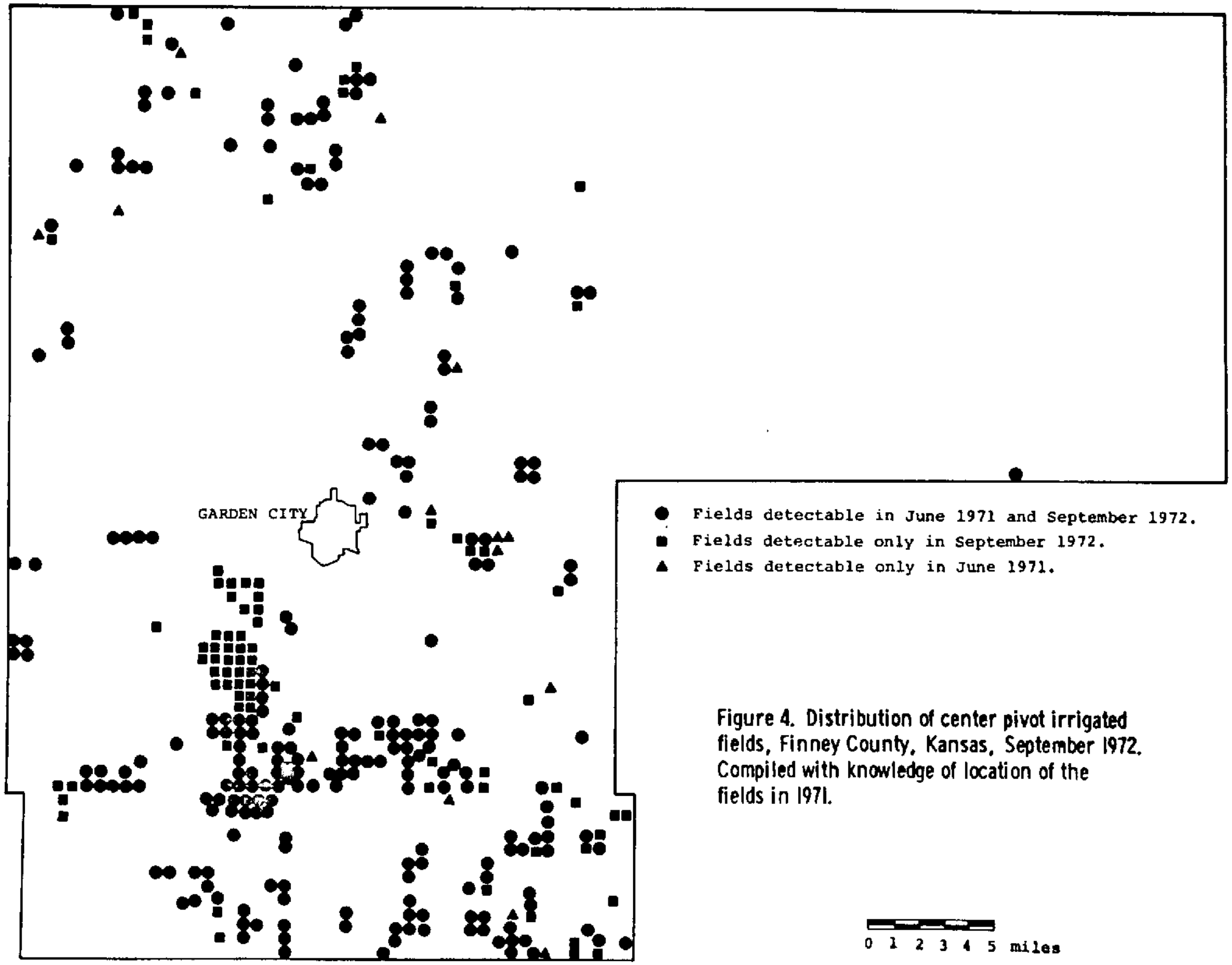



Figure 4. Distribution of center pivot irrigated fields, Finney County, Kansas, September 1972. Compiled with knowledge of location of the fields in 1971.

## REFERENCES


(1) Photogrammetric Engineering 34(4), cover photograph. 1968.

(2) U.S.D.A. Soil Conservation Service. Soil Survey, Finney County, Kansas. Series 1961, no. 30. 1965.

(3) Chapman, Frank. 1972. Center Pivot Irrigation Systems, Paper read before Great Plains/Rocky Mountain Division, Association of American Geographers, Annual Meeting.

# ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE 27 NOVEMBER 1972

PRINCIPAL INVESTIGATOR STANLEY A. MORAIN

GSFC U664

ORGANIZATION University of Kansas Center for Research, Inc., 2291 Irving Hill Rd., Space Tech Laboratories, University of Kansas, Lawrence, Kansas 66044

NDPF USE ONLY
D
N
ID

| PRODUCT ID (INCLUDE BAND AND PRODUCT) | FREQUENTLY USED DESCRIPTORS* Irrigation | Agriculture | | DESCRIPTORS |
|---|---|---|---|---|
| 1006-16511-5 | X | X | | |
| 1061-16511-5 | X | X | | |
| 1061-16512-5 | X | X | | |
| 1061-16564-5 | X | X | | |
| 1061-16570-5 | X | X | | |

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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301-982-5406

GSFC 37-2 (7/72)

## APPENDIX E

## DISCRIMINATION OF ALFALFA

Donald L. Williams

Alfalfa, primarily grown under irrigation, is an important and expanding crop in southwestern Kansas. For example, the farm value of alfalfa produced in Finney County, Kansas, in 1971 was $2,846,000 and accounted for more than 11.6 percent of the total value of field crops (Kansas State Board of Agriculture, 1972), although it occupied less than 7 percent of the harvested acreage.

Although alfalfa is a perennial plant, fields deteriorate with time. Some plants die, weeds invade, and the quality of the crop decreases. Consequently, replacement is a continuous process. The normal replacement procedure is to seed a new field and destroy the plants in the old field by cultivation and use the former field for other crops. Since soils under alfalfa fields develop very high nitrogen contents, these fields are extremely productive for other crops. Accurate knowledge of the location of alfalfa fields and the return of these fields to production of other crops would therefore be useful, both for estimation of alfalfa production and estimates of production of other crops.

Study of MSS-7 images acquired over Finney County during May 1973 revealed that alfalfa was uniquely distinctive at that time. At that time alfalfa exhibited a higher infrared reflectance than any other field condition. This image property was used to prepare the accompanying map which shows 28,000 acres of alfalfa. Surface observations were available for 9 percent of the county area and showed 4,6000 acres of alfalfa. Map accuracy for this sample area exceeded 97 percent. Because of the unique tonal properties of alfalfa in the image, fields as small as 10 acres were consistently identifiable. However, these extremely small fields often appeared somewhat larger on the image than actual size. Field sizes larger than about 40 acres could be determined quite accurately.

To study changes in the location of alfalfa, 1971 USDA photographs were interpreted and compared to the ERTS-derived map. Acreage determined from the photographs exceeded the published 1971 figure of 24,400 acres harvested for hay or seed by 20 acres. The ERTS-based figure of 28,000 acres represented an increase of 14.7 percent in total acreage from June 1971 to May 1973. Of the acreage present on the 1971 photographs 15,820 acres were mapped from ERTS while 8,600 acres were not. Thus, 35 percent of the 1971 acreage had been destroyed and replaced in two years, indicating a cycle time of six years for alfalfa in Finney County. It was also noted that most of the new acreage was close to a recently opened processing site and represented an expansion of the primary production area northeastward in the county.

## REFERENCES


Kansas State Board of Agriculture. 1972. Kansas Farm Facts, 1971-1972. Topeka, Kansas: State Printer.

NASA. ERTS-1 Images E-1295-16573-7, E-1295-16580-7, and E-1312-16520-7.

APPENDIX F

TEXT TABLES CONVERTED INTO METRIC UNITS

TABLE 1

COMPARATIVE ESTIMATES OF 1973 WHEAT AREA (HECTARES) FOR TEN COUNTIES IN SW KANSAS

| | SRS | | | ERTS |
|---|---|---|---|---|
| County | Area Estimate Official "Harvested" | | | Estimate |
| | May 1973 | Aug. 1973 | Feb. 1974 | March 1973 |
| Finney | 83,025 | 78,975 | 83,835 | 96,795 |
| Grant | 32,805 | 35,235 | 35,640 | 29,970 |
| Gray | 63,585 | 65,610 | 68,445 | 70,470 |
| Haskell | 42,120 | 44,145 | 44,145 | 44,550 |
| Kearney | 47,385 | 48,195 | 52,245 | 46,575 |
| Meade | 57,105 | 53,460 | 56,295 | 61,155 |
| Morton | 36,855 | 39,285 | 42,525 | 29,160 |
| Seward | 33,615 | 32,400 | 34,830 | 31,590 |
| Stanton | 54,675 | 53,460 | 57,915 | 43,740 |
| Stevens | 34,425 | 35,235 | 36,855 | 34,830 |
| Totals | 485,595 | 486,810 | 512,730 | 488,835 |

## TABLE 2
## COMPARISON OF ERTS AND "OFFICIAL" VALUES FOR WHEAT AREA, YIELD, AND PRODUCTION FOR 10 COUNTIES IN SOUTHWEST KANSAS

### WHEAT AREA (HECTARES)

| Date of Estimate | Source | Value |
|---|---|---|
| March 1973 | ERTS-1 Analysis | 488,835 |
| February 1974 | SRS (official, harvested) | 512,730 |
| August 1973 | SRS (estimate, harvestable) | 486,810 |

### AVERAGE YIELD

| Date of Estimate | Source | Value |
|---|---|---|
| July 1973 | Weather Model | 375.5 kg/ha |
| February 1974 | SRS (official) | 375.7 kg/ha |
| August 1973 | SRS (estimate) | 366.7 kg/ha |

### TOTAL PRODUCTION

| Date of Estimate | Source | | Metric Tons |
|---|---|---|---|
| July 1973 | ERTS-1 plus weather model | non-irrig. | 157,096.1 |
| | | irrig. | 41,253.1 |
| | | | 198,349.2 |
| February 1974 | SRS (official) | non-irrig. | 164,939.8 |
| | | irrig. | 34,886.9 |
| | | | 199,826.7 |
| August 1973 | SRS (estimate) | undiff. | 178,513.2 |

## 5.0 TEXT REFERENCES

ERTS-1 Imagery:

| DATE | FRAME NUMBER | QUALITY |
|---|---|---|
| 8-16-72 | 1024-16511-5 | Excellent |
| 9-21-72 | 1060-16505-5 | Good, partial cloud cover |
| 9-21-72 | 1060-16512-5 | Good, partial cloud cover |
| 9-22-72 | 1061-16564-5 | Good |
| 9-22-72 | 1061-16570-5 | Good |
| 12-21-72 | 1151-16575-5 | Good, partial snow cover |
| 3-20-73 | 1240-16523-5 | Good, partial snow cover |
| 5-31-73 | 1312-16520-5 | Excellent |
| 7-24-73 | 1366-16512-5 | Excellent |


Thompson, Louis M. (1969), "Weather and Technology in the Production of Wheat in the United States," Journ. of Soil and Water Conservation 24:6 (Nov.-Dec.), pp. 219-224.

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Williams, D. L., Morain, S. A., Barker, B. and Coiner, J. C. (1973), "Identification of Winter Wheat from ERTS-1 Imagery," in Symposium on Significant Results Obtained From the Earth Resources Technology Satellite-1, Vol 1, edited by S. C. Freden, E. P. Mercanti, and M. A. Becker. Washington D. C: National Aeronautics and Space Administration, pp. 11-18.

## CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technology Transfer Laboratory