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SLAR IMAGE INTERPRETATION KEYS  
FOR GEOGRAPHIC ANALYSIS

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# SLAR IMAGE INTERPRETATION KEYS FOR GEOGRAPHIC ANALYSIS

## ABSTRACT

This study suggests a means for SLAR imagery to become a more widely used data source in geoscience and agriculture by providing interpretation keys as an easily implemented interpretation model. Interpretation problems faced by the researcher wishing to employ SLAR are specifically described, and the use of various types of image interpretation keys to overcome these problems is suggested. With examples drawn from agriculture and vegetation mapping, direct and associate dichotomous image interpretation keys are discussed and methods of constructing keys are outlined. Initial testing of the keys, key-based automated decision rules, and the role of the keys in an information system for agriculture are developed.

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## INTRODUCTION

Geographers are continually faced with employing new techniques, such as multivariate analysis, modeling and remote sensing in their research, which has tended to cause the selection of a research technique to be synonymous with problem solution. This has occurred in the field of remote sensing.<sup>1</sup> Remote sensing, because of the broad span of technology which it encompasses, presents numerous research opportunities for scientists in general and geographers in particular. However, the opportunities to study spatially distributed phenomena by means of remote sensing, especially with Side-Looking Airborne Radar (SLAR), have remained largely a matter of "potential" and have not been exploited on a broad scale.

The use of SLAR technology in problem solving (specifically of a geographic nature) will neither guarantee a solution to the problem nor widen the sphere of SLAR's utility, if the approach does not have a linking mechanism which relates data in the image to the specific problem. Hence, if we are going to use SLAR successfully as a data collection tool, then methods must be found which effectively link specifications and remote sensor output. This paper discusses one method or model which can be used to define the links.

In the past, remote sensing reasoning has evolved as illustrated in the following case. Briefly, the example points out one of the major failings of remote sensing research, namely, that as a rule effective mechanisms relating desired data and data obtainable from remote sensor outputs have not been developed. The example shows that satellite sensing could aid in finding areas of the world where food production might be increased through transfer of agricultural technology, but it does not provide a means to interpret the data available. In the following paragraphs the logic which creates this predicament is developed. Although the capability to collect data on agricultural resource problems is generally attributed to remote sensors (Remote Sensing, 1970, pp. 9-16), few methodologies exist which can extract data from images to meet agricultural resource information requirements.

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<sup>1</sup>A recent example is found in Chapter 1 of Remote Sensing with Special Reference to Agriculture and Forestry (1970), where operational and potential capabilities are mixed and discussed without careful differentiation.

The case is as follows: A way of assessing where food supplies may be increased is to identify ecological analogs (Scrimshaw, 1963, p. 209) in those calorie-deficit countries shown in Figure 1.<sup>2</sup> Since the scope of the assessment is worldwide, it would appear that it could be carried out by orbiting satellites of the Earth Resource Technology (ERTS) type [see ERTS Data Users Handbook, 1971, pp. (2-1) - (2-9)] carrying photographic or other visual and near infrared sensors. It is proposed that ERTS imagery could be used to make direct comparisons between the physical features of highly productive areas and those that are not. Identification of ecological analogs would then be possible, and these ecological analogs could become the focus of transferred agricultural techniques which increase production.

This simple assessment method is hampered by the climate of the areas for which we are attempting to identify analogs. When the approximate cropland areas of the world (shown in Figure 2) are compared with worldwide cloud cover during January and July (shown in Figure 3), one sees that searching for analog areas with photographic or visual sensors (such as ERTS) is made difficult by cloud cover constraints. Gaining cloud free coverage of potential areas of interest is accomplished at approximately the rate of one image in six passes.<sup>3</sup> A solution to the problem of cloud cover is to replace the visual range sensor with a sensor from another portion of the electromagnetic spectrum which is unaffected by cloudiness and less affected by weather in general.<sup>4</sup> It is then concluded that the most suitable sensor/platform<sup>5</sup> combination that would operate effectively would be a SLAR/satellite.

In many instances, this is the point where past researchers have terminated their investigations. They would have correctly identified some of the constraints and matched the remote sensor and platform to the scope of the problem; however, the researchers would not have asked a critical question related to the implementation

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<sup>2</sup>Below 2,700 calories per day is considered undernourishment by the United Nations Food and Agriculture Organization.

<sup>3</sup>These figures assume twelve hours of daylight, with the cloud cover being equally distributed in the day/night period, an obviously impossible situation. As James Quick, Research Engineer (USAETL Field Office, Wright Patterson AFB, Ohio), has argued (personal conversation, 1972), there may be more daylight than night cloud cover, and the time synchronous nature of a satellite may not permit worldwide optimization of minimum cloud cover.

<sup>4</sup>For an overall discussion of the relationship of cloudiness to image acquisition, see Simonett, et al., 1969.

<sup>5</sup>"Platform" is normally defined as the vehicle which carries the sensor package.

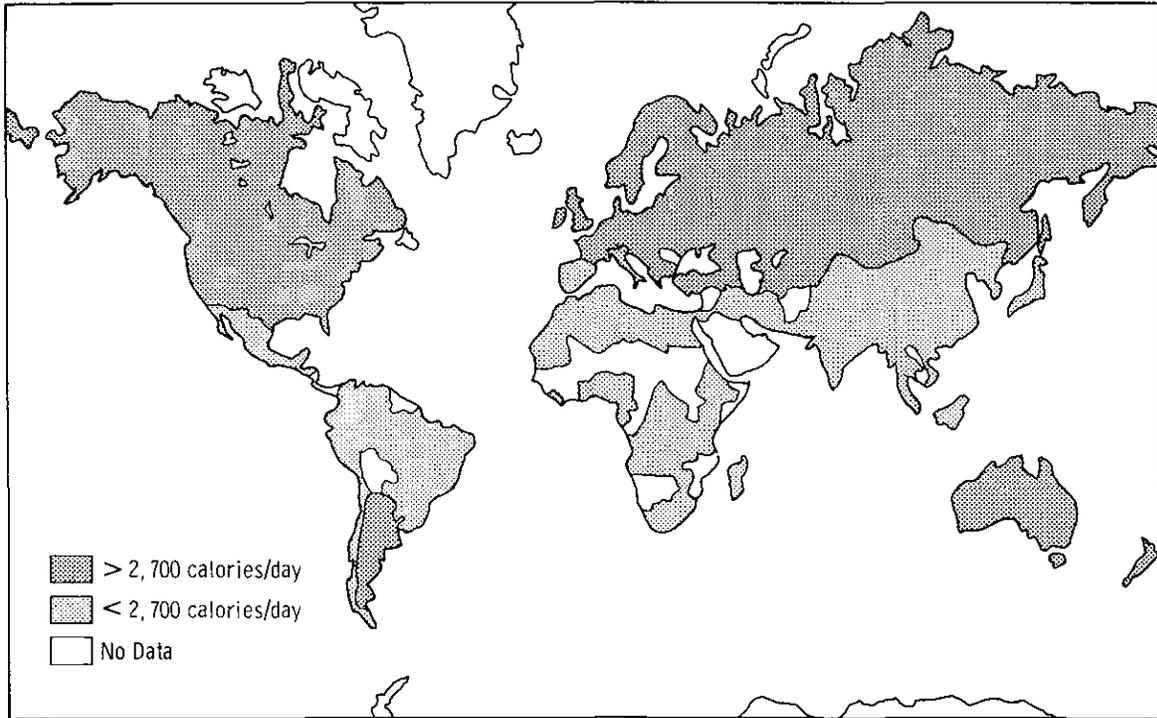


Figure 1. World Wide Food Consumption based on an acceptable minimum FAO standard of 2,700 calories per day (after Scrimshaw , 1963, pp. 210-211).

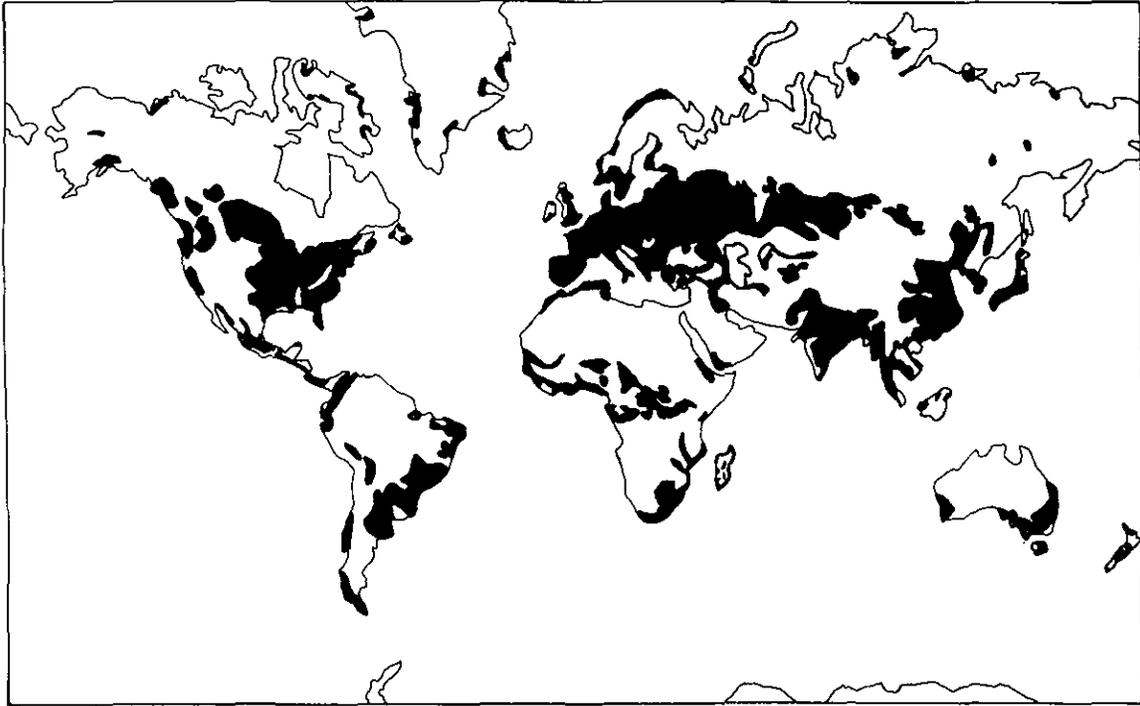


Figure 2. Approximate Cropland Areas of the World Including Fallow, Tree and Brush Crops Arable Land (from Remote Sensing, 1970, p. 8)

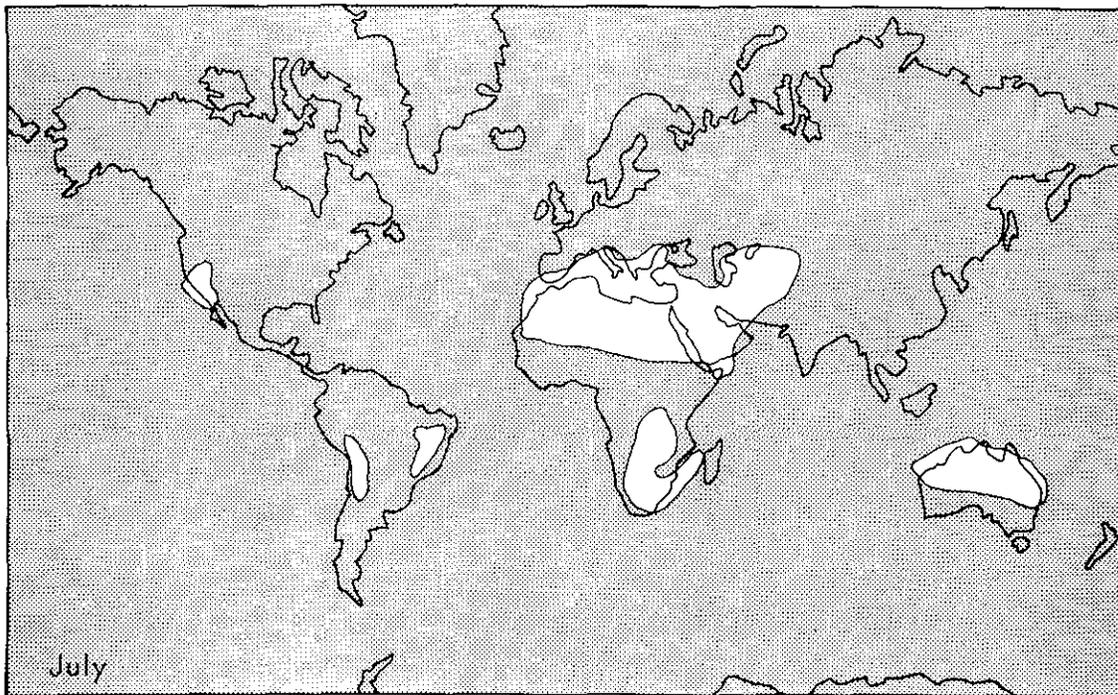
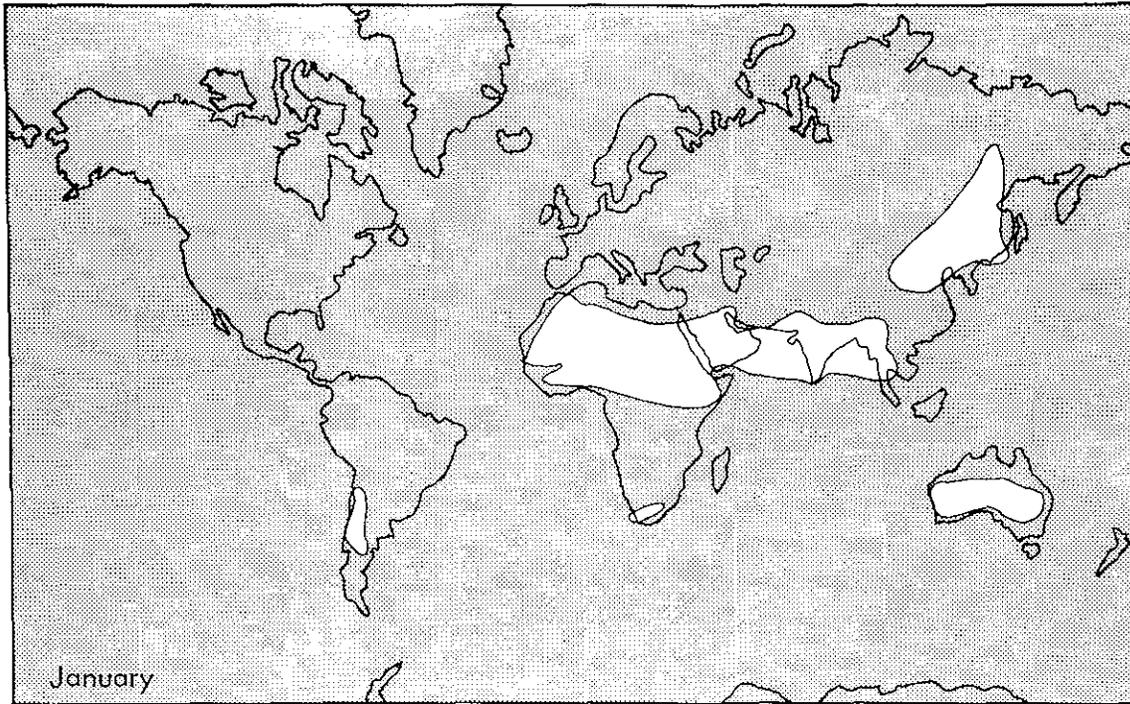


Figure 3. Worldwide Cloud Cover Using January and July Means: Areas shown in white are cloud covered less than 30% of the time (after Simonett, et al., 1969, p. 22).

of their proposed solution, that is, under the limits of the technology and within the framework of the problem, how could the remote sensing system selected be placed in operation. *Making a remote sensing system operational is a multifaceted problem* with many technical aspects which are often beyond the interest or scope of the geographer. Nevertheless, there is one aspect of the operational system which is not beyond his field of interest and which is crucial to his use of remote sensing as a research tool. This aspect is the interpretation model. The interpretation model is the scheme by which the researcher extracts useful data from the image (output) and defines those data in terms of the problem he is attempting to solve. In other words, the model forms a link between sensor produced data and information desired.

Returning to the previous case, it is necessary not only to select a SLAR/satellite system which will identify worldwide ecological analogs, but to analyze how the resultant SLAR image displays information related to the problem. Since SLAR imagery will cover various areas at various times, the analysis should provide an accurate, reproducible technique for continued extraction of similar data from all areas under consideration that are remotely sensed at different times. The resultant *definitive, repeatable methodology* comprises an interpretation model.

This paper presents one type of interpretation model, the image interpretation key for SLAR. "An image interpretation key is reference material designed to facilitate rapid and accurate identification and determination of the significance of objects (areas) by the image interpreter." (NAVAIR 10-35-685, 1967, pp. 3-56). The construction of keys and their utilization in interpreting SLAR imagery will be the primary focus of this paper. Examples of key construction and employment are drawn from agriculture and natural vegetation mapping, with the discussion carried out as follows: Chapter I reviews a) the literature of potential uses of SLAR, b) the technological nature of SLAR in terms of its effect on interpretation, and c) the history of image interpretation keys and definitions of terminology used. Chapter II discusses the construction of the textual segments of keys, provides examples of keys developed for use with SLAR imagery, and suggests visual associative aids to use with SLAR interpretation keys. Chapter III presents the results of tests conducted with preliminary keys for SLAR, and Chapter IV is a brief study of the use of keys to develop automated interpretation algorithms and to provide an interpretation model for an agricultural information system. Conclusions on the utility of keys, with suggestions for continuing research, are contained in Chapter V.

## CHAPTER I

### BACKGROUND ON SLAR AND KEYS

#### SLAR for Geoscience/Agriculture

The potential of SLAR as a tool for geoscience and agricultural investigation has been the subject of numerous papers since the mid 1960's. For example, Simpson (1966, p. 50) introduced SLAR to the geographic community by stating that it could be used for the following:

- 1) Tasks which require an overview of subcontinental magnitude.
- 2) Tasks which require an overview in which careful timing is critical.
- 3) Tasks which require an overview with maximum economy of time and money.

Simonett, et al. (1967) discussed the role of SLAR in the remote sensing of agricultural phenomena. They concluded that SLAR was potentially useful to discriminate crops and that it offered maximum advantage in overcoming the handicaps of weather, darkness and the integration of data over a large area. Subsequently, Morain and Simonett (1966), and Simonett (1968) suggested the employment of SLAR for geomorphic, vegetation and soil mapping studies. They found that SLAR had several possible applications for vegetation studies, including the generation of small-scale maps, delimitation of vegetation zones and detection of burn scars (Morain and Simonett, 1966, p. 605). Simonett stated that information about soils probably could be inferred from imaged data on vegetation, topography and drainage networks (Simonett, 1968, pp. 274-278).

The use of radar as a method of data collection for geoscience research has been limited to a far greater extent than its publicized potential would indicate. With few exceptions, geoscience studies using SLAR derived information have been conducted by a small group of individuals with a primary interest in the field of remote sensing. These studies were mainly designed to determine the capability of SLAR imagery, e.g., Morain and Simonett (1967) to map vegetation; Simonett, et al. (1967) to discriminate crops; McCoy (1967) to detect and analyze drainage basins; and Lewis (1971) to determine terrain slope. In the present study, problems which arise a generation beyond validation of capability will be investigated.

Before SLAR can be used generally as a method of geoscience and agricultural investigation, a number of technical difficulties involving both the sensor and the interpretation of the imagery which the sensor produces must be overcome (Moore, 1969). One of the most pressing of the technical difficulties is the lack of an interpretation model for SLAR imagery that is simple to develop and accurate to use. As mentioned previously, the model should require only a minimum of image interpretation expertise and should produce accurate and reproducible interpretations.

### SLAR as a Remote Sensor

Before construction of image interpretation keys can occur, an understanding of SLAR's parameters is required so that the system's limitations can be incorporated into the keys. SLAR is one of the most technically complex of the various remote sensors now available. When compared to photography, the image produced by SLAR is difficult to interpret because it does not record visually associative phenomena and therefore the human interpreter has no past visual experience to which he can relate the scene in the image.

There are two groups of parameters which affect imagery produced by SLAR and which control the content of the image (Moore, 1969). These groups are as follows:

1. Radar System Parameters

- Wavelengths

- Power

- Illuminated area

- Direction of illumination (both azimuth and elevation)

- Polarization

2. Ground Parameters

- Complex permittivity (conductivity and permittivity)

- Roughness of surface

- Roughness of subsurface to depth where attenuation reduces wave to negligible amplitude

Normally, the power return ( $P_r$ ) to the receiving antenna is mathematically expressed:

$$P_r = \frac{P_t G^2 \sigma^o \Delta A}{(4\pi)^3 R^4} \quad (1)$$

where

- $P_r$  is the average received power (watts)
- $P_t$  is the transmitted power (watts)
- $G$  is the antenna gain (same antenna for transmitter and receiver)
- $\sigma^o$  is the scattering cross section per unit area (dimensionless)
- $\Delta A$  is the illuminated area (square meters)
- $R$  is the average range to the scattering elements (meters)

We are interested as interpreters in one component of equation (1), that is  $\sigma^o$ , for  $\sigma^o$  contains the information about the target being sensed. This  $\sigma^o$  value may be expressed in terms of the previously stated radar parameters as follows:

$$\sigma^o = \frac{(4\pi)^3 R^4 P_r}{G^2 \lambda^2 \Delta A P_t} \quad (2)$$

where  $\lambda$  is the wavelength in meters (Moore and Waite, 1969).

To further explore the return, we must look at how the ground parameters act on the  $\sigma^o$  through the  $\Delta A$  expression (the illuminated area) in (2). The three ground parameters (complex permittivity, roughness of surface and roughness of subsurface) act simultaneously to control the nature of  $\Delta A$  and, thus, the return that is imaged by the radar system. Due to the nonlinear interaction of the three ground parameters in the backscatter,<sup>6</sup> the backscatter is too complex to be subjected to mathematical modeling. Therefore, the interpreter cannot mathematically predict the type and nature of the backscatter from a given scene.

When the returned electromagnetic signal generated by SLAR is processed into an image, the resultant image does not necessarily represent a one-to-one

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<sup>6</sup>"Backscatter" is the amount of the transmitted power ( $P_t$ ) that is returned to the antenna (receiver) by a given scene. It is equated with  $\sigma^o$ .

relationship (i.e., it is a nonlinear relationship) with the backscatter from the scene. This deviation presents a real problem for the interpreter. The nonlinear relationship between the backscatter and the image makes any interpretation technique an attempt to relatively associate the image and the scene.

The present state of the art in radar does not deny the usefulness of SLAR as a remote sensor; it does, however, point specifically to the constraints under which interpretation must be conducted. From 1966 to the present, densitometric<sup>7</sup> data derived from SLAR imagery have been used in a number of studies, all attempting to make agricultural discriminations concerning crop identification. Simonett, et al. (1967) attempted to use density plotted on scattergrams to define unique locations (data space) for each crop. Schwarz and Caspall (1968) employed clustering techniques to attempt discrimination, while Haralick, et al. (1970) employed a Bayesian decision technique to gain the same end. Morain and Coiner (1970) used scatterplots from fine resolution radar imagery to attempt definition of unique crop signatures. These studies have not been entirely successful in discriminating crops because of the relative relationship between the image and the radar return and the fact that densitometric data consider only a single parameter (gray scale) inherent within the image.

The basic reasons for an investigator's interpretation problems with SLAR include:

- (1) lack of appreciation for the parameters affecting generation of imagery. For example, the imagery for any given scene results from a complex series of interactions determined by:
  - a. the wavelength's ( $\lambda$ ) relationship in physical size to the object being sensed. In this study, three wavelength bands were used, Ka-band (.83 - .91 cm), Ku-band (1.74 - 1.97 cm) and X-band (2.7 - 5.8 cm). The entire range of bands potentially available for radar use and their frequencies are given in Table 1.
  - b. the angular relationship between the electromagnetic wave and the surface sensed when the wave strikes the surface (strike angles will vary with depression angle).

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<sup>7</sup>"Densitometry" is the measurement of the degree of optical opacity of a medium or material. Normally, when used in association with SLAR imagery, densitometry measures the variation in opacity (gray scale) on the imaged film (Morain and Coiner, 1970).

TABLE 1  
FREQUENCIES AND WAVELENGTHS OF RADAR BANDS\*

Band (U.S. Usage)	Nominal Range (GHz)	Wavelength (cm)
P	220 - 390	133 - 77
L	390 - 1,550	77 - 19
S	1,550 - 5,200	19 - 5.8
C	3,900 - 6,200	7.7 - 4.8
X	5,200 - 10,900	5.8 - 2.7
Ku	15,250 - 17,250	1.97 - 1.74
K	10,900 - 36,000	2.7 - 1.83
Ka	33,000 - 36,000	.91 - .83

\*(after Remote Sensing, 1970, p. 101)

- c. the surface's complex permittivity (dielectric properties) which may increase or decrease the intensity of a return.
- (2) the fact that previous studies of SLAR have not concentrated on the development of a broadly applicable interpretation model for the imagery.

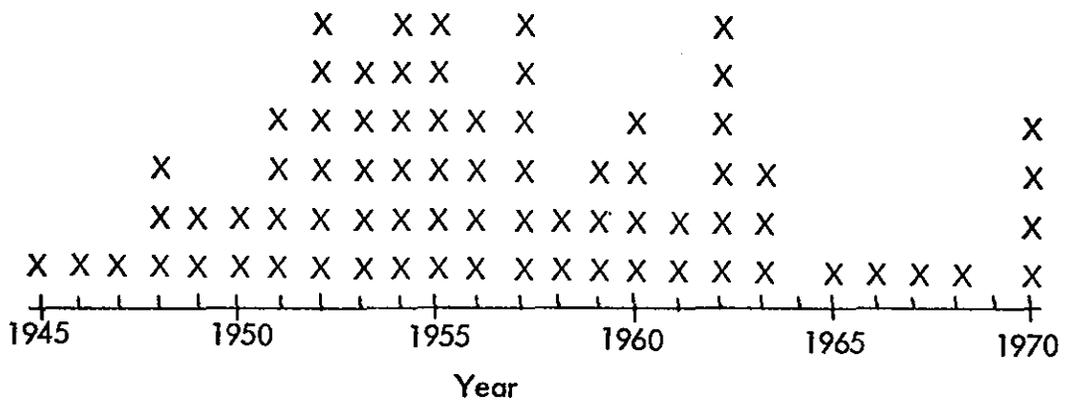
In part, these problems arise from the tendency to portray the sensor-problem interrelationship apart from an interpretation model.

### Interpretation Keys

The origin of interpretation keys can be traced to the biological sciences. Prior to the introduction of multivariate analysis, this approach was the most common for taxonomic purposes in botany and zoology, and even today it is an important tool in these endeavors (Mayr, 1969, p. 277). The first photo interpretation keys were developed during World War II to aid in the interpretation effort supporting Allied intelligence.<sup>8</sup> After the war, photo interpretation keys were adapted for non-military uses, and were mainly aided by the work (in forestry) of Colwell (1946 and 1953). Extensive use was also made of regional keys for analysis of different geographic regions of the world (Landis, 1955). Figure 4 shows the number of articles, published by year, pertaining to the construction and employment of image interpretation keys. The heavy concentration of articles in the mid-Fifties occurred because photo interpretation keys were widely accepted at that time as the primary reference aid to interpret aerial photography. The apparent lack of interest in keys in the mid and late Sixties (as reflected in published articles) probably stems from the shift of research to automated data processing. It would appear from Figure 4, however, that interest in key research has revived somewhat since 1970. This is attributed, in part, to the need for a systematic interpretation model applicable with remotely sensed data, particularly SLAR imagery.

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<sup>8</sup>"Photo interpretation key" was the original term applied only to keys used to interpret aerial photography. "Image interpretation key" is an expanded term developed to deal with all remote sensor interpretation techniques, including photography.



X = one bibliographic entry

Figure 4. Number of Published Materials Relating to Image Interpretation Keys: 1945-1970.

Source: Compiled by author from bibliographies in Bigelow (1963 and 1966) and Photogrammetric Engineering, vols. 33-37.

Since image interpretation keys are the interpretation model in this study, it is essential to use common terminology to discuss them. The terminology used here was originally developed for photo interpretation in 1952 by Commission VII of the International Society of Photogrammetry under the direction of R. N. Colwell (Colwell, 1952, pp. 383-390). Later, the Commission's terminology was revised by the Department of Defense for use in image interpretation (Image Interpretation Manual, Volume I, 1967, pp. 3-57). These revised definitions, which are directly pertinent to this study, are presented in Table 2.

From the table, it can be seen that keys vary in four essential characteristics: function (reflecting scope of use), technicality (reflecting experience level of the user), information relationships (reflecting imaged or non-imaged data and their combinations)<sup>9</sup> and format (reflecting organization and presentation). In any given key, these four characteristics interrelate with each other. For example, the technical level of the key influences choice of format. It is generally conceded that the lower the technical level, the more appropriate a dichotomous format would be (Manual of Photo Interpretation, 1960, pp. 112-113). By forcing the interpreter to make a binary choice, the dichotomous key allows selection of relevant elements from the heterogeneous data within the image. For a less experienced interpreter, the dichotomous format is easier to follow than others because it leads an interpreter from the general case to the specific by limiting the number of choices at each decision point. In cases where large amounts of data about various elements are taken from one image, it is desirable to construct a subject key. This type of key defines a number of items (elements) within the image, from which their interactions can be discerned. The dichotomous approach for a subject key may be cumbersome in certain instances, due to the structure of the data within the image (where a datum may relate to several elements). For these cases, an alternative, the selective format, should be employed. The selective format can be presented in a number of ways, the most structured of which is the integrated-selective key, and

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<sup>9</sup>The relationship between data and information has been defined as Data A + Data B equals Information C, thus data is a subset of information. Data itself can be considered to have two major parts, the data element (which is the generic part) and the data item (which is the specific part). For example, field would be a data element while number of fields would be a data item. These concepts are from Wellar and Graff (1971, p. 2).

TABLE 2  
DEFINITIONS RELATIVE TO IMAGE INTERPRETATION KEYS\*

An **image-interpretation key** is reference material designed to facilitate rapid and accurate identification and determination of the significance of objects or conditions from the analysis of their film images. Ideally, the key consists of two parts: (a) a collection of annotated or captioned stereograms and other images which are illustrative of the objects or conditions to be identified and (b) a graphic or word description which sets forth in some systematic fashion the image-recognition features of those objects or conditions.

Image-interpretation keys may be classified as to scope, technical level, intrinsic character, and manner of organization or presentation. Each of the following definitions is based upon the fundamental definition of an image-interpretation key, stated above.

#### 1. SCOPE OF IMAGE-INTERPRETATION KEYS

- a. An **item key** is one concerned with the identification of an individual object or condition.
- b. A **subject key** is a collection of item keys concerned with the principal objects or conditions within a given subject category.
- c. A **regional key** is a collection of item or subject keys concerned with the identification of the principal objects or conditions characteristic of a particular region.
- d. An **analogous area key** is a subject or regional key which has been prepared for any given area and in which information is presented as to its applicability for the interpretation of objects or conditions in inaccessible areas having similar characteristics.

#### 2. TECHNICAL LEVEL OF IMAGE-INTERPRETATION KEYS

- a. A **technical key** is one prepared primarily for use by image interpreters who have had professional or technical training or experience in the subject concerned.
- b. A **non-technical key** is one prepared primarily for use by image interpreters who have not had professional or technical training or experience in the subject concerned.

#### 3. INTRINSIC CHARACTER OF IMAGE-INTERPRETATION KEYS

- a. A **direct key** is one designed primarily for the identification of discrete objects or conditions directly discernible on films.
- b. An **associate key** is one designed primarily for the deduction of information not directly discernible on films.

#### 4. MANNER OF ORGANIZATION OR PRESENTATION OF IMAGE-INTERPRETATION KEYS

All image-interpretation keys are based upon diagnostic features of the film images of objects or conditions to be identified. Depending upon the manner in which the diagnostic features are organized, two general types of keys are recognized: "**Selective keys**" are so arranged that the image interpreter simply selects that example corresponding to the image he is trying to identify. "**Elimination keys**" are so arranged that the image interpreter follows a prescribed step-by-step process that leads to the elimination of all items except the one he is trying to identify. Where feasible of formulation, the latter type of key is considered preferable.

##### a. Selective keys

- (1) An **essay key** is one in which the objects or conditions are described in textual form, using images only as incidental illustrations.
- (2) A **file key** is an item key composed of one or more selected film images together with notes concerning their interpretation, assembled by an individual interpreter largely for personal use.
- (3) An **image-index key** is an item key composed of one or more selected film images together with notes concerning their interpretation, assembled for rapid reproduction and distribution to other image interpreters.
- (4) An **integrated-selective key** is one in which film images and image recognition features for any individual object or condition, within a subject or regional key, are so associated that by reference to the appropriate portion of the key the object or condition concerned can be identified.

##### b. Elimination keys

- (1) A **punch-card key** is one in which selected image-recognition features are arranged in groups on separate punch cards so that when properly selected cards are superimposed upon a coded base, all but one object or condition of the group under consideration are eliminated from view.
- (2) A **dichotomous key** is one in which the graphic or word description assumes the form of a series of pairs of contrasting characteristics which permit progressive elimination of all but one object or condition of the group under consideration.

\*From Image Interpretation Manual, Volume I, (1967), pp. 3-57.

it considers multiple data inputs about each element. The integrated-selective key provides more choices and more points of identification than a dichotomous key. In addition to these direct keys, the interpreter may find helpful an associative key. It allows the deduction of information not obvious in the image by the combination, in one key, of image data and collateral data. The dichotomous, integrated-selective and associative keys are the three types for SLAR use which receive emphasis in Chapter II of this study.

Although keys to aid in the interpretation of SLAR imagery have been suggested before by Hoffman (1960) and Simpson (1966), the development of a direct dichotomous key for use in the interpretation of SLAR imagery for non-military purposes did not occur until Morain and Coiner's (1970) interpretation of fine resolution imagery from the Garden City test site in Kansas. The resulting fine resolution imagery key was the motivational force behind the present study.

### Summary

In the preceding sections of this chapter, the parameters of a SLAR system affecting the design of an interpretation model were presented. These parameters can be classified into two groups: (1) those associated directly with the SLAR system and (2) those associated with the subject being sensed. Both groups of parameters influence the interpretation model. The image interpretation key is the model considered here and basically should be understood in the framework of its defined characteristics. These characteristics are: (1) function, (2) technicality, (3) information relationships and (4) format. It should be stressed that the characteristics are interdependent and as such must be assessed in combination.

The next chapter of this study will use existing SLAR imagery to construct examples of image interpretation keys. These keys will be drawn from agricultural crop discrimination and the interpretation of natural vegetation. They are intended solely to illustrate the methodology and not to limit their applicability or design.

## CHAPTER II

### CONSTRUCTION OF SLAR INTERPRETATION KEYS

#### Pre-construction Considerations

Construction of interpretation keys should be in the context of data desired by the geographer from the SLAR imagery, the degree of reliability required, and the type of support data available. These considerations are consistent with Colwell's view that it is necessary to define and limit the scope of an interpretation key prior to its construction (Colwell, 1953). Definition and limitation must be accomplished in terms of geographic area or region, types of phenomena, types of imagery, types of collateral support material and the level of expertise of the potential interpreter.

For SLAR interpretation keys, the delimitation of a geographic region should be in terms of the imagery's ability to provide a level of data that is constant throughout the region. This may require that several keys be developed for areas traditionally placed in the same geographic region, e.g., a crop discrimination key for irrigated agriculture in Finney County, Kansas would not be the same as one for Stanton County, Kansas (dryland wheat), although both are normally considered part of the Great Plains. A key "builder" must be careful when extending and generalizing the key from an area with supporting data (ground truth) to an area thought to be similar but without supporting data.

Image interpretation keys for various phenomena, such as vegetation or land use, vary according to the nature of the phenomena and the way the data representing these phenomena appear on the imagery. For example, in agricultural crop discrimination, keys developed thus far for Ka-band imagery have not employed image texture,<sup>10</sup> because this parameter has not yet appreciably aided in the interpretation. In the case of vegetation mapping, however, texture is a major contributor to the interpretation. Of particular note is the fact that radar returns do not provide clear geometric data (size and shape) about the imaged scene in the

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<sup>10</sup>"Texture" may be defined as the spatial variation of gray tone over area.

same manner as a photograph. For example, objects that have a size smaller than a given system's resolution cell, but having resonance with the system's wavelength, will be displayed in the image as gray scale phenomena. However, objects having sizes greater than several times the system's resolution cell will be displayed as *geometric shapes on the image*. With available resolutions, many objects shown on photography as geometric shapes are shown on radar imagery as gray tone and texture. Consequently, keys designed for radar must rely heavily on texture and tone relationships instead of on geometric relationships. Where geometric information is a major identification aid for a class of information (e.g., determination of urban housing quality), SLAR imagery will not easily provide the data. However, where area-extensive geometric shapes are to be determined, such as location of industrial areas, or central business districts, SLAR may prove to be a better tool than photographic imagery (Moore and Wellar, 1969, p. 42). Therefore, it is important to recognize the geometric relationships of a phenomena and to know how such information will appear on an image before attempting to construct an interpretation key.

The types of imagery available to the key designer are also important. If data from several missions using the same system over the same area are available, it will be possible to construct a more reliable and generalized key. Conversely, the more limited the imagery, the less reliable and generalized the key will be. In addition, SLAR imagery dictates the use of certain basic rules for key construction. One of these involves the necessity to account for changes in radar backscatter (gray level shifts) generated by angular dependencies between the scene and the radar system. Among the possible influences on radar backscatter is moisture. Moisture, whenever it is an integral part of the scene, greatly increases the conductivity of the individual elements, thus increasing their backscattering cross section. This means that in cases where moisture is present, it will be necessary to specify the slant ranges for which the key is valid. MacDonald and Waite (1971) have noted this in radar imagery of the Louisiana bayou and Hardy, et al. (1971) reported near-range moisture influence on the image from the marshy, low-lying areas of Yellowstone National Park. Smooth water bodies are an exception to this as they are specular reflectors.

Collateral information, such as that derived from thematic maps, weather data, ground observation or historical records should also be considered when constructing a key. Consequently, it is necessary to provide ways to incorporate these bits of information. This will allow the interpreter to assess all available data in order to determine their relationship to each other and to weight their validity so the information developed can be used in making decisions.

Finally, the level of interpreter expertise is an important consideration in key construction as it affects the terminology used in the textual segments of the key, the format of the key itself, and the type and extent of the graphics employed.

Once the scope of the key has been defined in the above terms, one may proceed with its construction. Construction consists of two parts: textual (narrative) materials and visual or graphic materials. For this study, one type of elimination key (dichotomous) and one type of selective key (integrated-selective) were constructed to exemplify the procedures used in designing keys, and to identify problems encountered when the keys are specifically developed for SLAR imagery.<sup>11</sup>

#### SLAR Systems Used and Keys Developed

The SLAR systems used in this study and the dates and sites of imagery acquisition are given below:

For agriculture, imagery taken of NASA test site 76, Garden City, Kansas was acquired by the following systems during the timeframes indicated:

- (1) AN/APQ-97 Ka-band, September 1965
- (2) Michigan X-band, October 1969
- (3) DPD-2 Ku-band, June 1970

For natural vegetation, imagery of Yellowstone National Park, Wyoming by one system only was interpreted, the AN/APQ-97 Ka-band system flown in September and October 1965.

In order to facilitate further discussion of keys developed in this study, an abbreviated reference system for these radar missions will be used. The Ka-band AN/APQ-97 radar will be referred to as the "Ka-imagery," the Ku-band DPD-2

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<sup>11</sup>These keys are hampered by the small amounts of SLAR imagery available. In particular, there are practically no multiple coverages of the same test site by the same SLAR.

imagery will be labeled "Ku-imagery." For the sake of simplicity in discussing the keys developed in this study, the direct dichotomous key will be called the "direct key" and the direct integrated-selective key will be called the "matrix key." The above abbreviated nomenclature for each radar system and for the keys developed from the mission/system combination is summarized in Table 3.

### Direct Key

Morain and Coiner (1970) developed a direct key for X-imagery. This key was constructed by comparing ground truth and imagery on a field by field basis to distinguish crops, to ascertain their status and to formulate a unique visual signature<sup>12</sup> for each crop/status combination. The same crops with similar status were grouped on worksheets, which were then used for selection of the most descriptive visual image signature. The key shown in Table 4 incorporates the resulting signatures. In this initial key, the authors used the indented key format (Mayr, 1969, p. 278). They found that, although the interpretation was clearly delimited, there was undue complexity leading to interpreter confusion. Moreover, the key was based only on the mid-range portion of the image.<sup>13</sup> A revised and simplified version of this key is shown in Table 5. Two changes were made: (1) the format was altered from indented to bracketed (after Mayr, 1969, p. 279), and (2) signatures which reinforced the identification of a given crop but which were not essential for its identification were removed. The importance of simplification cannot be overstressed for, the simpler the key, the more successful key-aided interpretations are (Narva, 1971, p. 299).

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<sup>12</sup>"Signature" is a term used to describe a unique feature or features within the imagery, i.e., gray tone, texture or shape, which distinguishes one imaged phenomena from another.

<sup>13</sup>"Near," "mid" and "far" range are the terms used to designate the depression angle of the sensor at time of image acquisition. "Far range" refers to low depression angles, from approximately 5° to 10°, "mid-range" indicates medium depression angles, from approximately 10° to 30°, and "near range" is high depression angles, from approximately 30° to 75°. Depression angles will vary with radar systems, therefore, no direct correlation in the mid, far and near ranges may exist between systems.

TABLE 3  
 ABBREVIATED NOMENCLATURE FOR RADAR SYSTEMS AND INTERPRETATION KEYS

System Name	Date Flown	Object and Place	Abbreviated System Name	Key Developed	Abbreviated Key Name
AN/APQ-97 Ka-band	Sept. 1965	Agriculture Garden City, Kansas	Ka - imagery	Direct Dichotomous	Direct
Michigan X - band	Oct. 1969	Agriculture Garden City, Kansas	X - imagery	Direct Dichotomous	Direct
DPD-2 Ku - band	July 1970	Agriculture Garden City, Kansas	Ku - imagery	Direct Dichotomous	Direct
AN/APQ-97 Ka - band	Sept/Oct 1965	Natural Vegetation, Yellowstone National Park, Wyoming	Ka - imagery	Direct Integrated Selective/ Associate Dichotomous	Matrix Associate

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TABLE 4

INITIAL DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT  
GARDEN CITY, KANSAS (X-BAND IMAGERY)

- A. Field has a moderately high to high return (light gray to white on radar positive) (with respect to HH)
- B. Field has a homogeneous tone (with reference to HH)
- C. Field displays a shift in tone from HH (lighter to HV (darker))
- D. Amount of tone shift is relatively unpronounced
  - E. HV tone is homogeneous-----sugar beets; or wheat > 3"
  - EE. HV tone is not homogeneous-----fallow
- DD. Amount of tone shift is relatively pronounced
- CC. Field does not display a tone shift HH (lighter) to HV (darker)
- F. Field displays a tone shift from HH (darker) to HV (lighter)
- G. Field has evident lineations-----cut alfalfa
- GG. Field does not have evident lineations
- FF. Field does not display a tone shift from HH (darker) to HV (lighter)
- BB. Field does not have a homogeneous tone
- AA. Field does not have a moderately high to high return
- H. Field has medium low to moderate return (medium dark to medium light on radar positive)
- I. Field has a homogeneous tone (with reference to HH)
- J. Field has lineations parallel to long axis of field
- K. Tone shift is evident from HH (dark) to HV (light)-----maturing alfalfa (flood irrigated)
- KK. Tone shift is not evident
- JJ. Field does not have lineations
- L. Field displays medium coarse texture
- LL. Field has no obvious image "texture"-----grain sorghum (rows ⊥ flight line)
- M. Field has a moderate tone shift (HH to HV)-----alfalfa > 12"
- MM. Field has an unpronounced tone shift-----wheat > 3"
- II. Field does not have a homogeneous tone
- N. Cultivation pattern is observable (particularly on HV image)-----emergent wheat
- NN. Cultivation pattern is not observable
- O. Boundary shadowing is observable-----mature corn
- OO. Boundary shadowing is not observable
- HH. Field does not have moderately low to moderately high return
- P. Field has very low return (very dark gray to nearly black on radar positive)
- Q. Field has a homogeneous appearance-----recently filled
- QQ. Field does not have a homogeneous appearance
- PP. Field does not have very low return

After Morain and Colner, 1970, p. 7. "Homogeneous" refers to the uniformity of return intensity within the boundaries of a given field, i.e., there is no evident mottling of tone.

TABLE 5  
 REVISED DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT  
 GARDEN CITY, KANSAS (X-BAND IMAGERY)

A	Field is light gray to white on HH -----	Go to B
A'	Field is <u>not</u> light gray to white on HH -----	Go to D
B	Field gray tone shifts from light gray/white HH to medium gray HV-----	Go to C
B'	Field gray tone shifts HV <u>lighter</u> than HH -----	<u>cut alfalfa</u>
C	Field gray tone on HV homogeneous -----	<u>sugar beets; or wheat &gt;3"</u>
C'	Field gray tone on HV <u>not</u> homogeneous -----	<u>fallow</u>
D	Field has medium to dark gray tone on HH -----	Go to E
D'	Field has very dark gray tone on HH -----	<u>recently tilled</u>
E	Field gray tone is homogeneous -----	Go to F
E'	Field gray tone is <u>not</u> homogeneous -----	Go to I
F	Field has lineations parallel to long axis -----	<u>maturing alfalfa</u>
F'	Field does <u>not</u> have lineations -----	Go to G
G	Field has medium coarse texture -----	<u>grain sorghum (rows <math>\perp</math> flight line)</u>
G'	Field does <u>not</u> have medium coarse texture -----	Go to H
H	Field has same gray tone on HH and HV -----	<u>wheat &gt;3"</u>
H'	Field has moderate gray tone shift HH to HV -----	<u>alfalfa &gt;12"</u>
I	Field has a cultivation pattern observable -----	<u>emergent wheat</u>
I'	Field does <u>not</u> have cultivation pattern observable but displays pronounced boundary shadowing -----	<u>mature corn</u>

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A direct key for Ka-imagery is shown in Table 6. This key was designed as a tool for acquiring specific data (crop types) desired by the user and is not necessarily the limit of information contained in the image. It is based on data from depression angles between  $18^{\circ}$  and  $23^{\circ}$  and the HH/HV image pair (Figure 5).<sup>14</sup> Changes in gray scale were the discrimination criteria on which this key was built. Reliance on gray scale alone may have caused some inaccuracies in the key, since gray scale is subject to processing manipulation and is not a quantitative measure. From the interpreter's point of view, the return is also non-quantitative because of system variables such as gain, which when altered change the gray scale on the image. These factors may influence the accuracy and transferability properties of a key, and they possibly have influenced the Ka-imagery key in Table 6. On the other hand, the X-imagery key may be more valid than the Ka-imagery key since the increased resolution of its applicable radar system allows the identification of morphic data which remain constant regardless of gray scale variation (Morain and Coiner, 1970, p. 4).

A direct key for Ku-imagery is depicted in Table 7. This key was originally developed to see how much discrimination between crop types could be derived from the DPD-2 radar image (Lockman, et al., 1970). A narrow strip of near-range data was used to prepare the key, with gray scale the only attribute. Re-interpretation indicates that the inclusion of an additional morphic attribute, that of field shape, would have increased the key's accuracy and reliability. A revised direct key for Ku-imagery, incorporating this additional signature, is shown in Table 8. It should be noted that despite the poor visual quality of the Ku-imagery (Figure 6), a key could be developed and employed to interpret usable data.

A logical extension of the direct keys shown here would be a multiple range key that accounts for the entire image (near, mid and far ranges). Unfortunately, it was impossible to construct multiple range keys for crop discrimination with the imagery available because nearly all imagery of Garden City had ground support data for only a limited angular range.

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<sup>14</sup>The AN/APQ-97 radar provides the interpreter with two simultaneously acquired images. One shows the scene in terms of energy transmitted and received in the same polarization (horizontal transmit, horizontal receive — HH). The other shows the scene in terms of energy transmitted in one polarization but received in another (horizontal transmit, vertical receive — HV).

TABLE 6  
 DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT GARDEN CITY, KANSAS  
 (For use with AN/APQ-97 Ku-band imagery for September)

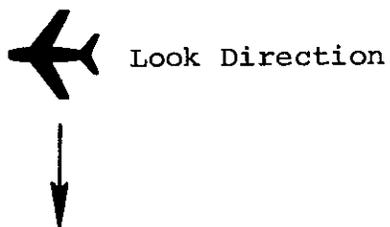
A	HH and HV are white -----	sugar beets
A'	HH is not white -----	Go to B
B	HH is light gray -----	Go to C
B'	HH is not light gray -----	Go to D
C	HH and HV are light gray -----	corn
C'	HH is light gray, HV almost white -----	alfalfa
D	HH is gray -----	Go to E
D'	HH is <u>not</u> gray -----	Go to G
E	HH <u>has even</u> gray tone -----	Go to F
E'	HH has <u>uneven</u> gray tone (also HV) -----	fallow
F	HV has similar gray scale to HH -----	wheat
F'	HV has lighter gray scale than HH -----	sorghum
G	HH is dark gray to black, even gray scale -----	Go to H
G'	HH is dark gray to black, uneven gray scale (possibly more noticeable in HV)--	Go to I
H	Area has regular boundaries -----	recently tilled
H'	Area has irregular boundaries -----	standing water
I	HV shows major shift toward gray to light gray -----	pasture
I'	Field shows only minor shift toward gray -----	fallow

Figure 5. Segment of AN/APQ-97 Ka-Band Imagery of the Garden City, Kansas Test Site.

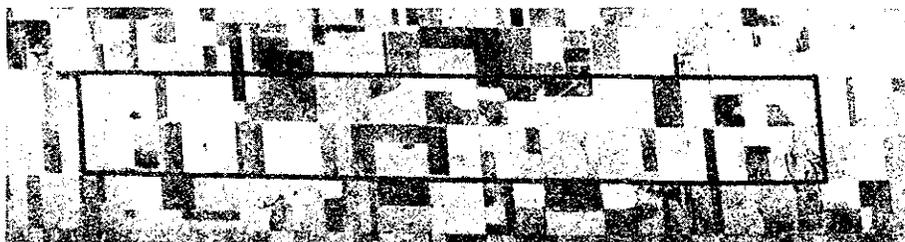
The outlined portion was the study area for the key constructed in Table 6. It is in the mid-range of the image and was acquired at depression angles between  $18^{\circ}$  and  $23^{\circ}$ .



HH



HV



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TABLE 7  
 DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT GARDEN CITY, KANSAS  
 (For use with NASA DPD-2 Ku-band imagery near range for July)

A	Field images white or light gray on both HH and VH -----	sugar beets
A'	Field images white to black HH and light gray to black VH ----- See B	
B	Field images white on HH and light gray on VH -----	corn (rows parallel to line of flight)
B'	Field images light gray to black on HH and light gray to black VH-- See C	
C	Field images light gray on HH to gray on VH -----	corn (rows perpendicular to line of flight) grain sorghum, alfalfa
C'	Field images gray on HH to gray on VH ----- See D	
D	Field images gray on HH and gray on VH -----	wheat stubble (unturned)
D'	Field images dark gray on HH to dark gray on VH ----- See E	
E	Field is dark gray on HH and VH with variations in the field from medium gray to dark gray -----	fallow, pasture and volunteer crop regrowth
E'	Field is black -----	tilled (row harrowing, drilling, etc)

TABLE 8  
 REVISED DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT  
 GARDEN CITY, KANSAS  
 (For use with NASA DPD-2 Ku-band imagery, near range for July)

A	Field is circular in shape-----	See B
A'	Field is <u>not</u> circular in shape-----	See C
B	Field is white on HH and light gray on VH-----	CORN
B'	Field is medium gray to black-----	FALLOW
C	Field images white or light gray on both HH and VH-----	SUGAR BEETS
C'	Field images white to black HH and light gray to black VH-----	See D
D	Field images white on HH and light gray on VH-----	CORN (rows = flight line)
D'	Field images light gray to black on HH and light gray to black on VH-----	See E
E	Field images light gray on HH to gray on VH-----	CORN (rows <u>⊥</u> flight line), GRAIN SORGHUM, ALFALFA
E'	Field images gray on HH to gray on VH-----	See F
F	Field images gray on HH and gray on VH-----	WHEAT STUBBLE (unturned)
F'	Field images dark gray on HH to dark gray on VH-----	See G
G	Field is dark gray on HH and VH with variations in the field from medium gray to dark gray-----	FALLOW, PASTURE and VOLUNTEER CROP REGROWTH
G'	Field is black-----	RECENTLY TILLED

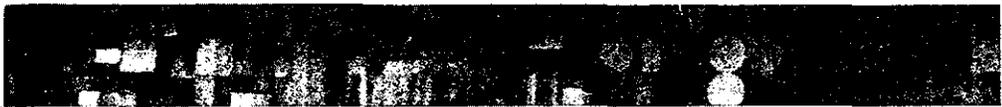
Figure 6. Segment of NASA DPD-2 Imagery of the Garden City, Kansas Test Site.

This imaged segment from the near-range was used to produce the keys in Tables 7 and 8.

Note the poor visual quality of the image when compared with the Ku-Band imagery in Figure 5. Despite the quality constraint, key construction was possible.



HH



VH

## Matrix Key

Geographers at the University of Kansas have, for a number of years, been interested in the mapping and classification of vegetation by use of imaging radar (Morain and Simonett, 1967; Hardy, et al., 1971). The construction of keys for natural vegetation is perhaps more involved than that for agriculture as the interpretation requires integration of both tonal and textural information. One way to handle this added level of complexity is to alter the key format, as shown in Table 9.<sup>15</sup> The key was necessarily constructed subsequent to an initial interpretation, because gray scale and textural relationships had to be determined from the image, and thus represents a method by which the reproducibility of the interpretation could be validated. Since a "matrix key" illustrates the gray scale/texture relationships in the image, it may also provide an excellent training aid for other interpreters.

The construction of this key is based on the concept of a matrix within a matrix. The image is divided into gray tone levels, from dark gray-black to light gray-white. (Normally, interpreters can distinguish between three and six gray levels). The ordinate and abscissa of the matrices are the polarizations. Within each gray scale square on the matrix, a texture matrix is inserted, with values such as fine, medium and coarse textures given.

The matrix key offers several advantages to the more experienced interpreter: (1) Each point decision does not require retracing the entire logic of the interpretation as is necessary in the dichotomous key. (2) The key may provide an excellent method of interpretation transfer from one interpreter to another and may substantially increase the consistency of a given interpretation (Bigelow, 1966, p. 3). (3) The matrix key surfaces those points within the interpretation where the image fails to clearly separate data elements. For example, note the overlap between Lodgepole Pine, Mixed Conifer and Medium Elevation Dry Area in Table 9. This identification of areas of ambiguity allows the interpreter to concentrate on associate data (in the form of associate keys) for those categories where clear-cut identification is not possible.

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<sup>15</sup>This key was initially designed by S. A. Morain in conjunction with vegetation studies, still in progress of Horsefly Mountain, Oregon.

		HH										
		COARSE (TEXTURE)		MEDIUM (TEXTURE)		FAINT (TEXTURE)		ABSENT (TEXTURE)				
Tone		Dark	Medium	Light	Dark	Medium	Light	Black	Dark	Medium	Light	
HY	COARSE (TEXTURE)	Dark	Medium	Light	Dark	Medium	Light	Black	Dark	Medium	Light	
	Dark											
	Medium											
	Light											
MEDIUM (TEXTURE)	Dark	Medium	Light	Dark	Medium	Light	Black	Dark	Medium	Light		
Dark												
Medium												
Light												
FAINT (TEXTURE)	Dark	Medium	Light	Dark	Medium	Light	Black	Dark	Medium	Light		
Dark												
Medium												
Light												
ABSENT (TEXTURE)	Black	Dark	Medium	Light	Black	Dark	Medium	Light	Black	Dark	Medium	Light
Black												
Dark												
Medium												
Light												

Table 9. Matrix Key for Natural Vegetation at Yellowstone National Park. (For use with Ka-Band Imagery, September and October)

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## Other Types of Keys

Although this study is predominantly concerned with the development of direct keys, the same strategies can be applied to develop associate keys, which integrate radar derived data with other sources. An associate key for use in assigning vegetation types at Yellowstone National Park is shown in Table 10. The key integrated elevation data derived from maps with imagery data to permit the interpreter to make deductions about natural vegetation.

Some other approaches which may be helpful to the geographer are the analogous key, the error key and the multi-system key. An analogous key would be a useful tool to support initial SLAR reconnaissance of a previously unimaged area. The interpreter could check imagery already available for an area similar to that being newly imaged. By doing this, he could provide himself with a basis for his initial interpretation.<sup>16</sup>

The error key, although a potentially useful tool, has not been extensively employed. Simply stated, the error key is a catalog of errors made, and it provides correction techniques. Smith (1953) first proposed the use of error keys in his work on terrain analysis.

The multi-system key in Table 11 is an attempt to use a direct key to extract data from images acquired nearly simultaneously by two different radar systems. The simultaneous use of multiple radar frequencies is becoming more widely recognized. However, methods to extract information from multi-frequency images have not been studied in depth. The multi-system key for X and Ka-imagery was designed as follows. A direct key was first prepared for the X-imagery (Table 5, p. 23) and, in those cases where clear-cut crop discrimination could not be obtained, the Ku-imagery was incorporated in a combined direct key to resolve between-crop ambiguities. With additional frequencies, this approach is identical to that employed in multispectral analysis, except that in the microwave region, variations in local weather conditions or conditions of solar illumination are less of an interpretation problem.

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<sup>16</sup>This approach could be used to solve the interpretation problem posed in the Introduction, namely, the identification of worldwide ecological analogs. The researcher could define, in terms of a key, the imaged properties of a high production area and then by a "best fit" technique, identify the ecological analogs.

TABLE 10  
 ASSOCIATE DICHOTOMOUS KEY FOR NATURAL VEGETATION  
 YELLOWSTONE NATIONAL PARK  
 (For coordinated use with Ka-band imagery and USGS 1:125,000 map N4408)

A	Area has a medium texture and medium gray tone (HH)-----	Mixed Coniferous Forest
A'	Area does <u>not</u> have a medium texture and gray tone varies from light to black ----- See B	
B	Area has a coarse texture appearing "cottony" to observer with medium to light gray tone (HH) -----	Douglas Fir (probable)
B'	Area has fine texture with light gray to black tone-- See C	
C	Area between 6,500 to 8,500 feet with light gray to medium gray tone -----	Marsh or Low Elevation Wet Areas
C'	Area between 6,500 to 10,000 feet with dark gray to black tone ----- See D	
D	Area between 6,500 to 8,500 feet ----- See E	
D'	Area between 8,500 to 10,000 feet ----- See F	
E	Area has dark gray tone (HH) and is homogeneous -----	Low Elevation Dry Area
E'	Area has black tone -----	Lake or Other Water Bodies
F	Area has medium gray tone (HH) -----	Medium and High Elevation Dry Areas
F'	Area has dark gray tone-----	Upland Meadow (possible)

TABLE 11  
 DIRECT DICHOTOMOUS KEY FOR CROP TYPES AT GARDEN CITY, KANSAS  
 (For combined use with X-band and Ku-band imagery for October)

A	Field is light gray to white on HH (X-band) -----	Go to B	
A'	Field is <u>not</u> light gray to white on HH (X-band) -----	Go to E	
B	Field is white on HH/HV (Ku-band) -----		<u>sugar beets</u>
B'	Field is not white on both HH/VH (Ku-band) -----	Go to C	
C	Field gray tone shifts from light gray/white (X-band) HH to medium gray HV -----	Go to D	
C'	Field gray tone shifts HV (X-band) lighter than HH -----		<u>cut alfalfa</u>
D	Field gray tone on HV (X-band) homogeneous and field appears gray on Ku-band HH -----		<u>wheat &gt; 3"</u>
D'	Field gray tone on HV (X-band) <u>not</u> homogeneous -----		<u>fallow</u>
E	Field has medium to dark gray tone on HH (X-band) -----	Go to F	
E'	Field has very dark gray tone on HH (X-band) -----		<u>recently tilled</u>
F	Field gray tone is homogeneous -----	Go to G	
F'	Field gray tone is <u>not</u> homogeneous -----	Go to J	
G	Field has lineations parallel to long axis on HV (X-band) and is light gray HH (Ku-band) shifting toward medium gray HV (Ku-band) -----		<u>alfalfa</u>
G'	Field does not have lineations (X-band) -----	Go to H	
H	Field has medium coarse texture (X-band) and shifts from gray HH (Ku-band) toward light gray VH (Ku-band) -----		<u>grain sorghum</u>
H'	Field does <u>not</u> have medium coarse texture (X-band) -----	Go to I	
I	Field has same gray tone on HH and HV (X-band) and tends to shift from medium gray HH (Ku-band) toward dark gray VH (Ku-band) -----		<u>wheat &gt; 3"</u>
I'	Field has moderate gray tone change from HH to HV (X-band) and has gray tone shift from light gray HH (Ku-band) toward medium gray VH (Ku-band) -----		<u>alfalfa &gt; 12"</u>
J	Field has cultivation pattern observable (X-band) -----		<u>emergent wheat</u>
J'	Field does not have cultivation pattern observable, displays pronounced boundary shadowing ( X-band ) and medium gray on HH and VH (Ku-band) -----		<u>mature corn</u>

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## Visual Aids

Visual aids are critical to the correct interpretation of imagery because desired data in the imagery are transferred visually by the interpreter to another medium (Manual of Photo Interpretation, 1960, p. 112). This means that the most successful approach to interpretation usually rests on visual association, i.e., the comparison of one visual representation with another, rather than the comparison of a descriptive/verbal representation with visual representation.<sup>17</sup>

For one who is constructing keys, an optimum technique for supporting the interpretations could be the creation of a display of previously identified object types which require repeated identification in the images under study. This would allow another interpreter to duplicate the original interpretations by selecting the most similar objects from the display. The displays which follow reveal several methods of potential usefulness with radar, however, the reader is cautioned that these examples are based on single image data sets and merely exemplify format. In this study, three different formats of supporting graphics were developed. These were: (1) the context graphic, (2) the branch graphic and (3) the matrix graphic.

The context graphic, shown in Figure 7, was developed to support analysis of the Ka-imagery. This graphic is used in conjunction with the textual segment of the direct key shown in Table 6, p. 25. Since terminology is relative in the textual description, it is important to display to the interpreter the meaning of a term such as "light gray" as it relates to the image's multiple gray scale values. The graphic's purpose is to illustrate how specific crop types generally appear on imagery in the context of adjacent fields/crops.

The branch graphic is a key that visually presents the dichotomous decisions required to make identifications on an image. For the example shown in Figure 8, data from the Ka-imagery was used. This figure displays the dichotomous branching required to break down the data elements of the radar image and is a flow diagram of the direct key shown in Table 6, p. 25.

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<sup>17</sup> Considerable research on human factors in interpretation has been conducted by the Army Behavioral Research Laboratories and is extensively reported in Bigelow (1963 and 1966), Sadacca (1963) and Narva (1971).

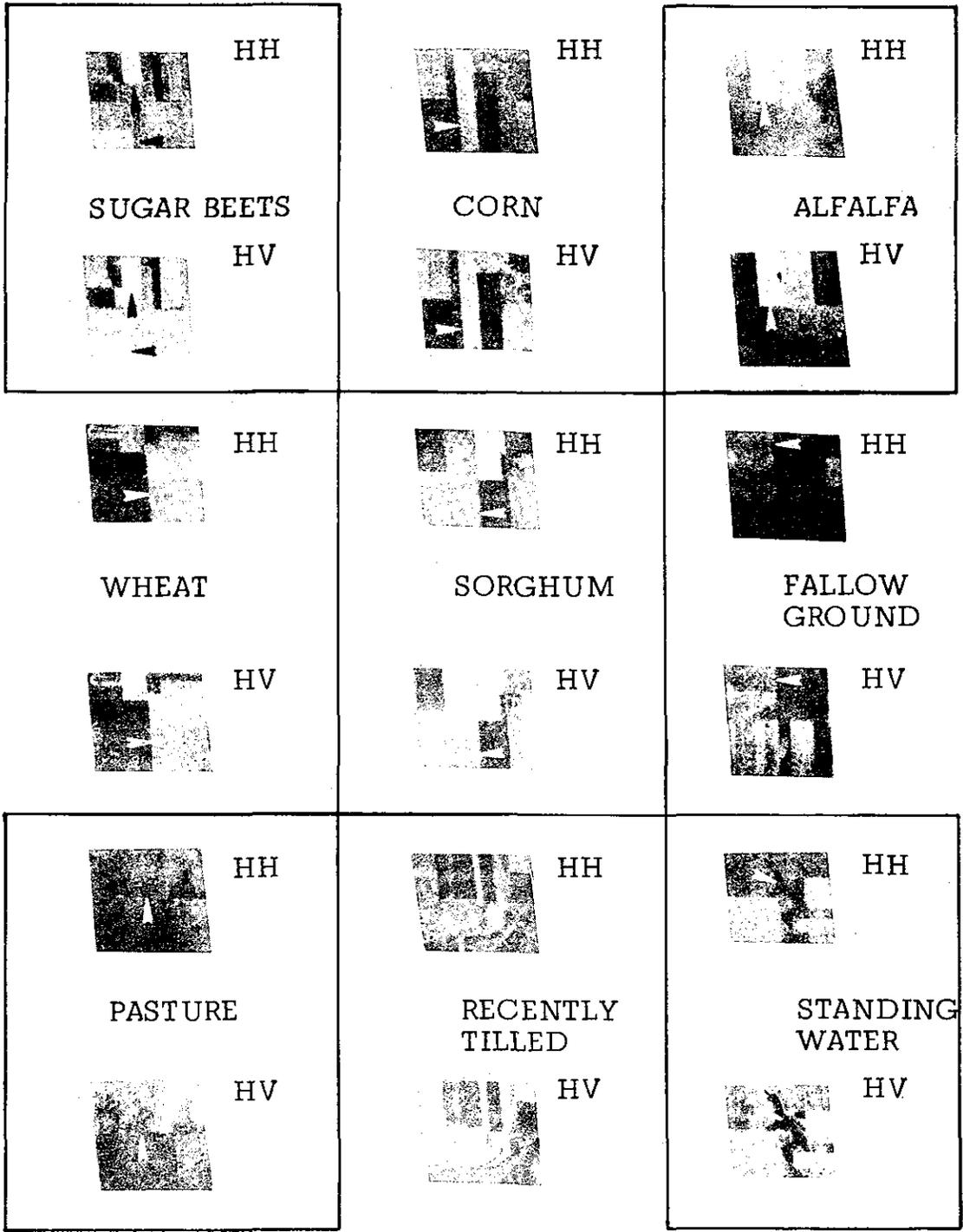


Figure 7. Context Graphic for the AN/APQ-97 Ka-Band Imagery of the Garden City, Kansas Test Site.

Note that the graphic defines the gray scale of each field relative to other fields of varying gray scale.

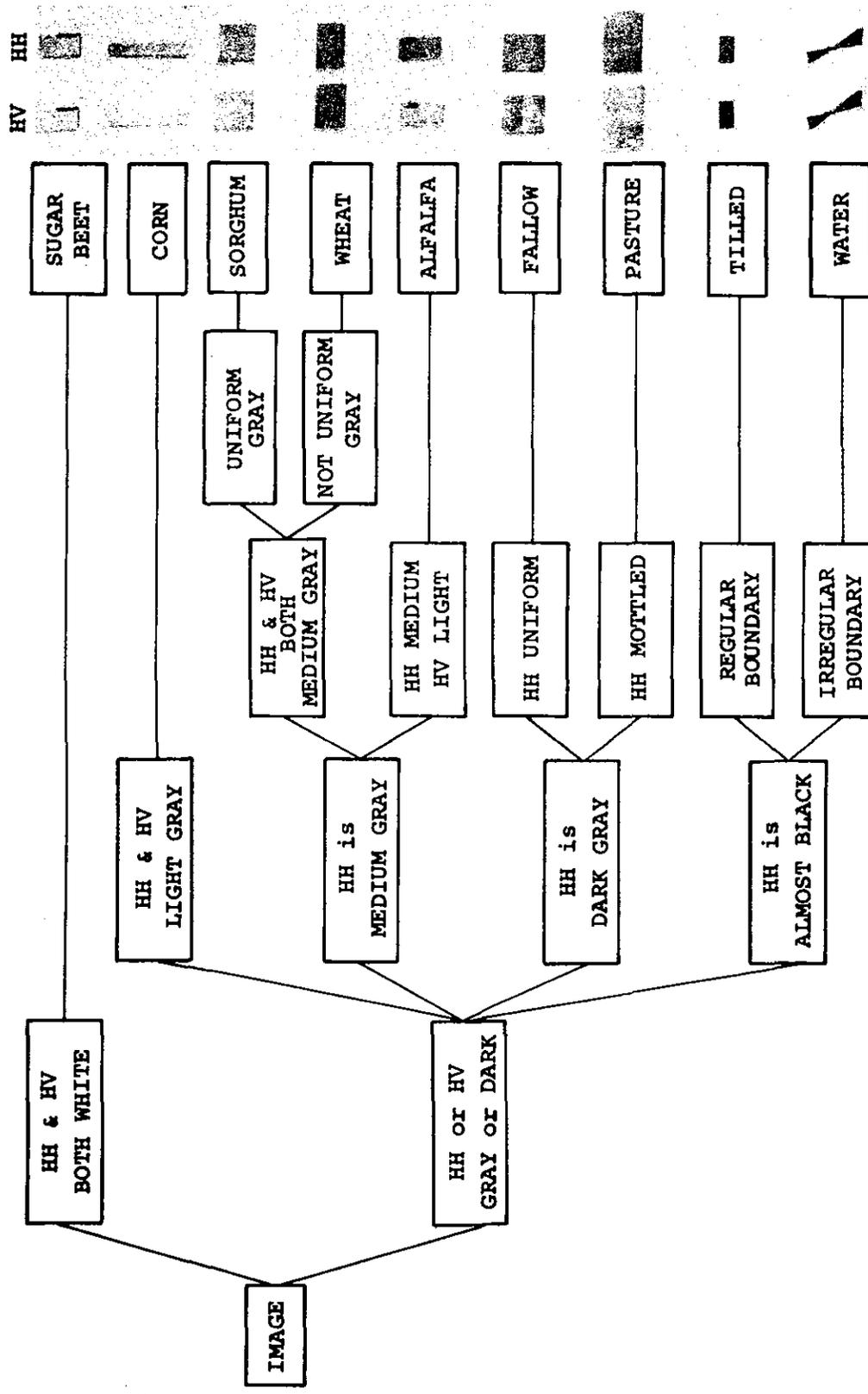


Figure 8. Branch Graphic for the AN/APQ-97 Ka-Band Imagery of the Garden City, Kansas Test Site. This graphic is a flow diagram of the decisions described in the direct key shown on Table 6.

The matrix graphics shown in Figures 9 and 10 were constructed by substituting image chips for textual material in the matrix key previously discussed (Table 9, p. 31). These graphics are particularly suited for the interpretation of dual polarized radar imagery because they allow the direct integration of imagery data from both radar polarizations. The matrix graphics prepared here are for crop type and natural vegetation Ka-imagery. It should be pointed out that both the matrix key and graphics are basically visual associative interpretation aids, and they place less emphasis on textual material. As a result of this feature, they may facilitate use and may offer higher reliability than other interpretation aids.

### Summary

In this chapter, a number of approaches to the textual and graphic presentation of keys have been discussed. It has long been held that the best textual presentation is the dichotomous key. As Colwell (1953) states:

It [the dichotomous key] has two important advantages: it exploits the fact that the human mind usually can distinguish any given object or condition from one other object or condition more readily than from a group of other objects or conditions. The dichotomous key's second important advantage is that, by virtue of its repeated two-branching nature, it permits subdividing the entire group of objects or conditions, first into two halves, each of these in turn into two halves, etc., until by this repeated forking each object or condition is relegated to its own particular fork, at which point the desired answer is given.

For the purpose of this study, the matrix key was developed because of its similarity to the dichotomous key and its ability to deal specifically with the dual polarized imagery produced by SLAR. As the supply of radar imagery increases, visual support graphics may prove to be the most effective method of revising and generalizing radar interpretations. Those direct keys constructed from imagery now available will be subjected to interpreter tests in the next chapter to examine the validity of the key approach.

		HH				
		ALMOST WHITE	LIGHT GRAY	MEDIUM GRAY	DARK GRAY	ALMOST BLACK
HV	ALMOST WHITE	SUGAR BEET				
	LIGHT GRAY		CORN	ALFALFA	(MOTTLED) PASTURE	
	MEDIUM GRAY		SORGHUM	WHEAT		
	DARK GRAY				FALLOW	
	ALMOST BLACK					RECENTLY TILLED

JBC-1971-CRINC

Figure 9. Matrix Graphic for the AN/APQ-97 Ka-Band Imagery of the Garden City, Kansas Test Site.

The matrix key is particularly suited for the interpretation of dual polarized imagery. In the above figure, only one parameter (gray scale) was used in contrast to Figure 10 where the matrix incorporates two parameters (gray scale and texture).

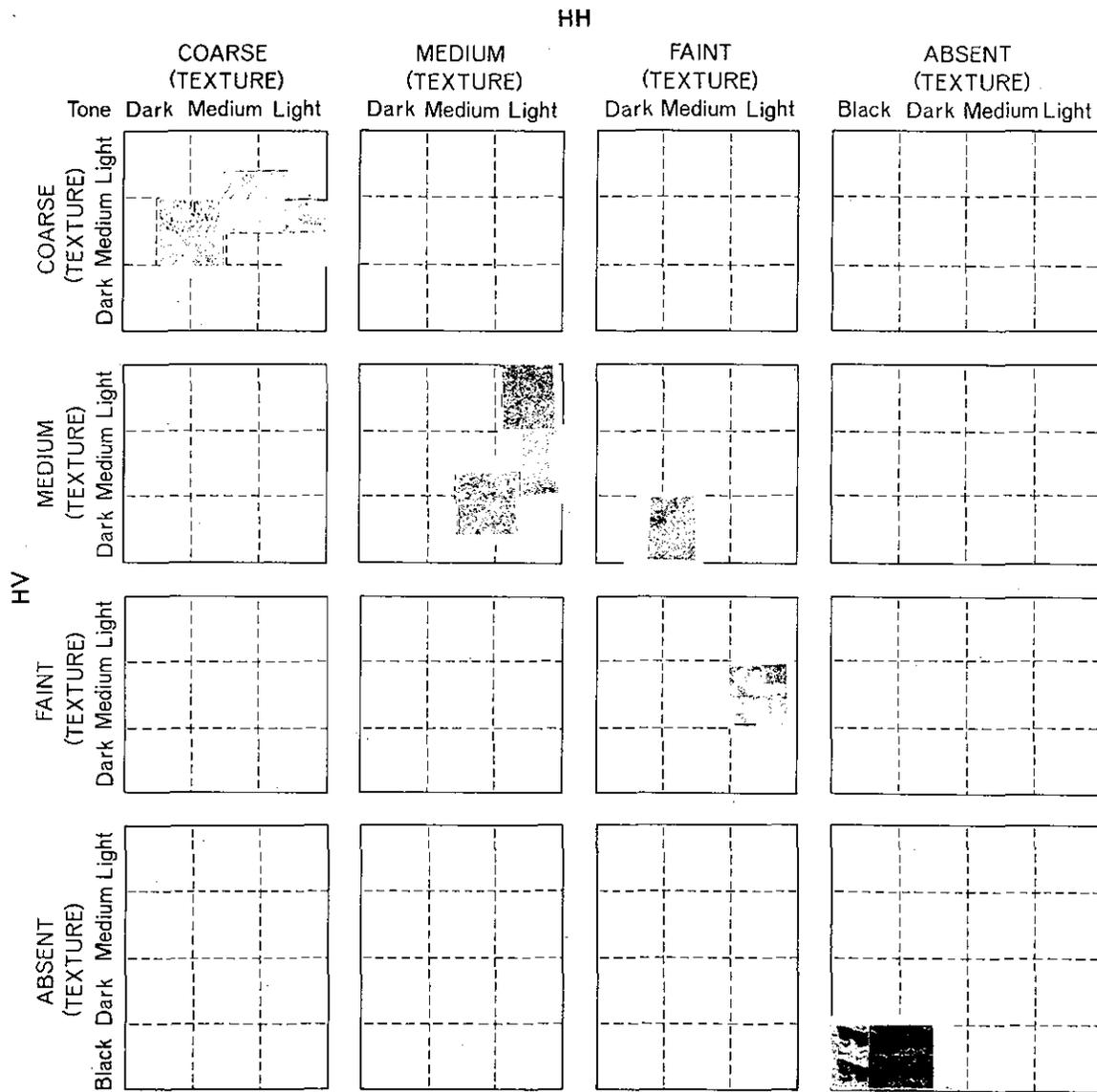


Figure 10. Matrix Graphic for AN/APQ-97 Ka-Band Imagery of Yellowstone National Park, Wyoming.

This graphic substitutes image chips of vegetation classes for narrative used in Table 9. Two parameters (gray scale and texture) are shown.

## TESTING OF SLAR INTERPRETATION KEYS

Methodology

Two of the keys, the Ka and Ku-imagery direct keys (Tables 6 and 7, pp. 25 and 27), developed in Chapter II were subjected to interpreter tests to assess their validity as interpretation models. These keys were chosen because the related imagery could be disseminated<sup>17</sup> and the amount of time to take the test sequence was not thought to be an unreasonable imposition on interpreters taking the tests. Twenty interpreters known from the literature to have exposure to radar imagery or agricultural interpretation were forwarded test packets which contained (1) the imagery to be interpreted (Ka and Ku), (2) the keys developed for use with each imagery and (3) background information on the Garden City test site. Examples of these materials are contained in Appendix I, Parts 1-6. No attempt was made to define a precise procedure for conducting the interpretations. The instructions merely requested that the interpreter use the keys to analyze 55 fields shown on an overlay for the two images (each consisting of an image pair). Five questions were asked about the interpreter's experience, and each interpreter was instructed to briefly describe the interpretation method used on the test.

Of the twenty interpreters asked to participate, ten responded by completing the test. Of the ten, eight were either professional geographers active in the field of remote sensing or geography graduate students specializing in remote sensing. The remaining two respondents were involved in research and land management. Because of the small number of respondents, no attempt was made to use inferential statistics.<sup>18</sup> This situation would still have existed had all requests been answered. The key test for the Ku-imagery was based solely on a textual key, whose designed level of discrimination grouped fields (cropped and non-cropped) with similar radar returns. No unique signature was given for each crop in the area imaged. Six groups were developed for 10 crops or field conditions.

<sup>17</sup>X-imagery, from which the direct key on Table 5, p. 23 was developed, has controlled dissemination.

<sup>18</sup>It is generally accepted that a minimum sample size of approximately 30 is required before inferential statistical methods are reliable (Cole and King, 1968, pp. 117-118).

The key for the Ka-imagery consisted of both a textual key and a visual aid (context graphic), with the design of the key providing a unique signature for every crop or field condition (10 in number) on the imagery. Because of the design differences in the two keys, the units measured were not comparable (crops versus crop groups); therefore, no direct comparisons were made between the results of the two key tests. Testing was further complicated in that the relative level of difficulty of the tests could not be assessed.

## Results

The results of the interpretation tests are summarized in Table 12. This table ranks the interpreters according to their general experience as expressed in responses to the five experience questions, and it gives each interpreter's percentile correct score for the Ka and Ku tests.

On the Ka test, scores ranged from 57 per cent to 26 per cent correct, with an average score of 41 per cent correct identifications based on ground truth. As expected, interpreters with the most overall experience scored the highest. This is reinforced by a map of the best and worst interpretation results shown in Figure 11. The figure also highlights the difference between errors made by an experienced interpreter and a less experienced interpreter. Errors by the experienced interpreter involved the selection of crops which had similar radar returns. For instance, confusion between sugar beets and alfalfa (both with bright returns) and between sorghum and wheat (both with medium returns) caused many of the experienced interpreter's errors. In other words, if the experienced interpreter selected the wrong crop, his error was a matter of differentiation between two similar gray scales.<sup>19</sup> The less experienced interpreter not only failed to distinguish between crops with similar radar returns, but also could not consistently distinguish crops with dissimilar radar returns.

The results of the Ka test can be viewed in different perspective from that above. Since each field was a discrete unit about which the interpreter had to make a decision, a map of the composite correct score by all interpreters for

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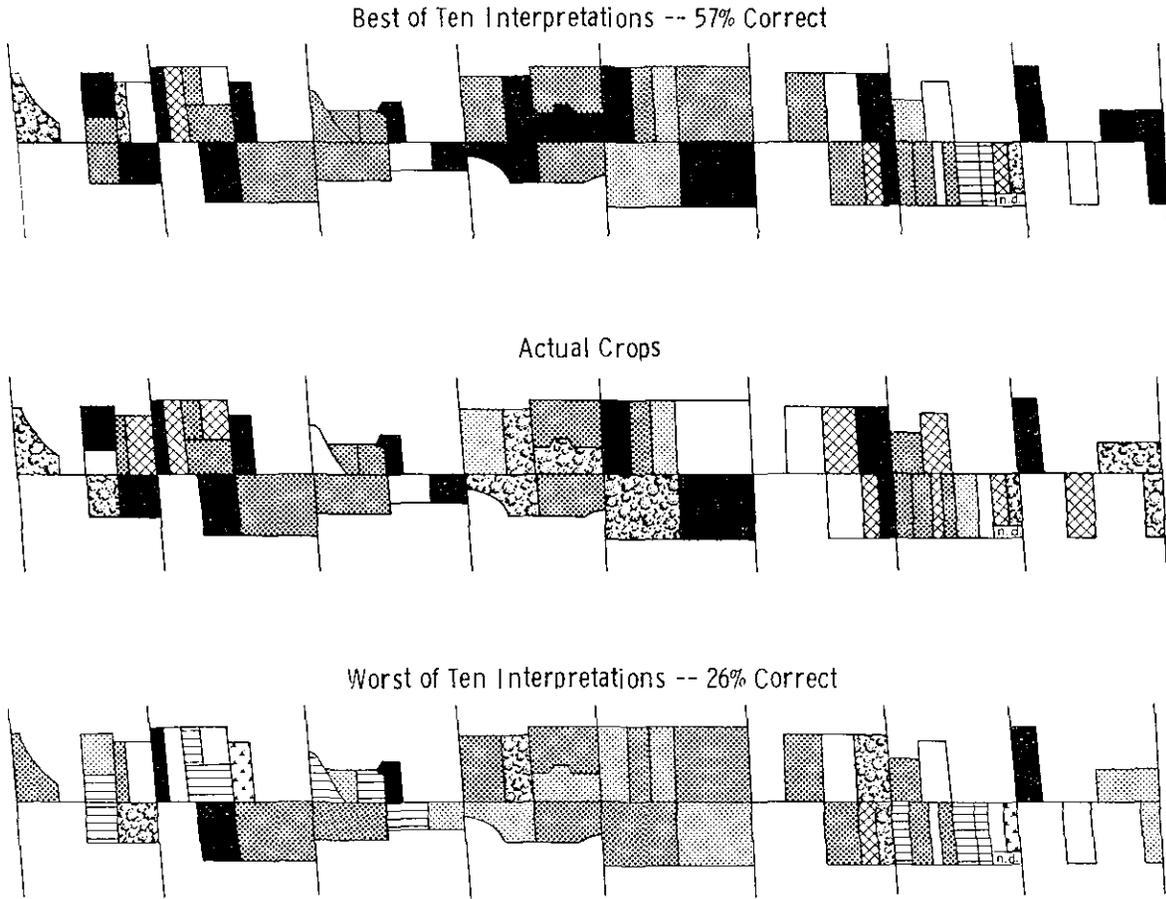
<sup>19</sup>This has been the case with other interpretation methodologies applied to the same imagery (Schwarz and Caspall, 1968, p. 242 and Haralick, et al., 1970, p. 136).

TABLE 12  
 RESULTS OF IMAGE INTERPRETATION TESTS:  
 PERCENTAGE CORRECT CROP IDENTIFICATION BY TEN IMAGE INTERPRETERS  
 USING KEYS DERIVED FROM K $\alpha$ -BAND AND KU-BAND IMAGERY

Interpreters  (Ranked according to general interpretation experience; 1 = high)	% Correct Crop Identification	
	AN/APQ-97 K $\alpha$ -band 9/65	DPD-2 Ku-band 7/70
1	44	34
2	31	35
3	57	55
4	48	52
5	35	50
6	43	68
7	33	68
8	44	25
9	52	41
10	<u>26</u>	<u>57</u>
Average	41	49

(After Coiner and Morain, 1971, p. 406)

FIGURE 11. RESULTS OF THE BEST AND WORST TEST SCORES FOR Ka-IMAGERY AS COMPARED WITH ACTUAL CROPS IMAGED. (Legend Shows Direct Key Gray Scale Values for Each Crop)



Legend

Gray Scale Representation	Map Legend	Gray Scale Representation	Map Legend
HV  HH	SUGAR BEETS	HH	WHEAT
HV  HH	ALFALFA	HH	FALLOW
HV  HH	CORN	HH	PASTURE
HV  HH	SORGHUM	HH	RECENTLY TILLED
		n. d.	NO DATA

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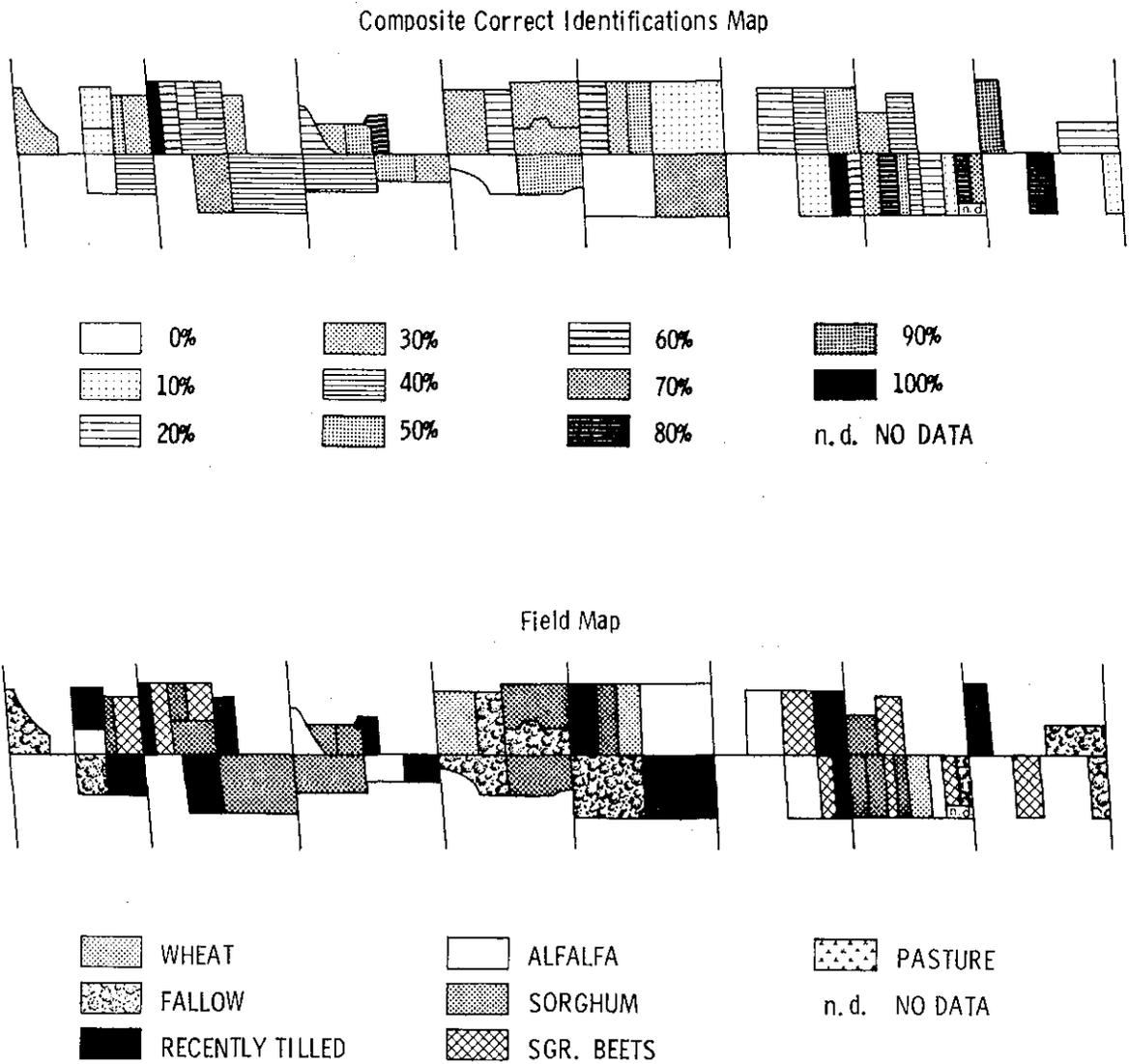
each field could be made. This map, with a corresponding field map, is shown as Figure 12. Figure 12 illustrates two important results of the interpretation tests. (1) Certain crops of field conditions consistently had higher per cent correct scores. These were recently tilled and sugar beets. Recently tilled fields represented one extreme of the gray scale (very dark) and sugar beets, the other (very light) on both the HH and HV polarizations; therefore, confusion was less likely to occur. (2) Neither field size nor the location of the field within the test site appeared to affect correct identifications. This was a result of two spatial properties: (a) the area covered was small enough to mitigate distance decay and (b) the fields selected were large enough at the image scale and had sufficiently defined boundaries to allow the interpreter to discriminate gray scales between fields.

The results of the test can also be studied by aggregating the interpreter decisions. This is shown as a matrix in Table 13, with the row showing the correct field or crop conditions and the columns showing the interpreter decision. The row/column orders of crops in Table 13 were arranged to reflect their gray scale relationships, the upper left hand corner being the brightest return for a crop and the lower right being the darkest return for a field condition. On this table, there are three intersections where relatively high correct decisions were made — one in the light gray scale region (sugar beets), one in the medium gray scale region (grain sorghum) and one in the dark gray scale region (recently tilled). The high correct decision areas at the extremes and the middle of the diagonal intergrade with zones of ambiguity, where lower correct decisions occurred. Therefore, the image condition directly reducing accuracy appeared to be ambiguous gray scale. The matrix table supports the results shown in Figure 11, which revealed that the experienced interpreter's incorrect decisions were caused by the confusion of two crops with similar radar returns. In Table 13, with its graduated gray scale format, interpreter confusion is evident from the concentration of decisions in rows adjacent to the diagonal.

On the Ku test, scores ranged from a high of 68 per cent correct identification to a low of 25 per cent correct, with an average correct score of 49 per cent (see Table 12). The results of the Ku test could also be plotted and compared with a field map, but inspection revealed a similar situation (crops or field conditions exhibiting extreme gray scales were more readily discriminated than those in the intermediate range) to that shown earlier in Figures 11 and 12 for the Ka test.

FIGURE 12. COMPOSITE CORRECT IDENTIFICATIONS OF Ka-IMAGERY ON A FIELD BY FIELD BASIS AS COMPARED TO ACTUAL FIELD CONDITIONS

Comparing the same field in each map will show the interpretation score for the field condition. Recently tilled and sugar beets were most often correctly identified.



DECISIONS ON CROP / FIELD CONDITION								
	Sugar Beets	Alfalfa	Corn	Sorghum	Wheat	Pasture	Fallow	Recently Tilled
ACTUAL CROP / FIELD CONDITION	Sugar Beets	42	35	2	1	0	0	0
	Alfalfa	1	13	20	27	7	0	2
	Corn	0	0	0	0	0	0	0
	Sorghum	0	8	24	61	44	0	7
	Wheat	0	2	5	6	10	0	6
	Pasture	0	0	0	0	0	0	0
	Fallow	0	1	7	10	25	5	19
	Recently Tilled	0	0	0	0	13	4	30

Table 13. Aggregation of Interpreter Decisions for Ka-imagery Test. Crops are ordered to reflect light to dark gray scale. Circled entries on diagonal represent correct decisions.

Due to the marked similarity in the results of the two tests when displayed on a field by field basis, it was felt that the Ku tests did not warrant additional illustrations. On a decision by decision basis, the Ku test revealed (see Table 14) a similar dispersion around the diagonal as that shown on Table 13 for the Ka test.

Because the Ka-imagery key attempted to discriminate, as unique, those crops and field conditions known to exist in the test site, and the Ku-imagery key did not (groups of crops were discriminated in critical cases, such as corn, grain sorghum and alfalfa), it was felt that the Ka test was more significant in the context of developing a usable model for SLAR interpretation. Consequently, in this study the Ku test did not receive as extensive an analysis as the Ka test.

### Analysis of Results

In analyzing the test results, two causes of test error need to be noted: (1) those caused by limitations inherent in the system and therefore transferred to the image, and (2) those caused by inadequacies in the interpretation model. It cannot be expected that the model will correct system limitations as reflected in image ambiguities, but the model can be changed to overcome its own shortcomings. The real problem, however, is separating those errors that are system caused from those caused by the model. This cannot be easily accomplished, because system's errors influence the model's errors. For example, shifts in gray scale due to antenna patterns in the imagery affect the validity of the gray scale statements in the key.

The low correct scores on the interpreter tests could be related to both system limitations and model inadequacies. However, based on analysis of previous studies of the same type of imagery for the same area using density (gray scale) as the discriminant, the ability to distinguish unique crop categories was not appreciably higher when models other than the key were used (Schwarz and Caspall, 1968, p. 235 and Haralick, et al., 1970, p. 136). This indicates that regardless of interpretation model (scattergrams by Schwarz and Caspall, and Bayes decision rule by Haralick, et al.), the system limitations hampered discrimination of unique crop categories and forced their grouping to overcome error. Thus, limitations within the system tended to make any model based predominantly on gray scale prone to those errors caused by system's generated ambiguities.

DECISIONS ON CROP / FIELD CONDITION							
ACTUAL CROP / FIELD CONDITION		Sugar Beets	Corn II*	Corn I** Grain Sorghum Alfalfa	Wheat Stubble	Fallow Pasture Volunteer Regrowth	Recently Tilled
	Sugar Beets	17	2	2	0	0	0
	Corn II*	8	16	3	0	0	0
	Corn I** Grain Sorghum Alfalfa	5	50	91	26	12	7
	Wheat Stubble		8	15	23	18	1
	Fallow Pasture Volunteer Regrowth	1	3	7	11	20	4
	Recently Tilled	0	9	6	5	26	35

\* Rows parallel to the line of flight

\*\* Rows perpendicular to the line of flight

Table 14: Aggregation of Interpreter Decisions for Ku-Imagery Test. Crops are ordered to reflect light to dark gray scale. Circled entries on diagonal represent correct decisions.

In view of the above system limitation/model inadequacy relationship, the question arises whether a model (when based on gray scale alone) can be improved to significantly upgrade results such as those achieved on the interpreter tests in this study. The results of the test indicate, in part, that the direct keys were too simplified, in terms of those properties interpretable from the image. The keys failed to extract morphic information which could aid in the interpreter decisions. An example of a morphic consideration not taken into account in the present keys is the circular field, which could assist in correctly discriminating corn in the Ku- imagery. As radar resolution increases, morphic considerations seem to have a more important role when such crop related phenomena as tillage patterns are observed on the image (Morain and Coiner, 1970, p. 15). This leads to a hypothesis which may be generally applicable to an uncalibrated imaging radar system: the less reliance placed on gray scale and the more reliance placed on morphic considerations, the higher degree of interpretation accuracy. By adding another parameter, such as morphic data, the basis of the interpreter decision is broadened and the sole reliance on gray scale relationships is tempered, possibly increasing accuracy.

The heavy reliance on gray scale creates a number of problems.<sup>20</sup> The first of these, as previously noted, is that gray scale is subject to system limitations which distort the image gray scale relationships. The second is that there is no unique gray scale associated with a single crop. Each crop occupies a range of gray scales, dependent upon systems' parameters and the nature of the crop itself (row spacing, moisture, slope, etc.). The test results demonstrated the overlapping gray scale ranges that existed between crops. Therefore, for any given gray scale, a degree of uncertainty existed as to the crop imaged. This argues for the development of probabilistic keys, which present a series of probabilities for crops whose ranges might extend into the specific gray scale. Krumpel, et al., (1971, pp. 119-122) developed such a key for forest tree species identification from color infrared photography. The third problem relates to the definition of gray scale in the key. This may lead to errors which are due to the key designer's failure to communicate his perceptions of gray scale. In other words, light gray is a relative term in the mind of the interpreter as well as in the image. One possible method to

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<sup>20</sup>The systems used in this study were uncalibrated, therefore, the gray scale relationships could not be associated directly with backscatter ( $\sigma^{\circ}$ ). If calibrated systems were available which related backscatter with gray scale, gray scale would be a more reliable measure.

counter the relative nature of the return is to reduce the number of levels to be discriminated by combining the unique crops/field conditions into groups with similar gray scales, as shown in Table 15. These groups have a higher per cent accurate interpretation but cross-sectional data has limited usefulness. If repeated acquisitions of imagery occur, a crop's gray scale would change through time thereby changing the groupings, and this may allow more meaningful discrimination at the higher, desired accuracy.

Interpreter perceptions associated with gray scale also raise the issue of experience as it affects the results of interpretations. In general, on the Ka test, the more experienced the interpreter, the higher his percentage correct. However, the fact that the sample included some in house personnel, who had limited experience but daily exposure to the Ka-imagery, may have made some of the less experienced interpreters' scores higher in relation to the overall average. When the daily exposure factor is considered in conjunction with general interpreter experience, it is clear that experience and/or exposure has a positive bearing on interpretation results. On the Ku test, it appeared that interpreter experience decreased accuracy, with three less experienced interpreters attaining the highest correct test scores. This is an anomaly due to the fact that although these three interpreters had less overall experience, they had the most daily exposure to Ku-imagery of those in the test group, and they had worked closely with the author.

The results of the interpreter tests have suggested reasons for the low test scores. These have been discussed above and some possible improvements were suggested. In addition, certain other improvements for overall interpretation accuracy are implied from the results. These improvements are (1) multiple acquisition, (2) additional non-image information and (3) improved visual aids.

Multiple acquisitions could reduce the decision matrix and therefore the number of gray scale differences for a single interpretation, as previously noted in relation to Table 15. All keys in this study were based on single images. They are therefore specific and the ability to generalize them is unknown. Keys based on imagery from repeated acquisitions would be capable of generalization, because they represent the phenomena under study in its various aspects, and the most generalized aspect could be defined as the primary key signature. The advantage of repeated acquisitions would therefore be the availability of a multiple image file, which would allow better descriptive generalizations of the phenomena.

DECISIONS BASED ON GROUPINGS OF CROPS / FIELD CONDITIONS WITH SIMILAR GRAY SCALE					
	Sugar Beets Alfalfa	Alfalfa Corn Sorghum	Corn Sorghum Wheat	Pasture Fallow Recently Tilled	
ACTUAL CROP / FIELD CONDITION	Sugar Beets	52	1	0	
	Alfalfa	35	12	8	
	Corn	2	20	29	
	Sorghum	1	27	59	
	Wheat	0	7	48	
	Pasture	0	0	0	
	Fallow	0	1	13	
	Recently Tilled	0	0	2	
	Per Cent Correct	98%	87%	86%	73%

Table 15: Aggregate Decisions for Crop Groupings with Similar Gray Scales for Ka-Imagery Test. Crops and crop groups are ordered to reflect light to dark gray scales. Circled entries are considered correct. (After Coiner and Morain, 1971, p. 408)

Additional non-image collateral information may be critical if systems similar to those tested are to be widely used. This can be seen from the test results. Interpreters identified wheat in relation to grain sorghum on the Ka test at a ratio of approximately 1:1 (see Table 13, p. 47). If the interpreter had known that in irrigated areas, the relationship between acreage planted to wheat and grain sorghum was 1:5, he could have reassessed his interpretation to more closely reflect the collateral information, which is available from Agricultural Stabilization and Conservation Services data on feed and cash grains.<sup>21</sup>

The visual aid used with the Ka-imagery key may have reflected distorted gray scale levels, which were difficult to associate with the image. This distortion is caused by failure to control reproduction of the graphic. Gray scale similarity is essential in SLAR visual aids because of the heavy reliance on this attribute for interpreter decisions, and processing control should be emphasized in the production of visual aids, including the introduction of gray scale wedges on all graphics.

### Summary

Two direct keys were used by ten interpreters to interpret agricultural data from Ka and Ku-imagery. Although the accuracy of the interpretations varied considerably, the averages on both tests were between 40 per cent and 50 per cent correct interpretations. This low level of accuracy may have been caused by two primary factors: (1) the system did not clearly discriminate the data desired and (2) the interpretation model was too simplified. Since system's limitations were beyond the author's control, emphasis was placed on seeking ways to upgrade the model within the system's limitations.

Methods of improving keys were identified by analyzing the test results. The most important improvement considered was the addition of morphic signatures to the key to decrease direct reliance on gray scale. Another improvement suggested was the reduction of decision classes by grouping crops of similar gray scale. This brought accuracy to acceptable levels, however, it reduced utility

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<sup>21</sup>This misidentification may have been due to the interpreter's preconception that Kansas is a "wheat state."

of data for a single acquisition. Multiple acquisitions, it was argued, would overcome the reduced utility. In addition, interpreter experience or exposure to the type of imagery being interpreted was identified as an important influence on interpretation accuracy, although the nature of the sample in this study limited supporting evidence. Other influences on the accuracy of SLAR interpretations were also mentioned. These included collateral information and improved visual aids.

The evidence derived from the tests indicate that any highly effective interpretation model will require multiple data inputs, such as multiple parameters within the image, multiple acquisitions and multiple types of collateral information. The control of these data inputs will demand a rigorous interpretation model, and most logically, image interpretation keys will be required as an integrating and focusing mechanism. This role for the key in terms of automated data processing will be explored in the next chapter.

## CHAPTER IV

### IMAGE INTERPRETATION KEYS AND AUTOMATED DATA PROCESSING

#### Need for Automated Data Processing

The utility of a remote sensing system, regardless of the sensor/platform combination, is generally hampered by the great disparity between the inordinate amount of data that the sensor collects and the ability of any existing human/machine system to analyze the data on a timely basis. Attempts to reduce this disparity have generally called upon some forms of automated processing. These various forms, however, have not succeeded in reaching the point where they can effectively handle large data inputs at the levels of accuracy required or at acceptable cost/benefit ratios.<sup>22</sup> As Shelton and Hardy (1971, p. 1573) have suggested, a closer interaction between human interpretations and automated data processing may provide higher levels of interpretation accuracy and better cost/benefit ratios.

The role of the interpretation key in the above setting is to act as a transfer vehicle from human interpretations to machine usable algorithms. The key would allow the human interpreter to maintain control of the decision criteria under which the machine operates. This human interpreter control is essential when two specific problems affecting automated interpretation are considered: (1) Human typology<sup>23</sup> of information within the environment is not necessarily structured in such a way as to allow mathematical discrimination, i.e., what humans classify as similar objects need not be mathematically classified as similar, especially in terms of data collected by remote sensors. (2) The areal variation within the environment being sensed makes the implementation of purely mathematical decision rules an extremely

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<sup>22</sup>The research emphasis on machine data processing can be seen in the fact that one paper out of every five presented at the Seventh International Symposium on Remote Sensing was directly concerned with machine assisted data handling (Proceedings Seventh International Symposium on Remote Sensing of Environment, 1971, pp. xv-xxii).

<sup>23</sup>"Typology" is the systematic classification of observed phenomena.

difficult problem (see Hoffer and Goodrick, 1971, p. 1967), because even over relatively small areas, the algorithm for specific data may require constant changing. The need for a changing algorithm is caused by the "distance decay function," which reflects that data elements interact in different spatial agglomerations. Since the above two problems adversely affect mathematical generalization, the human input could account for these factors in the form of a key, which could aid in defining remotely sensed data in terms of human typologies and areal variation. The first step in realizing the concept of the key as a transfer vehicle for automated processing is to convert a key into a machine usable algorithm.

### An Automated Image Interpretation Key

The image interpretation key can be viewed as a step-by-step procedure which links a problem and its solution. For agriculture, some problems and their solutions (through use of key-aided interpretations) are: the problem of area planted to certain crops, the solution being crop acreage; the problem of status of soil conservation programs, the solution being areas which have been subjected to effective terracing and the construction of waterways; the problem of compliance with government crop acreage, the solution being field sizes and acreage in a given crop; and the problem which is central to much of the information needed in agriculture — unidentified field condition, the solution being the status and condition of a crop within the field. When the key is considered as a step-by-step, problem solving mechanism, this function of the key fits Turing's theorem that "any procedure which can be specified in a finite number of steps can be automated" (Tobler, 1970, p. 128). In the following section, the direct key will be equated with a machine algorithm by using the key which was developed for the Ka-imagery (Table 6, p. 25) to construct a machine usable FORTRAN IV program which discriminates crops.

The conversion of the key to a FORTRAN IV program can be accomplished in a number of ways. The simplest conversion is to assemble each branching of the key as a logical "if" statement. This type of program is shown in Table 16, however, it is difficult to generalize for wide scale use. To overcome the generalization problem, another program was developed, and its documentation is included in

TABLE 16

COMPUTER PROGRAM SEGMENT FOR CROP IDENTIFICATION  
DEVELOPED FROM DIRECT KEY FOR KA-IMAGERY

```

SUBROUTINE DI KEY (IHH,IHV,ITYPE)
DIMENSION ICROP(8)
DATA ICROP/'SGRBTS','CORN','ALFAL','FALLOW','WHEAT',
1 'SORGUM','PASTUR','TILLED'/
1 'PASTUR','TILLED'/
DATA IQUES/0171717171717/
IF (IHH .NE. 4 .AND. IHV .NE. 4) GO TO 5
ITYPE = ICROP (8)
RETURN
5 IF (IHH .NE. 3 .AND. IHV .NE. 3) GO TO 10
ITYPE = ICROP (4)
RETURN
10 IF (IHH .NE. 3 .AND. IHV .GT. 3) GO TO 15
ITYPE = ICROP (7)
RETURN
15 IF (IHH .NE. 2 .AND. IHV .NE. 2) GO TO 20
ITYPE = ICROP (5)
RETURN
20 IF (IHH .NE. 2 .AND. IHV .NE. 1) GO TO 25
ITYPE = ICROP (3)
RETURN
25 IF (IHH .NE. 2 .AND. IHV .GT. 2) GO TO 30
ITYPE = ICROP (6)
RETURN
30 IF (IHH .NE. 1 .AND. IHV .NE. 1) GO TO 35
ITYPE = ICROP (2)
RETURN
35 IF (IHH .NE. 0 .AND. IHV .NE. 0) GO TO 40
ITYPE = ICROP (1)
RETURN
40 ITYPE = IQUES
RETURN

```

Appendix II. The second program's unique feature is the use of a matrix key as the basis for crop type assignments. The program's flow is as follows:

- (1) Both the HH and HV polarizations of the Ka-image are digitized at a 50 micron spot size and stored as digital data in individual files on tape.
- (2) This tape is accessed by the PICTURE subroutine of the KANDIDATS program (Gunnels, 1971), and the PICTURE printout is used to map the unidentified fields.
- (3) The fields are transferred from the master HH and HV files to separate field files for each polarization. It is necessary to keep the polarization files unique to develop descriptor statistics for each polarization. These files provide the basic input to the dichotomous key subroutine (DIKEY), shown in Figure 13 as a flow diagram.
- (4) Subroutine DIKEY first reduces each field to a preassigned descriptor statistic.<sup>24</sup> This descriptor statistic is then converted to an integer value. One integer value represents the HV's.<sup>25</sup> The integer values are used to describe a location in a label matrix illustrated in Figure 14. This matrix contains the names of the categories to be discriminated (crop types) which were predetermined by the interpreter.
- (5) The file identification and crop label assignments are printed for all files in the operating sequence. A sample output is shown in Table 17.

<sup>24</sup>The descriptor statistic used in these initial tests was the mean gray scale for the field. With slight modification, however, the subroutine can use any descriptor statistic which best defines the category being discriminated.

<sup>25</sup>The range of the descriptor statistic in relation to the integer value assigned can also be controlled to aid in the optimization of discrimination. If all mean values on the HH between 0 to 50 are associated with a certain crop types, e.g., recently tilled, the integer value for the HH image file 1 would represent all means between 0 and 50. The mean range which can be assigned to a given integer can be varied as conditions change from area to area to maintain key effectiveness.

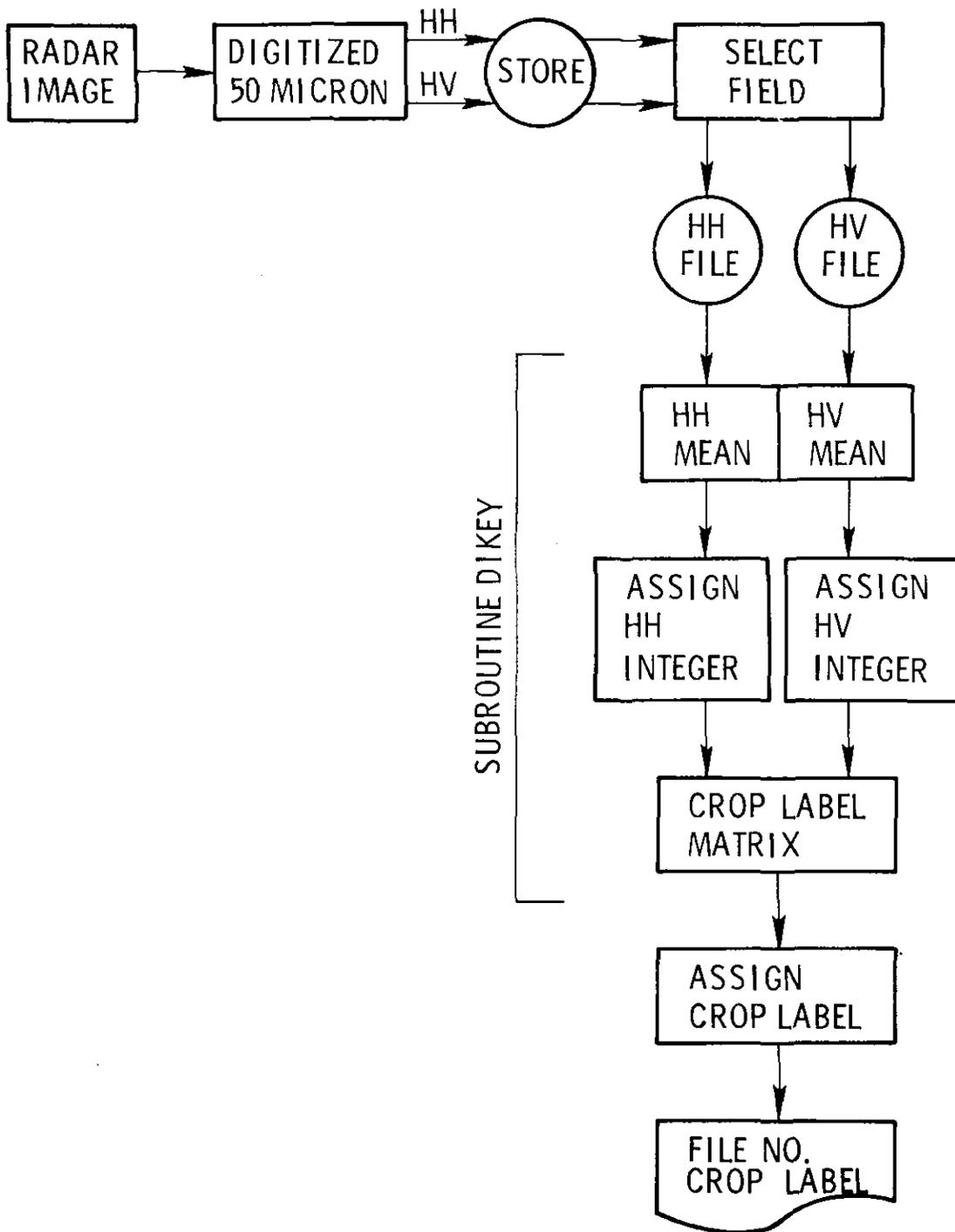


Figure 13. Digitized Image Flow Diagram for Subroutine DIKEY.

HH 1 (DARK)	RECENTLY TILLED	FALLOW	NCA*	NCA*	NCA*
2	FALLOW	FALLOW	WHEAT	WHEAT	NCA
3	NCA	NCA	SORGHUM	ALFALFA	NCA
4	NCA	NCA	NCA	ALFALFA	SUGAR BEETS
5 (LIGHT)	NCA	NCA	NCA	NCA	SUGAR BEETS
	HV 1 (DARK)	2	3	4	5 (LIGHT)

\*NO CROP ASSIGNED

Figure 14. Preliminary Label Matrix Derived from an Image Interpretation Key.

This matrix is loaded into the program and is accessed by integer values developed from descriptor statistics of the classes to be identified.

TABLE 17  
SAMPLE OUTPUT FROM THE SUBROUTINE DIKEY

THE IMAGE NUMBER 7 WAS CLASSIFIED AS A SUGGIS FIELD
THE IMAGE NUMBER 8 WAS CLASSIFIED AS A RCTIL FIELD
THE IMAGE NUMBER 9 WAS CLASSIFIED AS A SUGGIS FIELD
THE IMAGE NUMBER 10 WAS CLASSIFIED AS A SORGHM FIELD
THE IMAGE NUMBER 11 WAS CLASSIFIED AS A SORGHM FIELD
THE IMAGE NUMBER 12 WAS CLASSIFIED AS A SORGHM FIELD
THE IMAGE NUMBER 13 WAS CLASSIFIED AS A RCTIL FIELD
THE IMAGE NUMBER 14 WAS CLASSIFIED AS A RCTIL FIELD
THE IMAGE NUMBER 15 WAS CLASSIFIED AS A SORGHM FIELD
THE IMAGE NUMBER 19 WAS CLASSIFIED AS A RCTIL FIELD
THE IMAGE NUMBER 20 WAS CLASSIFIED AS A SORGHM FIELD
THE IMAGE NUMBER 21 WAS CLASSIFIED AS A SUGGIS FIELD
THE IMAGE NUMBER 22 WAS CLASSIFIED AS A FALLOW FIELD
THE IMAGE NUMBER 23 WAS CLASSIFIED AS A ALALF FIELD
THE IMAGE NUMBER 24 WAS CLASSIFIED AS A FALLOW FIELD
THE IMAGE NUMBER 25 WAS CLASSIFIED AS A RCTIL FIELD
THE IMAGE NUMBER 26 WAS CLASSIFIED AS A SORGHM FIELD
THE IMAGE NUMBER 27 WAS CLASSIFIED AS A FALLOW FIELD
THE IMAGE NUMBER 28 WAS CLASSIFIED AS A SORGHM FIELD

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In the initial test sequence, for 34 fields of the 55 fields tested in the Ka-imagery test, equal mean gray scale ranges were assigned to each of the integers used to enter the label matrix. With an equal range for the mean gray scale, a level of only 28 per cent correct was achieved. However, when the ranges of the means assigned to each integer value were redefined to account for the way that the digital output was affecting the gray scale information,<sup>26</sup> levels of correct identification were at 73 per cent accuracy.

For more wide scale use, the value of this program is that it is highly flexible and can be manipulated by varying the descriptor statistic, the range of the descriptor statistic assigned to an integer, or the label matrix, thereby creating the best approximation of data desired from the imagery. The fact that an algorithm could be developed from a dichotomous key supports the contention that keys can be used as a transfer vehicle from human interpretation to automated processing of remotely sensed data. The ability of the key to perform in both human and machine interpretation situations raises questions as to the utility of the key within a general information system context. This possible role for a key is discussed in the next section.

### Role of Keys in Designing an Agricultural Information System

Within the theoretical construct of an information system, Wellar (1970, p. 459) has identified eleven components: "data acquisition, information system linkages, data base definition, data base organization, maintenance of a dynamic data base, data base documentation, data base standardization, data access control plan, hardware, software and operations/control planning-based system." Remote sensing can be considered a method of "data acquisition," which makes it critical to the entire information system, as Wellar pointed out (1970, p. 460), since all other components/activities are influenced by data acquisition and vice versa.

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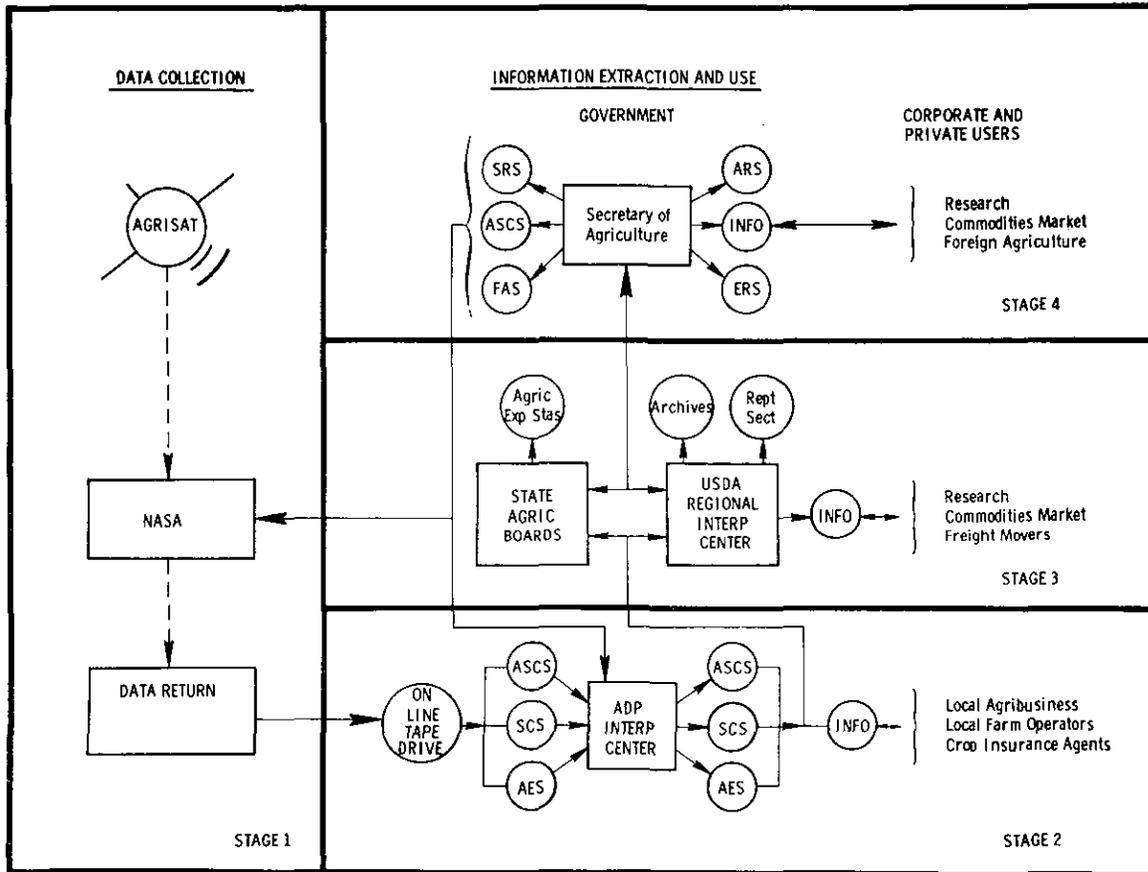
<sup>26</sup>The digital output can reduce gray scale to integer values between 1 and 256. For any given image, the range is not normally the full 256 integer range and thus causes some skewing from the interpreter's assessment.

The problem is slightly more difficult than Pruitt (1970, p. 12) envisioned when she forecasted a direct sensor-to-user system with only machine interpretation of the remotely sensed data. Remotely sensed data are not, in the main, directly human usable. They are either in a format or a structure for which human typologies have not been developed. This leads the author to agree with Boyle (1970, p. 47) that an intervening step between the user/information system and the remotely sensed data must exist, at least for the present. The intervening step is the interpretation of remotely sensed data and the input of this interpretation into the other components of the information system. The step is necessary to convert the remotely sensed data to human usable format. In other words, the standard formulation of A data + B data = C information (Wellar and Graff, 1971, p. 2) is more complex when remote sensing is the data acquisition method, because A (remote sensing) data + B (remote sensing) data may sum to C (human usable) data, which in turn will have to be summed to become information. It is in this role of converting remotely sensed data to human usable data and information that the image interpretation key (in both its human and automated form) provides a filter between remote sensors as the data acquisition component and the remaining component activities of an information system.<sup>27</sup>

Considering the approaching general availability of data from orbital and airborne sensors, an information system to both specify information requirements and to place information into the hands of decision makers is desirable. One of the areas which would be affected by the general availability of sensor data would be agriculture. The use of remote sensors as data sources for agricultural information systems has been the topic of several papers (see for instance, Holmes, 1968; Lorsch, 1969; Holter, et al., 1970; and Morain, 1972). The majority of this research has been directed at both ends of the information flow. Holmes discussed platforms and sensor requirements, while Lorsch defined the types of information such systems might supply. Holter, et al. provided a preliminary definition of a "resource management system," and recently, Morain defined a complete flow from sensor/platform to user. Morain's agricultural information system, a diagram of which is shown in Figure 15, would rely on county level agricultural personnel to extract data from imagery.

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<sup>27</sup>The concepts developed here are supported in part by Wellar (1969, 1970, 1971).



From Morain, 1972 (p. 10)

Figure 15. General Flow Diagram for Proposed Agricultural Information System.

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The model which the local agricultural agent would use to aid in his interpretation of the imagery would be the image interpretation key. If funding were available, a semiautomated system incorporating the automated key routines discussed above could be designed and implemented for county agricultural units. The entire system exploits two generally accepted interpretation criteria:

- (1) The more knowledgeable about a subject and area an interpreter is, the more accurate his interpretation.
- (2) The smaller the areal unit under study, the less extreme fluctuations in environmental factors. This would reduce the requirement for individual interpreters to make multiple, unique interpretations.

Implementation of a key-based information system would be directed toward the development of a series of keys which could be used by personnel whose primary duties were non-interpretive in nature. By interaction between these personnel and experienced interpreters, it should be possible to develop a series of interpretation keys which allow extraction of various information requirements from imagery. These information requirements could be defined simultaneously for local, regional (state) and national administrative levels in the agricultural hierarchy.

The radar mosaic shown in Figure 16 is an example of a single acquisition which the county agent of Finney County, Kansas might be responsible for interpreting under a key-based information system. To support his interpretation, he would have available a series of keys, for example, one which would assist him in determining the status of soil conservation projects. These keys could be employed in any sequence on the imagery to meet time critical requests directed to the agent. The usefulness of a key-based remote sensing information system lies in its flexibility to deal with changing local, regional and national conditions and requirements.

### Applications of an Information System for Agriculture

Research in agricultural geography could benefit from an information system such as that proposed by Morain (1972). For example, Gregor (1970) has defined

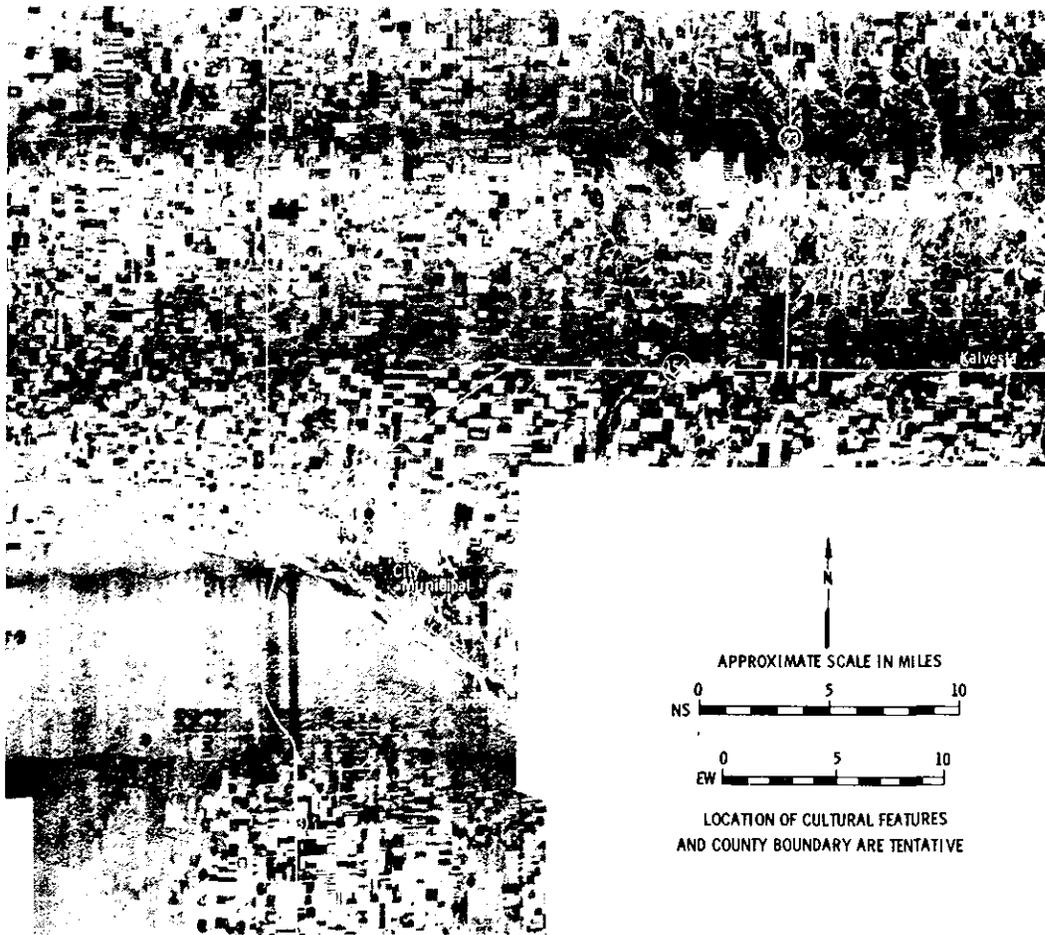


Figure 16. Ku-Band Radar Mosaic for Finney County, Kansas, June, 1971.

This mosaic represents a single mission acquisition to be interpreted by a county agent.

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nine major areas<sup>28</sup> of research in agricultural geography. Of these nine, only one, "historical," is excluded from using data collected by the information system.

Three major advantages accrue to the researcher who has access to an agricultural information system. One advantage is the commonality of the data source. Data from all areas of the country in their disaggregate, imaged form would be directly comparable. At present, there are differences in state statistical reporting procedures which hinder comparability of agricultural data. The second advantage is the data could be acquired by the researcher in a disaggregated form, allowing him to aggregate it as he desires. Currently, it is difficult to acquire disaggregate data on agricultural phenomena. Although of less importance to the researcher than to the manager, the third is the timeliness of the data. Agricultural data at the state level now lags by twelve months. Since this is one complete growing season, any impact of research on a given phenomena may lag a minimum of two growing seasons behind actual observation of the phenomena.<sup>29</sup>

Geographers who study innovation and dispersion of agricultural techniques should find the agricultural information system an invaluable data source. At present, there is no way to monitor on a near real time basis the spread of an innovation or even shifts in cropping practices, because for most research, one is dependent upon data derived from historical records. With data acquisition reaching near real time for the information system, innovation could be monitored as it occurred and models of innovation could be tested against actual data.

The information system may also change the concept of agricultural regionalization. Regions, such as those developed by Marschner (1959) and Austin (1965) become static once they are defined. However, Marschner (p. 76) himself

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<sup>28</sup>Gregor's nine areas are: "the role of environment," "spatial organization," "the cultural impress," "political reflections," "the historical context," "regional types and patterns," "regional boundaries," "resource destruction," and "population and food supply" (from chapter titles 3 through 11, pp. vii-ix).

<sup>29</sup>For an illustration of this, one could observe the introduction of irrigation techniques in Finney County, Kansas, particularly Garden City. Sprinkler irrigation was introduced in 1967 and by the Spring of 1972 irrigated over 32,000 acres. The consequences of this change in irrigation are just now being seriously studied, possibly too late to stop the spread of a potentially detrimental irrigation method (personal conversation with A. B. Erhart, Director, Kansas State University Agricultural Experiment Station, Garden City, Kansas, 1972).

recognizes, the agricultural reality upon which the regions are based is not static, being subject to continuous change due to the introduction of new technologies, crops, etc. When an information system is based on remote sensing, the data provided are highly compatible with quantification techniques, similar to those used by King (1969, pp. 165-184) to define crop regions in Ohio. By coupling quantitative methods with data from the agricultural information system, the ability to define regions in terms of rate of change should be available to the research geographer. Validity of regions could be tested and even new types of regions, based on rate of change, could be formulated.

Although the impetus for further research in agricultural geography should be significant, the major role of the agricultural information system is in the management of agricultural resources within the United States. Morain (1972, pp. 14-15) has pointed out two primary, national level uses in the areas of "potential land available for crops" and crop/production/yields. These two uses, however, do not represent the scope and flexibility of the information system in agricultural resource management. As Figure 15 shows, three stages of data aggregation are defined in the proposed system. Each of the stages has a distinct set of information requirements defined by their position in the agricultural hierarchy.

The local level's role is in the management of programs specified by higher levels. The local Agricultural Stabilization and Conservation Service (ASCS) oversees compliance with feed grain and cash grain programs; the local Agricultural Extension Service promotes agricultural improvement programs, e.g., farm pond construction, introduction of new crop types and dissemination of new farming techniques; and the local Soil Conservation Service (SCS) supports programs for the prevention and control of soil erosion. Their information needs are extremely diverse but geographically centralized and precisely defined—normally by counties. Examples of the type of information available from the remotely sensed data component of the information system, which the local level would desire to extract, could be: (1) general land use (crops, pastures, feed lot facilities, farm ponds, fallow land, etc.); (2) compliance with acreage allotment programs; (3) areas where soil conservation measures have been employed; and (4) areas which have been subject to natural disasters (tornadoes, crop diseases, flooding, fire, etc.). The SLAR mosaic shown in Figure 16 is an example of the amount of imagery one county would generate and from which information requirements postulated above could be partially met through interpretation.

At the regional level, primary information requirements are in the area of statistical reporting. The statistics could be generated, in part, from the local level interpretations. It may also be necessary to develop regional interpretation centers to meet more generalized specifications, which would require interpretations covering multiple county units or counties which did not have a direct output from the agricultural satellite system (due to low agricultural investment in the county). Regional levels in the agricultural hierarchy would probably be more interested in aggregated county level data than in generating new data from the remote sensor component. However, an agricultural information system would provide the regional level with the ability to extract point and area information for such problems as acreage, large scale disasters, change and innovation which may affect the marketing structure and its support facilities (e.g., the need for new grain elevators, roads, terminals, etc.) and the implementation of irrigation control with respect to water use.

At the national level, the information system could be used mainly to improve the predictive capability of high level management. Management could access both compatible disaggregate data for the local level and compatible aggregate data for the regional level. The capability would allow the development of more realistic program planning in terms of overseas markets, overall goals for crop production (implemented as allotments), definition of priorities in terms of the national budget allocation for agriculture and generally, the development of national agricultural resource plans. To assess current policies on the future of agriculture, this information system may provide the basis for large scale simulations.

As the above agricultural information needs demonstrate, the local level is concerned with implementation, the regional level with monitoring and control, and the national level with planning and prediction. An agricultural information system which relies on remotely sensed data collection and local interpretation may be admirably suited to fulfill all three levels' data needs within the existing agricultural hierarchy.<sup>30</sup>

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<sup>30</sup>The information system described here was postulated to provide an integrating theme for SLAR research. Studies are underway, with the help of local level, county USDA users, to develop specifications for an information system which will meet specific local needs.

## Summary

In this chapter, the interpretation keys were viewed according to their usefulness in two areas:

- (1) Their convertibility for automated data processing, and
- (2) Their role in an agricultural information system.

The image interpretation key, when assessed in light of these two criteria, appears to have a valid role in the future of remote sensing information systems.

This chapter also discussed the need for automated data processing to interpret the large amounts of data that remote sensors could produce. Concurring with recent general opinion, the author agreed that without automated data processing, no large scale remote sensing system was feasible. The author proposed that the algorithm required for automated data processing be based on image interpretation keys similar to those developed in the previous chapters of this study. From the earlier keys, an automated image interpretation key was developed as a machine readable (FORTRAN IV) program. In the resulting automated interpretation, crops were correctly identified three times out of four when the key was used on a field basis.

The concluding section considered an information system for agriculture which employed remotely sensed data as the data acquisition component. For the proposed information system, interpretation would be conducted at the local level in the existing agricultural hierarchy, using image interpretation keys to aid in the interpretations. Data from the information system was shown to be of possible use for various research problems in agricultural geography. It was felt that the information system also promised to meet the data requirements of agriculture at the local level in the implementation of programs, the regional level in the monitoring and controlling of programs and the national level in the development and planning of programs and the forecasting of needs.

## CHAPTER V

### CONCLUSIONS AND RECOMMENDATIONS

This study is based on the assumption that in order for SLAR to gain wide acceptance as a research tool in geography, a need exists for an interpretation model to link SLAR's data collection capability with identifiable research problems. It is proposed that one such model, which may provide both facility and reliability in use, is the image interpretation key. The key has already successfully functioned in this modelling capacity for aerial photographic interpretation. To develop the thesis that the key represents an appropriate interpretation model for SLAR, keys of several types were designed from existing/SLAR imagery for crop discrimination and natural vegetation.

The keys were constructed recognizing three sets of preconstruction constraints. These constraints relate to the radar system acquiring the imagery, the defined characteristics of the image interpretation key, and the nature of the data desired. Constraints identifiable with the system are (1) there is no method at present to mathematically predict at a high level of accuracy the type and nature of a radar return from a given scene because of the complexity of the backscatter; (2) there is not a one-to-one correspondence between backscatter and the image presented to the interpreter due to processing; and (3) there is continuous change in the way the sensed subject is imaged due to the varying angular relationships between the sensor and the subject. As a result of these constraints, the image is a relative presentation of a sensed scene, which possibly varies considerably within the same image. The system's constraints require the key builder to develop less generalized interpretations and to specify precisely the system's parameters (wavelength, depression angles, etc.) for which the key is valid.

The second set of preconstruction considerations are characteristics of an image interpretation key which affect its construction. They include function, technicality, information relations and format. Since these characteristics structure the key, they will control the method by which the data desired by an interpreter is extracted from an image.

The third set of preconstruction considerations relate to the data desired from the image. These considerations, previously defined by Colwell (1953), are: geographic area, types of phenomena, types of imagery and types of collateral support material. Such data specifications directly influence the choice of the characteristics to be used in the key itself. An example of how all three sets of constraints affect an interpretation is as follows: Angular relationships vary within the image (due to system's constraints), therefore, the identification of similar types of phenomena will vary with their position in the image, which necessitates changes in the key characteristics (reflecting information relations) to account for multiple signatures of the same subject (type of phenomena). As can be seen in the example, the three sets of preconstruction constraints are interrelated. Consequently, the key requires construction with a knowledge of the sensing system, a knowledge of the data desired from the imagery produced and a knowledge of key characteristics.

Recognizing the constraints, keys were designed in this study for each of three frequencies of SLAR imagery, X, Ka and Ku-bands. Emphasis was placed on the direct dichotomous key because humans usually distinguish between two groups of items easier than they distinguish between one item and a larger group of items and because the binary structure of the dichotomous key leads the interpreter to an identification. The direct associate key (defined as the matrix key) was also developed because it allows distinct itemization of all desired data with immediate association to the item. This type key was found to be useful with SLAR imagery since it was adaptable for displaying the decision structure of dual polarized imagery. Graphics, which were thought to aid in the visual association of data in the image with data desired by the interpreter, were illustrated. In addition, a preliminary direct key for multiple frequency radar imagery (X and Ku-bands) was developed. As the various keys shown in this study attest, keys constructed from SLAR imagery are feasible and can serve as an interpretation model.

In order to determine whether or not the above keys were valid as an interpretation model, two of the keys were tested by ten interpreters. The test results yielded accuracies ranging between 25 per cent and 70 per cent correct. These relatively low scores may have stemmed from several factors:

1. inherent limitations in the two systems involved in the test,
2. over simplicity of the keys tested by use of a single parameter, gray scale,
3. interpreter perceptions which the key did not adequately offset,

4. failure to include collateral information, and
5. lack of image processing control which distorted gray scale similarity in support graphics.

The tests also indicated that high interpreter experience or high exposure to SLAR imagery had a positive influence on test scores. In order for SLAR to be accepted as a research tool (with keys as the interpretation model), it was concluded from these tests that the factors which contributed to the low scores should be the primary focus of further research.

This study suggested several ways for improving the key, excluding improved SLAR systems, to gain better interpretation results with SLAR. Essentially, the following improvements are hypotheses which require substantiation by continued research.

1. That reliance on a single parameter, such as gray scale, leads to a lower interpretation accuracy than the use of morphic considerations (size, shape, etc.) in conjunction with gray scale.
2. That in crop discrimination, by reducing the number of crop classes/field conditions, interpretation accuracy would be increased at the expense of unique crop discrimination, resulting in accurate identification of crop groups.
3. That, assuming the implementation of Hypothesis 2, unique discriminations can be regained by time sequential missions which rely on crop calendar divergence to separate within group crops.
4. That correct identification of crops or crop groups could be increased by the assignment of probabilities (in the form of a probability key) relating specific crops to various gray scales.
5. That collateral information from existing USDA data series could aid in improving interpretation accuracy.
6. That improved visual aids could aid in increasing interpretation accuracy.

Although the key, within the framework for existing SLAR systems, did not provide the desired accuracy and discrimination of human interpretations, it could function in another role, i.e., a method for defining human interpretations in such a manner that they could be converted to machine usable algorithms. In this study, the direct key originally developed for Ka-imagery was converted to a matrix key and was used as the basis of a FORTRAN IV program to interpret digitized

radar imagery. The algorithm key was able to discriminate six categories of crops in 34 fields at the 75 per cent correct level of accuracy. This was a preliminary test and should be considered indicative of an undeveloped capability. Further research on larger data sets are recommended and are currently underway.

The study also depicted the key as a link between the data acquisition component of an information system and the other component/activities of the system. For the *conceptualized, nationwide agricultural information system* developed by Morain (1972), it was suggested that the key provides the interpretation link necessary to conduct interpretation at the local (county) level. Local agricultural authorities with knowledge of their own area could interpret the imagery assisted by keys which they prepared in conjunction with professional interpreters. The data thus extracted from the imagery and used as information at local levels could then become input data to a nationwide information system. This system could impact at both regional and national levels by providing the basis of information required for monitoring at the regional level and for planning and forecasting at the national level. It was hypothesized that such a system would offer many research opportunities in agricultural geography, among them, land use studies, innovation and dispersion studies, and regionalization. Further investigation of both the potential of remote sensors as data acquisition instruments and the requirements of geographers of multi-level bureaucracies for information is needed. The role of keys in linking the two has, thus far, only been postulated. Future research should develop keys which link the remote sensors with actual data specifications in information systems.

## BIBLIOGRAPHY

- Austin, M. E., (1965), Land Resource Regions and Major Land Resource Areas in the United States (exclusive of Alaska and Hawaii), Agricultural Handbook 296, Government Printing Office, Washington, D.C.
- Bigelow, G. F., (1963), "Photographic Interpretation Keys -- A Reappraisal," Photogrammetric Engineering, 29, pp. 1042-51.
- Bigelow, G. F., (1966), "Human Factors Problems in the Development and Use of Image Interpretation Keys," Research Study 66-4, U.S. Army Personnel Research Office, Washington, D.C.
- Boyle, A. R., (1970), "Data Input," in Environment Information Systems, edited by R. F. Tomlinson, The Proceedings of the UNESCO/IGU First Symposium on Geographical Information Systems, International Geographical Union Commission on Geographical Data Sensing and Processing, Ottawa, Canada, pp. 44-52.
- Coiner, J. C. and S. A. Morain, (1971), "Image Interpretation Keys to Support Analysis of SLAR imagery," Papers from the 1971 ASP-ACSM Fall Convention, American Society of Photogrammetry, Falls Church, Virginia, pp. 393-412.
- Cole, John P. and C. A. M. King, (1968), Quantitative Geography, John Wiley & Sons Ltd., London.
- Colwell, R. N., (1946), "The Estimation of Ground Conditions from Aerial Interpretation of Vegetation Types," Photogrammetric Engineering, 12, p. 159.
- Colwell, R. N., (1952), "Report of Commission VII (Photographic Interpretation) to the International Society of Photogrammetry, Part 1, General," Photogrammetric Engineering, 18, pp. 375-400.
- Colwell, R. N., (1953), "Procedure for the Construction of Photo Interpretation Keys," Selected Papers on Photogeology and Photo Interpretation, Research and Development Board Committee on Geophysics and Geography, Washington, D.C.
- Colwell, R. N., Editor, (1960), Manual of Photographic Interpretation, American Society of Photogrammetry, Washington, D.C.
- Committee on Remote Sensing for Agricultural Purposes, Agricultural Board, (1970), Remote Sensing with Special Reference to Agriculture and Forestry, National Academy of Sciences, Washington, D.C.
- ERTS Data Users Handbook, (1971), Goddard Space Flight Center, National Aeronautics and Space Administration, Washington, D.C.

- Gregor, H. F., (1970), Geography of Agriculture: Themes in Research, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- Gunnels, G., (1971), "KANDIDATS: Kansas Digital Image Data System," CRES Technical Report 133-22, University of Kansas Center for Research, Inc., Lawrence, Kansas.
- Haralick, R. M., F. Caspall, and D. S. Simonett, (1970), "Using Radar Imagery for Crop Discrimination: A Statistical and Conditional Probability Study," Remote Sensing of Environment, 1, pp. 131-42.
- Hardy, N. E., J. C. Coiner and W. O. Lockman, (1971), "Vegetation Mapping with Side-Looking Airborne Radar: Yellowstone National Park," Propagation Limitations in Remote Sensing, ed. by John B. Lomax, North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development, London, pp. 11-1 - 11-19.
- Hoffer, R. M. and F. E. Goodrick, (1971), "Variables in Automatic Classification Over Extended Remote Sensing Test Sites," Proceedings of the Seventh International Symposium on Remote Sensing of Environment, Volume III, University of Michigan, Ann Arbor, Michigan, pp. 1967-1981.
- Hoffman, P. R., (1960), "Progress and Problems in Radar Photo Interpretation," Photogrammetric Engineering, 26, pp. 612-18.
- Holmes, R. A., (1968), "An Agricultural Remote Sensing Information System," EASCON '68 Record, pp. 142-9.
- Holter, Marvin R., H. W. Courtney and T. Limperis, (1970), "Research Needs: The Influence of Discrimination, Data Processing and System Design," Remote Sensing with Special Reference to Agriculture and Forestry, Committee on Remote Sensing for Agricultural Purposes, Agricultural Board, National Academy of Sciences, Washington, D.C., pp. 354-421.
- King, L. J., (1969), Statistical Analysis in Geography, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- Krumpe, P. F., H. R. DeSelm and C. C. Amundsen, (1971), "The Delineation of Forest Cover and Site Parameters by Multiband Remote Sensing," Papers from the 37th Annual Meeting, American Society of Photogrammetry, Falls Church, Virginia, pp. 98-122.
- Landis, G., (1955), "Concept and Validity of Associative Photographic Interpretation Keys in Regional Analysis," Photogrammetric Engineering, 21, pp. 705-6.
- Lewis, A. J., (1971), "Geomorphic Evaluation of Radar Imagery of Southeastern Panama and Northwestern Columbia," CRES Technical Report 133-18, University of Kansas Center for Research, Inc., Lawrence, Kansas.

- Lockman, W. O., L. T. James and J. C. Coiner, (1970), "NASA 90-Day Mission Report, Mission 133," CRES Technical Memorandum 177-15, University of Kansas Center for Research, Inc., Lawrence, Kansas.
- Lorsch, H. G., (1969), "Agricultural Resources Information System -- The User's Point of View," Paper presented at the Joint National Meeting, American Astronautical Society and Operations Research Society, June 17-20, 1969, Denver, Colorado.
- MacDonald, H. C. and W. P. Waite, (1971), "Soil Moisture Detection with Imaging Radar," Water Resources Research, 7 (1), pp. 100-110.
- Marschner, F. J., (1959), Land Use and Its Patterns in the United States, Agricultural Handbook 153, U.S. Department of Agriculture, Washington, D.C.
- Mayr, E., (1969), Principles of Systematic Zoology, McGraw-Hill Book Company, New York.
- McCoy, R. M., (1969), "Drainage Network Analysis with K-Band Radar Imagery," The Geographical Review, pp. 493-512.
- Moore, Eric G. and Barry S. Wellar, (1969), "Urban Data Collection by Airborne Sensor," Journal of the American Institute of Planners, 35 (1), pp. 35-43.
- Moore, R. K., (1969), "Radar Return from the Ground," in Solink, editor, Radar Handbook, McGraw-Hill Publishing Co., New York.
- Moore, R. K. and W. P. Waite, (1969), "Radar Scatterometry," CRES Report No. 118-15, University of Kansas Center for Research, Inc., Lawrence, Kansas.
- Morain, S. A. and D. S. Simonett, (1966), Vegetation Analysis with Radar Imagery, "Proceedings of the Fourth Symposium on Remote Sensing of Environment," University of Michigan, Ann Arbor, Michigan.
- Morain, S. A. and D. S. Simonett (1967), "K-Band Radar in Vegetation Mapping," Photogrammetric Engineering, 33, pp. 730-740.
- Morain, S. A. and J. C. Coiner, (1970), "An Evaluation of Fine Resolution Radar Imagery for Making Agricultural Determinations," CRES Report No. 177-7, University of Kansas Center for Research, Inc., Lawrence, Kansas.
- Morain, S. A., (1972), "Radar Applications in Agriculture/Forestry," Annual Report supported by NAS 9-10261.
- Narva, M. A., (1971), "Evaluation of Selected Pictorial Characteristics of Image Interpretation Keys," Papers from the 37th Annual Meeting, American Society of Photogrammetry, Falls Church, Virginia, p. 299.
- Pruitt, E. L., (1970), "Thoughts on Inputs to Information Systems," The Professional Geographer, 22, pp. 12-14.
- Sadacca, R., (1963), "Human Factors in Image Interpretation," Photogrammetric Engineering, 29, pp. 978-88.

- Schwarz, D. E. and F. Caspall, (1968), "The Use of Radar in the Discrimination and Identification of Agricultural Land Use," Proceedings of the 5th Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan, pp. 233-247.
- Scrimshaw, Nevin, S., (1963), "Food," Readings in Agriculture from Scientific American, W. H. Freeman and Co., San Francisco, pp. 206-214.
- Shelton, R. L. and E. E. Hardy, (1971), "The New York State Land Use and Natural Resources Inventory," Proceedings of the Seventh International Symposium on Remote Sensing of Environment, Volume II, University of Michigan, Ann Arbor, Michigan, pp. 1571-1575.
- Simonett, D. S., J. E. Eagleman, A. B. Erhart, D. C. Rhodes and D. E. Schwarz, (1967), "The Potential of Radar as a Remote Sensor in Agriculture," CRES Report No. 61-21, University of Kansas Center for Research, Inc., Lawrence, Kansas
- Simonett, D. S., (1968), "Potential of Radar Remote Sensors as Tools in Reconnaissance Geomorphic, Vegetation and Soil Mapping," Technical Letter NASA 125, U.S. Department of the Interior, Washington, D.C.
- Simonett, D. S., J. R. Marshall, J. R. Eagleman and S. A. Morain, (1969), "The Complementary Roles of Aerial Photography and Radar Imaging Related to Weather Conditions," in The Utility of Radar and Other Remote Sensors in Thematic Land Use Mapping from Spacecraft, USGS T4-08-0001-10848, Second Annual Report.
- Simpson, R. B., (1966), "Radar, Geographic Tool," Annals of the Association of American Geographers, 56 (1), pp. 80-96.
- Smith, H. T. U., (1953), "Photo Interpretation of Terrain," Selected Papers on Photogeology and Photo Interpretation, Research and Development Board Committee on Geophysics and Geography, Washington, D.C.
- Tobler, W. R., (1970), "Index Paper on Data Display and Presentation," in Environment Information Systems, edited by R. F. Tomlinson, International Geographical Union Commission on Geographical Data Sensing and Processing, Ottawa, Canada.
- U. S. Department of the Navy, (1967), Image Interpretation Manual, Volume I, NAVAIR 10-35-685, Government Printing Office, Washington, D.C.
- University of Michigan, (1971), Proceedings of the Seventh International Symposium on Remote Sensing of Environment, Volumes I-III, University of Michigan, Ann Arbor, Michigan.
- Wellar, B. S., (1969), "The Role of Space Photography in Urban and Transportation Data Series," Proceedings of Sixth International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, pp. 831-854.

- Wellar, B. S., (1970), "Data Acquisition: Bane of Information Systems Development," Papers from the Eighth Annual Conference of the Urban and Regional Information Systems Association, edited by John E. Rickert and Sandra L. Hale, Urban and Regional Information Systems and Kent State University, Kent, Ohio, pp. 456-469.
- Wellar, B. S., (1971), "Paradigms for the Development of Standardized Data Bases," Papers Presented at the Annual Conference of the American Institute of Planners, San Francisco, available from Information Systems Department, American Institute of Planners, Washington, D. C.
- Wellar, B. S. and T. O. Graff, (1971), Geographic Aspects of Information Systems: Introduction and Selected Bibliography, Council of Planning Librarians, Monticello, Illinois.

## APPENDIX I

### INTERPRETER TESTS OF DIRECT DICHOTOMOUS KEYS FOR SLAR

- Part 1. Cover letter and interpreter instructions.
- Part 2. Interpretation Questionnaire.
- Part 3. Introduction to the Garden City, Kansas, Radar Test Site by Floyd M. Henderson.
- Part 4. Location of Radar Test Strip Garden City, Kansas.
- Part 5. DPD-2 Direct Dichotomous Key with DPD-2 image pair (HH-VH) showing fields to be interpreted.
- Part 6. AN/APQ-97 Direct Dichotomous Key, Key graphic, and AN/APQ-97 Image pair (HH-HV) showing fields to be interpreted.



PART 1.

Cover letter and interpreter instructions for direct dichotomous key test.

Dear Sir:

Your assistance in the enclosed Image Interpretation testing sequence is requested. These tests are intended to provide a basis for evaluating the effectiveness of dichotomous image interpretation keys as an aid in the interpretation of side-looking airborne radar (SLAR) imagery.

As enclosures to this letter you will find the following materials:

- (1) An AN/APQ-97 SLAR positive transparency of the Garden City, Kansas NASA Test Site. (HH-HV)
- (2) An AN/APQ-97 SLAR positive print image of the Garden City, Test Site. (HH-HV)
- (3) Two DPD-2 SLAR positive transparency images of the Garden City Test Site. ( 1 HH - 1 VH )
- (4) Two DPD-2 positive print images of the Garden City Test Site. ( 1 HH - 1 VH )
- (5) A line drawing map of the Garden City Agriculture Test Site.
- (6) A numbered overlay for the AN/APQ-97 images showing the fields to be interpreted.
- (7) A numbered overlay for the DPD-2 images showing the i to be interpreted.
- (8) A description of the physical setting and main agricultural practices of the Garden City site prepared by F. M. Henderson.
- (9) An AN/APQ-97 dichotomous key.
- (10) A DPD-2 dichotomous key.
- (11) An Interpretation Key Questionnaire.



The test is divided into two interpretations, both of the NASA radar test site at Garden City, Kansas. You are requested to use the information in Floyd M. Henderson's description of the Garden City agricultural milieu to provide yourself with some pre-interpretation background. Then using the dichotomous keys, interpret the two image pairs ( 1-AN/APQ-97 and 1-DPD-2 ) of the test site.

This test is intended for experienced interpreters only. No attempt will be made to specify interpretation procedures to be followed other than to use the key, as each interpreter will have developed his own "style". For this reason, both positive transparencies and prints are included. I only request that in the space provided at the bottom of the Interpretation Key Questionnaire, each interpreter briefly describe the procedures he/she employed while interpreting the enclosed images, i.e., I used the positive transparency and a B & L ZOOM 70 mounted on a Richards light table.

Your further assistance will be requested in a few weeks to assist me in the development of an experience matrix, however, this will require only a few minutes of your time.

If you have any comments, criticisms or impressions of the keys as interpretation aids, I would appreciate receiving them.

Thank you for your help.

Sincerely,

Jerry C. Coiner

PART 2.

Interpretation Key Questionnaire

Please fill out the questionnaire below. It is intended to provide data to assist in the evaluation of your key supported interpretation.

Name: \_\_\_\_\_

A. Training

\_\_\_\_\_  
Photo Interpretation  
College

\_\_\_\_\_  
Photo Interpretation  
Military

\_\_\_\_\_  
Special Training in  
SLAR interpretation

Time  
in  
Weeks

B. Experience

1. Photo interpretation

less than

1 year      1-2 years      2-3 years      3-4 years      4-5 years      5+ years

\_\_\_\_\_

2. SLAR Interpretation

less than

1 year      1-2 years      2-3 years      3-4 years      4-5 years      5+ years

\_\_\_\_\_

3. Interpreting Imagery of any kind for Agricultural Information

no previous      up to 1 year previous      1-2 yr.      2-3 yr.      3-4 yr.      4-5 yr.      5+ yrs.  
experience      experience      expr.      expr.      expr.      expr.      expr.

\_\_\_\_\_

C. Knowledge of Dichotomous Keys

Have  
never  
used  
or been  
trained  
to use

Have  
been  
trained  
to use  
as a  
Photo interp.

Have  
been  
trained  
to use  
in Bio. Sc.

Use  
regularly  
in my  
work

\_\_\_\_\_

BRIEFLY EXPLAIN THE PROCEDURES YOU USED TO INTERPRET THE ENCLOSED SLAR IMAGERY ON THE ATTACHED SHEET OF PAPER.

## PART 3.

### INTRODUCTION TO THE GARDEN CITY, KANSAS, RADAR TEST SITE

Floyd M. Henderson

The Finney County-Garden City, Kansas, test site has been studied by the Center for Research, Inc., for over six years. The physical setting, changing land use practices, and aspects of the environment susceptible to investigation by remote sensors, specifically radar, will be described briefly in the following paragraphs.

#### Physical Setting

Finney County is situated in the High Plains of southwestern Kansas and occupies about 832,280 acres. It is the second largest county in the state. The Arkansas River passes through its lower third dividing it into two regions: a broad band of sand hills to the south which is used mainly for cattle grazing; and an irrigated agricultural region to the north. North of the river slopes average from zero to one per cent, although some areas range up to three per cent. Erosion, aside from wind, has had virtually no effect on the landscape.

A semi-arid climate, the area's average annual precipitation is about 19 inches, but this has varied from as little as 5 inches to more than 23 inches annually in the last 15 years. Most of the precipitation (74%) falls during the growing season from April to October. Also at this time high temperatures and frequent strong winds create high evaporation rates and lead to problems of water allocation. An average of over 200 frost free days provides a prolonged growing season while the lack of severe cold temperatures places it in the winter wheat belt. The combination of dryland and irrigated farming, large uniform fields and extensive agriculture makes Finney County typical of the winter wheat belt in the High Plains today.

## Crop and Growing Season

Five main crops are grown commercially: (1) wheat, (2) corn, (3) sorghum, (4) alfalfa, and (5) sugar beets. Winter wheat is planted in the fall between September and October. By the time of the first frost, usually late October or November, it is about two to four inches high. As a frost would then damage the crop cattle may be grazed on the wheat to prevent it from growing any taller. Through the winter the wheat lies dormant but in late March or early April it begins growing again and is harvested from late in May to early and mid-June.

Corn, sorghum, alfalfa and sugar beets all have about the same growing season; they are planted in March or April and harvested in September or October. There are two main kinds of sorghum grown — grain and silage; the former is sold over the market as grain and the latter is cut and used as cattle feed. Although both are sorghums, each has a different plant geometry, grain head, color, and field density. Alfalfa is a fast-growing crop used to produce livestock feed and feed pellets and is harvested or cut five to six times a year. Thus, one may see a mature alfalfa field of about 26" - 30" in height adjacent to a cut field only 2" - 3" in height. Sugar beets, like corn and sorghum, are harvested once in the fall. It is significant to note that in addition to between crop variations there are also within crop varietal differences that may affect a sensor's signal response.

Fields not in crops are left fallow or are in pasture. Fallow fields are those left idle after a harvest for one growing season in order to conserve moisture and nutrients for the following year's crop. Crop rotation is practiced but the exact cycle varies from farmer to farmer. One may plant a field in wheat, then fallow, sorghum, fallow, and wheat again; another may go from wheat to fallow, corn, alfalfa, and then to sugar beets on successive years. Other common practices are to plant alfalfa continually for two to six years as it builds up soil nutrients, or to repeatedly plant one crop in a field for two to three years using fertilizers to maintain soil fertility.

Irrigated fields are usually longer than they are wide to permit optimum use of irrigation pipes or ditches and minimize work and reduce evaporation losses. Ten to twenty pipes or gates are opened and water flows into these furrows until it reaches the other end of the field. For this reason the fields have a very slight slope to permit the gravitational pull of water. The pipes or gates are then shut and the next series of adjacent furrows are irrigated. This process is continued until the entire field has been irrigated. The pipes or gates are then opened at the initial starting point and the process begins anew. For sugar beets and alfalfa this is done almost continually, but for wheat and other crops only two or three water applications during the growing season are necessary. It is important to note that soil moisture may vary by several percentage points across an irrigated field. When viewed by radar this difference may be significant enough that the field appears as two fields to the radar or causes variation in across the field. Fields per se are generally square or have a large aspect (length to width ratio, i.e., the ratio is one to one or equal to or greater than two to one. The ratio may aid in determining its use. For example alfalfa fields have a large aspect ratio but the ratio is less evident for irrigated wheat fields. Still the final decision of when or if to irrigate a crop, the field size and shape are those of the farmer — and vary according to individual preferences and perceptions. Dryland and irrigated fields exist side by side but irrigation has diffused over the area wherever water is available (Foley, 1967).

#### Planting and Plowing Procedures

As mentioned above the time for planting is within roughly a two month period — September to October for wheat and March to April for other crops. There are some minor differences but these are insignificant when viewed overall. The important item to be considered is that a farmer has two months effective leaway to plant his crops. This means that the level of maturity for one crop type can theoretically vary a great deal from field to field based solely on planting time and regardless of varietal differences. The direction he plants his crop depends on the way his

irrigation pipes or ditches run, the size and slope of his field, and his own peculiar planting methods which include row direction, row spacing, and plant density. For example, a farmer may plant a field of corn variety "A" on April 22 with east-west rows, have 12 inch row spacing and 4 inches between plants, irrigate the field on May 2 and apply fertilizer "M" on May 20. Varying only one item in an adjacent corn field may change its radar return significantly. Imagine the potential difference to radar in two "corn fields" if he plants the next one with variety "B", on April 29 in north-south rows of 18 inch row spacing and 2 inches between plants, applies fertilizer "Z" on May 4 and irrigates on May 27. Planting time can also be influenced by environmental hazards such as early frost, hail, drought, flood or tornado — all of which can compel the farmer to replant or abandon his crop for that year.

Plowing practices vary as much as do planting practices, nevertheless some general characteristics are discernable. Because of the grid system of field orientation most farmers plow north-south, east-west, or rectangularly around a field so . However, there are exceptions where the farmer plows diagonally. Many times after plowing a field the farmer will harrow or disc it; this slices the earth into finer clods conserving moisture and prevents wind erosion if the field is prepared perpendicular to the prevailing wind direction i.e. northwest-northeast. In essence each time a farmer plows or discs his field or the way he plants his field can alter the signal return of a sensor. Two bare fields or fallow fields may appear quite different on the imagery depending on the size of clod, row direction, if any, soil moisture, and weathering. The potential differences between two fields of the same type have already been discussed. It is evident that field can change its appearance in five minutes as well as five months — an important factor to inconsistent radar returns.

### Farm Practices

As is typical in many farming regions the number of farms is declining while the acreage under cultivation is increasing. Successful farmers and companies are buying out the small family farm operation. Although farms average over 1200 acres (many run over twice that) one person

## Irrigation and Dryland Farming

Irrigation ditches were first constructed in the 1880's and the variety and types of irrigation have continually expanded since that time. There are three main types in use in the test area today: sprinkler, ditch flood, and pipe flood. Sprinkler systems irrigate in a circular manner as the pipe rotates around the field on wheels spraying the crop. This type is very limited in use however due to the limited soil permeabilities and high evaporation rates in the area. Ditch flood and pipe flood are very similar to each other in application. Both water the field by streams of water going between the furrows. The ditch flood method uses syphon hoses (4 to 6 feet long) to transport the water from the ditch to the field while the pipe flood method is operated by opening vents or locks on a pipe running along the edge of a field. River water is not used to any degree for irrigation. Its quality is often below that acceptable for irrigation and the quantity available when needed is not reliable. Well-water, being of higher quality and consistent in quantity, is used almost exclusively. Yet, soil salinity is a growing problem in some areas.

Dryland farming consists of using only natural moisture. A field is cropped once a year and then allowed to lie fallow for a year to obtain enough soil moisture for another crop. Although dryland farming is less time consuming and less costly to implement, the yields are lower than on irrigated fields (dryland wheat averages 8 - 10 bushels/acre and irrigated wheat 40 - 50 bushels/acre). Moreover, there is a higher risk of drought hazard and crop failure. Consequently only certain crops such as wheat and corn can be successfully dryland farmed in this area (sorghums can be but very seldom are). Sugar beets and alfalfa require water almost constantly to produce a marketable crop.

Field size as judged from May, 1970, field data cannot consistently determine if a field is irrigated or dryland farmed. Apparently a farmer keeps relatively the same field size but alters irrigation or dryland cropping practices. There are only two general trends observable: (1) more land is irrigated than dryland farmed and (2) irrigated fields are usually smaller (21-40 acres) than dryland fields (160 acres).

seldom owns that much. Rather, land is rented from large land companies, e.g., Garden City Company, or from non-resident owners. Moreover many farm operators themselves do not live on the land but are sidewalk or suitcase farmers (Kollmorgen and Jenks, 1958). Detailed data acquisition for use with radar on a per field basis is subsequently more difficult here than in areas where the farmer still owns and resides on his family acreage.

Self propelled machinery and hired labor are a necessity to harvest the large acreages. Alfalfa mills and large grain elevators dot the landscape. Alfalfa acreage is increasing as more cattle are fed in the area and to service this trend the number of dehydrating and pelletizing mills has increased. More and more farmers are feeding cattle to supplement their income, and commercial feedlot operation is expanding in the county. As a result more corn and sorghum are grown for silage and sold along with the alfalfa for cattle feed. Generally as the total acreage under cultivation increases yearly, the acres planted to each crop also increases. It appears that the gradual trend is away from solely commercial grain farming and into a mixed farm operation using irrigation to insure crop harvest.

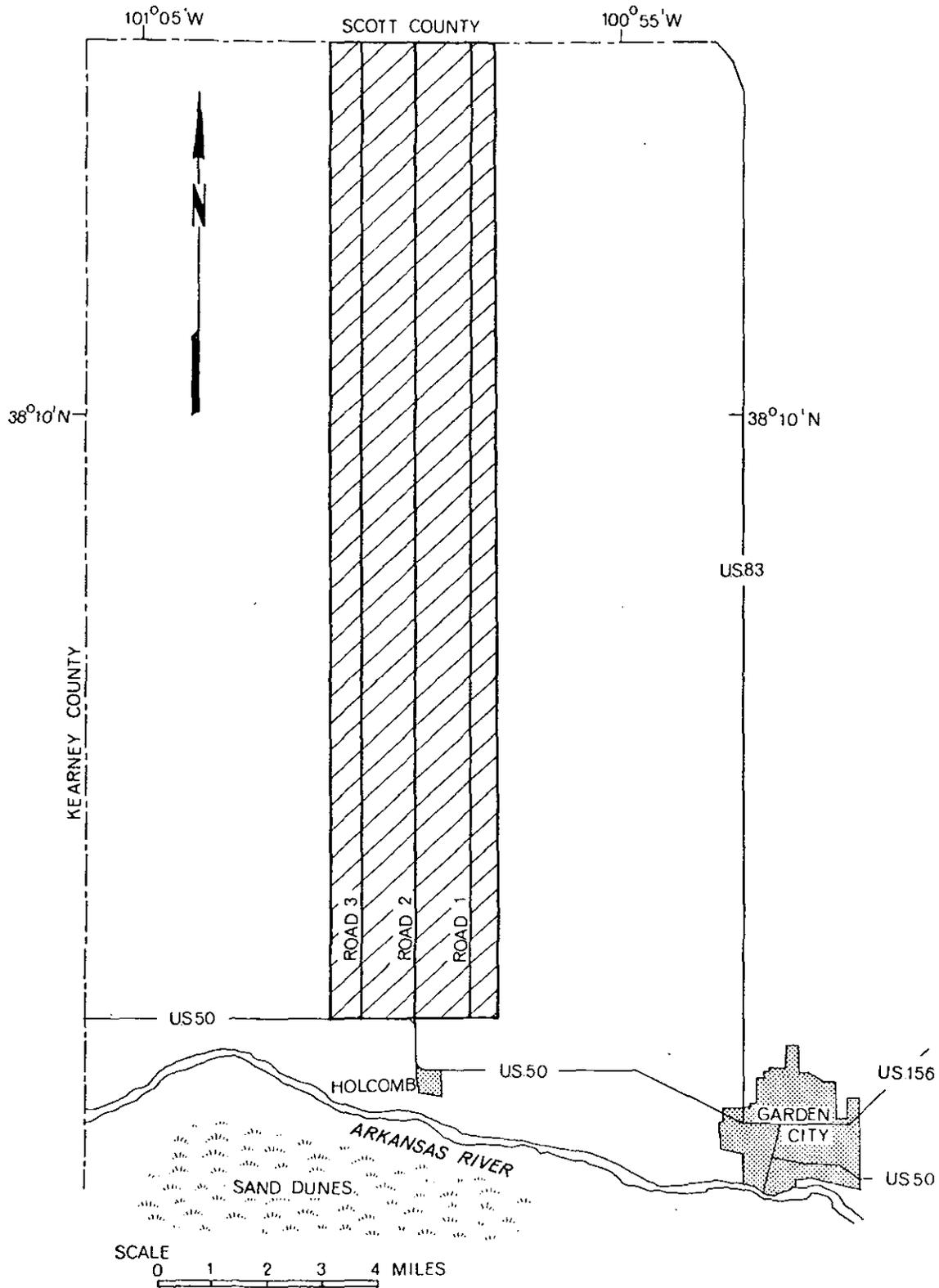
It is now apparent that land use practices are as complex and variable as the mechanical parts of the sensor itself. These are some of the major factors that an interpreter must concern himself when interpreting imagery.\*

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\*This introduction represents excerpts from CRES Technical Memo. 177-17, dated January 1971, and is intended to provide an overview of the agricultural milieu at the Garden City test site.

PART 4.

LOCATION OF RADAR TEST STRIP  
GARDEN CITY, KANSAS

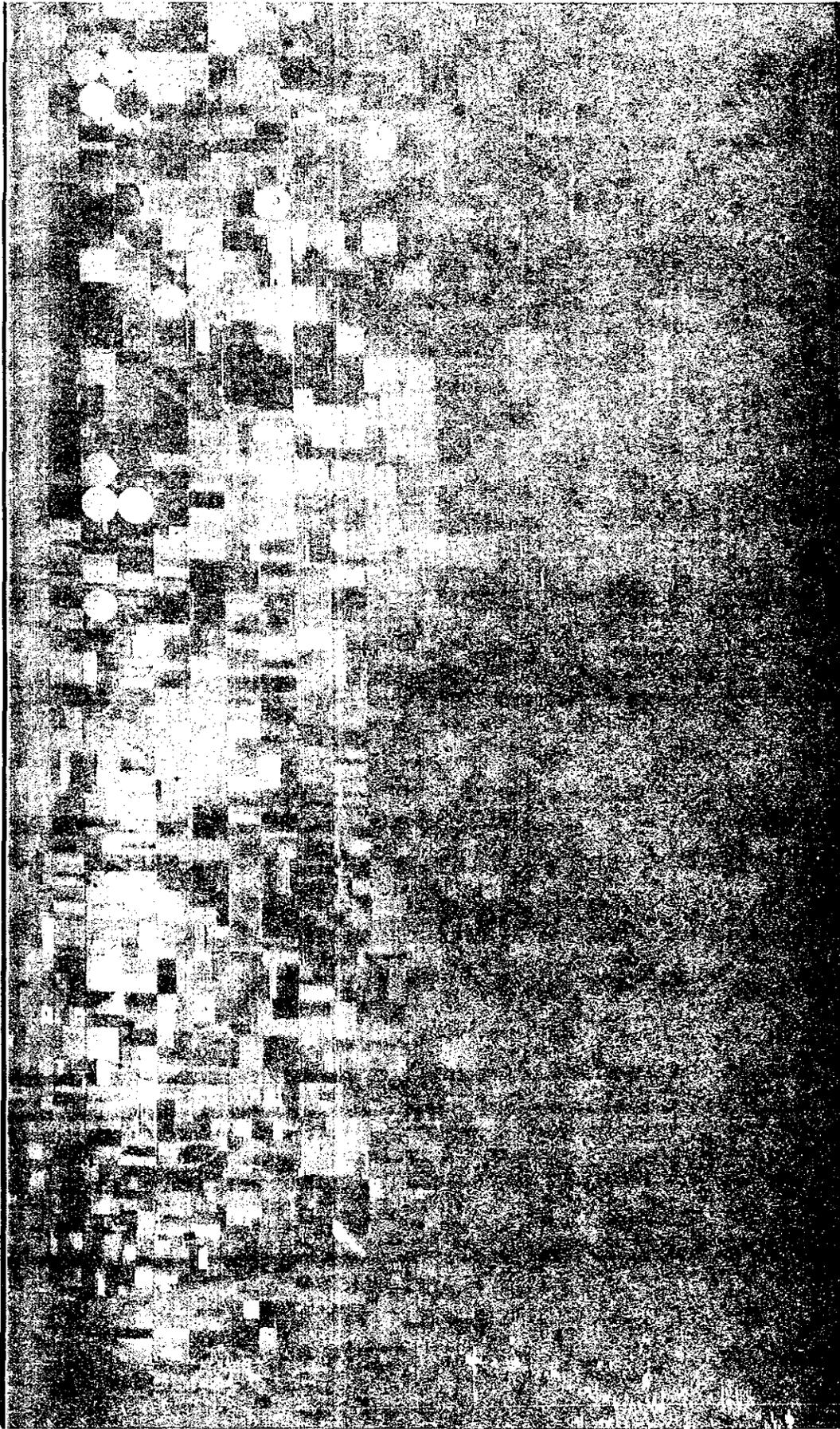


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PART 5.

KEY TO DPD-2 IMAGERY

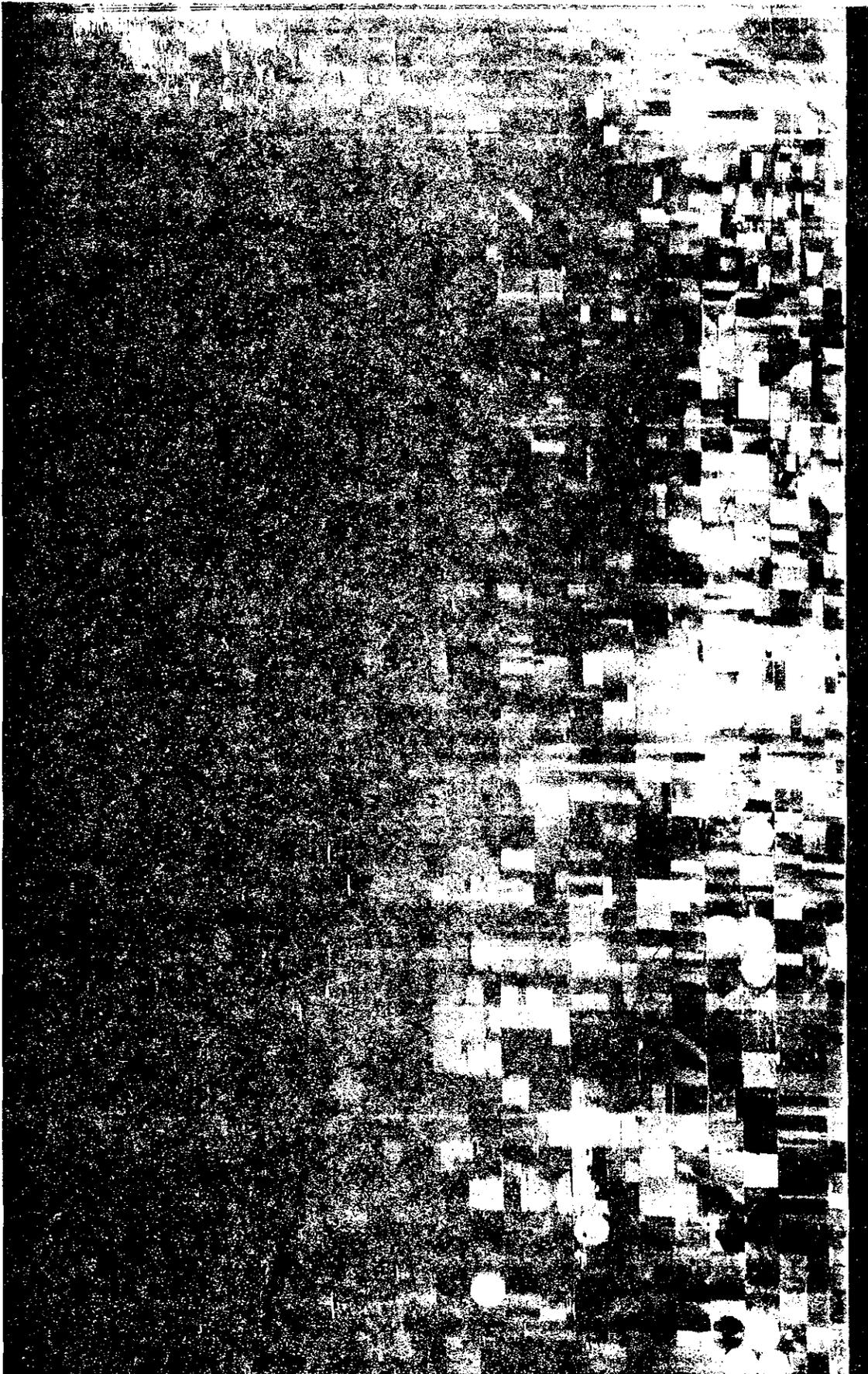
A	Field images white or light gray on both HH and VH		Sugar Beets
A'	Field images white to black HH and light gray to black VH	See B	
B	Field images white on HH and light gray on VH		Corn (rows Parallel to line of flight)
B'	Field images light gray to black on HH and light gray to black VH	See C	
C	Field images light gray on HH to gray on VH		Corn (rows perpendicular to line of flight) Grain Sorghum, Alfalfa
C'	Field images gray on HH to gray on VH	See D	
D	Field images gray on HH and gray on VH		Wheat Stubble (unturned)
D'	Field images dark gray on HH to dark gray on VH	See E	
E	Field is dark gray on HH and VH with variations in the field from medium gray to dark gray		Fallow, Pasture, and volunteer crop regrowth
E'	Field is black - Field is in some state of tillage (row harrowing, drilling, etc)		



NASA DPD-2 7-5-70 Real/VH

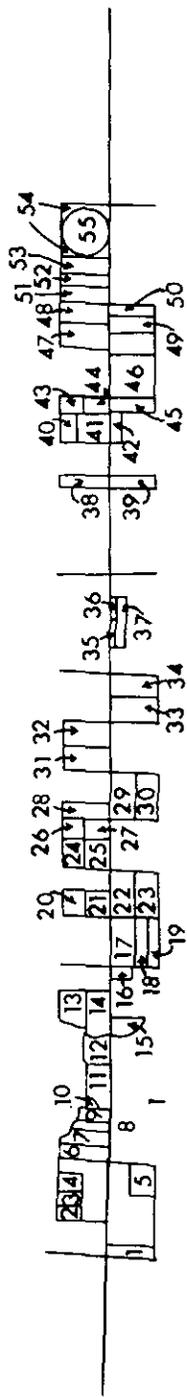
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C-2



NASA DPD-2 7-5-70 Redl/HH

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Fields to be Interpreted from NASA DPD -2 Overlay to HH Positive Transparency



PART 6.

KEY FOR AN/APQ-97 IMAGERY  
Garden City, Kansas, September, 1965

Based on Five Gray Levels for Both HH and HV

A	HH and HV are white		Sugar Beets
A'	HH is not white	Go to B	
B	HH is light gray	Go to C	
B'	HH is not light gray	Go to D	
C	HH and HV are light gray		Corn
C'	HH is light gray, HV almost white		Alfalfa
D	HH is gray	Go to E	
D'	HH is <u>not</u> gray	Go to G	
E	HH <u>has even</u> gray tone	Go to F	
E'	HH has uneven gray tone (also HV)		Fallow
F	HV has similar gray scale to HH		Wheat
F'	HV has lighter gray scale than HH		Sorghum
G	HH is dark gray to black, even gray scale	Go to H	
G'	HH is dark gray to black, uneven gray scale (possibly more noticeable in HV)	Go to I	
H	Area has regular boundaries		recently tilled
H'	Area has irregular boundaries		Standing water
I	HV shows major shift toward gray to light gray		Pasture
I'	Field shows only minor shift toward gray		Fallow

KEY TO AN/APQ-97 SEPTEMBER 1965



HH

SUGAR BEETS



HV



HH

CORN



HV

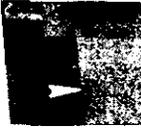


HH

ALFALFA



HV



HH

WHEAT



HV



HH

SORGHUM



HV



HH

FALLOW  
GROUND



HV



HH

PASTURE



HV



HH

RECENTLY  
TILLED



HV

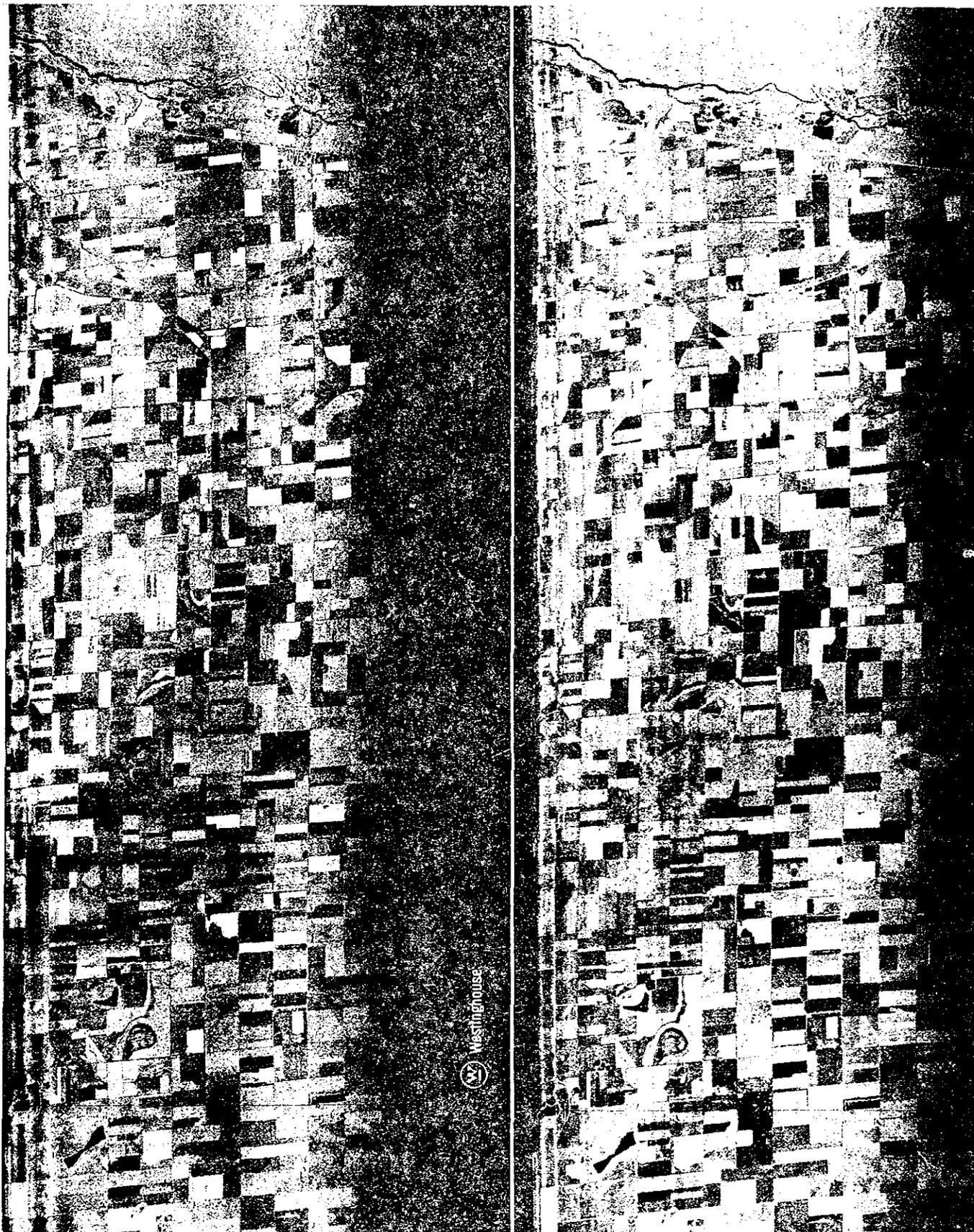


HH

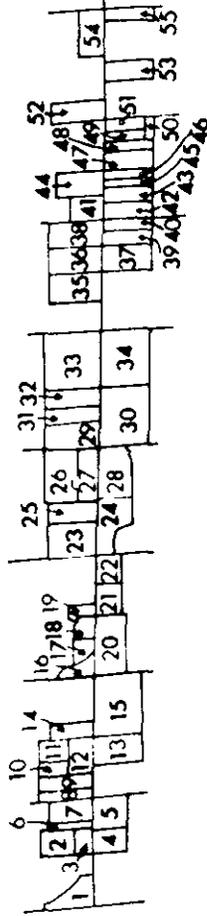
STANDING  
WATER



HV



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Fields to be Interpreted from NASA ANAPQ-97 Overlay to MH Positive Transparency

## APPENDIX II

### AN AUTOMATED INTERPRETATION PROGRAM DERIVED FROM A RADAR INTERPRETATION KEY

Percy P. Batlivala and J.C. Coiner

Purpose: To use radar data that has been digitized to interpret crops by converting a human based interpretation key into a form that can be employed as a computer algorithm.

Method: The radar image is digitized using 50 micron spot size. It is stored on tape, and then printed out as a computer map using the KANDIDATS Picture Program. The fields to be interpreted are then selected and called out onto a separate tape with each field having two files (one for the HH polarization image and one for the HV polarization image). The field is called from the tape with each file being reduced by mean and mean assignment to a single integer value between 1 and 5. The HH file integer value then is used as value I while the HV integer value is used as value J. These integers (I and J) are used to define allocation within the matrix A, which consists of crop labels to be applied to the field (i.e., if the HH value is reduced to 3 and the HV value to 3, the location in matrix A is then defined as  $A_{IJ}$  and contains the label "grain sorghum"). This crop label with file identification is then printed out. Figure 1 is a simplified flow diagram of the program, and Figure 2 is a pictorial representation of a preliminary label matrix derived from an image interpretation key.

Subroutine Name: DIKEY

Calling Statement: CALL DIKEY (ILABEL, NLEVEL, IARRAY, NROWM, NCOLM, II, IMIN, IMAX, IDUM1, IDUM2, NIMAGE, NFILE, IFILE)

Arguments:

ILABEL is the input array of labels used for classification.

NLEVEL      are the number of levels used for classification. ILABEL is  
                  dimensional (NLEVEL, NCEVEL)  
 IARRAY      is the field to be classified.  
 NROWN      is the largest number of rows on any field.  
 II            is an integer value from 1 to 10 depending on the type of  
                  processing to be done.  
 IMIN        is the minimum brightness level on any field.  
 IMAX        is the maximum brightness level on any field.  
 IDUM1  
 IDUM2      are scratch vectors of size NIMAGE.  
 NIMAGE     is the number of fields to be classified.  
 NFILE      is the file code used to designate the file on which the  
                  images are placed. The images are read a line at a time.  
                  An end of file mark must designate the end of an image.  
 IFILE      is the file array of dimension NIMAGE.

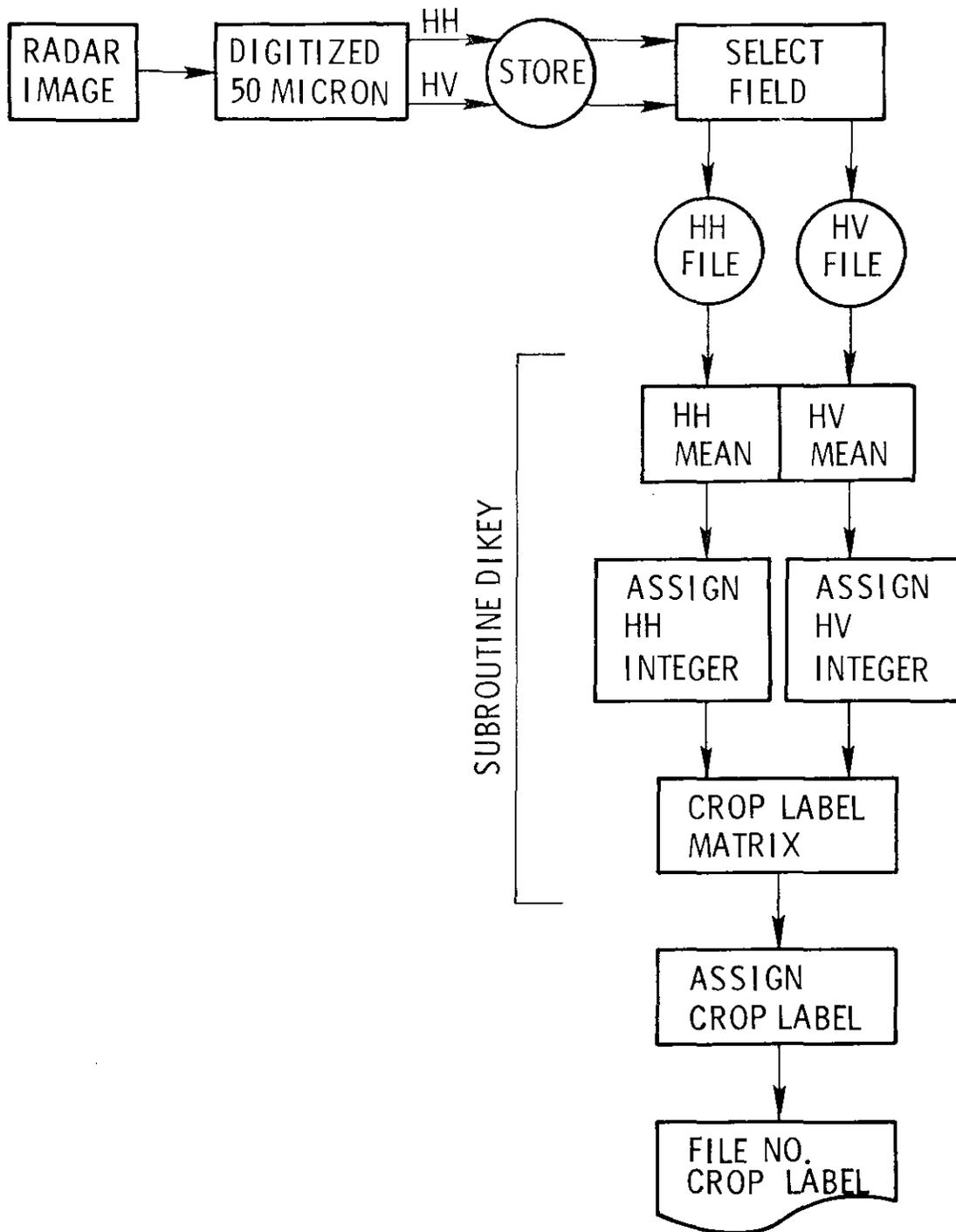


Figure 1. Digitized Image Flow Diagram for Subroutine DIKEY.

HH 1 (DARK)	RECENTLY TILLED	FALLOW	NCA*	NCA*	NCA*
2	FALLOW	FALLOW	WHEAT	WHEAT	NCA
3	NCA	NCA	SORGHUM	ALFALFA	NCA
4	NCA	NCA	NCA	ALFALFA	SUGAR BEETS
5 (LIGHT)	NCA	NCA	NCA	NCA	SUGAR BEETS
	HV 1 (DARK)	2	3	4	5 (LIGHT)

\*NO CROP ASSIGNED

Figure 2. Preliminary Label Matrix Derived from an Image Interpretation Key.

This matrix is loaded into the program and is accessed by integer values developed from descriptor statistics of the classes to be identified.

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MAINLINE FOR DI-KEY

1 CJI MAIN

MAINLINE FOR DI-KEY

2 DIMENSION LABEL(5,5), IARRAY(256) , IDJM(55,2), IFILE(55)

3 C MAIN LINE

4 NLEVEL=2

5 NRDM = 137

6 NCOLM = 256

7 NIMAGE = 55

8 IMIN=0

9 I MAX=255

10 N-ILE=1

11 I1 =2

12 CALL DIKEY(ILABEL,NLEVEL,IARRAY,NRDM,NCOLM,I1,IMIN,

2 I MAX, IDJM, N I AGE, N I - E, I FILE)

14 STOP

15 END

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88662 01 07-11-72 19.176 D-I-K-E-Y
1 CJI-KEY D-I-K-E-Y
2 SJJRQJINE DIKEY(ILABEL,NLEVEL,JARRAY,NROWM,NCOLM,II,
3 IIMIN,IMAX,IDUM,NIMAGE,NFILE,IFILE)
4 EXTERNAL NINBIT
5 DIMENSION JARRAY( NCOLM),ILABEL(NLEVEL),IDJM(NIMAGE,
6 $2),IFILE(NIMAGE),IPL(11)
7 INTEGER R,LABEL
8 DATA IMEAN,GMEAN,LR_(1),J,D,207
9 *****
10 C THIS SJJRQJINE USES TECHNIQUES OF VISUALLY INTERPRETTED
11 C RADAR IMAGERY. THE CATEGORY MATRIX,ILABEL,IS PREDETERMINED
12 C AND IS USED AS A INPUT PARAMETER.
13 C *****
14 R=AD(2,101) ((ILABEL(I,J)),J=1,NLEVEL),I=1,NLEVEL)
15 FORMAT(13A6)
16 WRITE(6,105)
17 FORMAT(1X//,'THE CATEGORY MATRIX'//)
18 WRITE(6,104) ((ILABEL(I,J)),J=1,NLEVEL),I=1,NLEVEL)
19 FORMAT(5(5X,1A6))
20 DO 11 IIF=1,NIMAGE
21 READ(2,102) IFIL
22 FORMAT(6X,1S)
23 IFILE(IIF)=IFIL
24 11 CONTINUE

```

```

25 MIMAGE=2*NIMAGE
26 *****
27 C START READING IN DATA
28 *****
29 DO 1 KKK=1,MIMAGE
30 I=(RLABEL(KKK,1,LB-),I,0) STOP
31 NROW=L3L(3)
32 NCOL=L3L(4)
33 WRITE(6,106) NROW,NCOL
34 106 FORMAT(1X,'NROW=',I3,1X,'NCOL=',I3)
35 CALL UMEAN(IARRAY,NLEVEL,NROW,NCOL,VRJW,NCOLM,II,IMIN,IMAX,GMEAN
36 1,KKK,NIMAGE,IMEAN)
37 NROW=NROW+1
38 DO 10 I=2,NROW
39 I=(LREAD(KKK,I,IARRAY(1)),LT,0) CALL ABORT(2HEP)
40 CALL UMEAN
41 10 CONTINUE
42 NROW=NROW-1
43 C *****
44 C STORE IN DUMMY ARRAY IDJM THE MEANS OF THE HH AND HV
45 C POLARIZED IMAGES RESPECTIVELY.
46 C *****
47 I=(KKK,LE,NIMAGE) GO TO 110
48 KKF=KKK-NIMAGE
49 IDJM(KKF,2)=IMEAN
50 GO TO 1
51 110 IDJM(KKK,1)=IMEAN
52 1 CONTINUE

```

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88662 01 07-11-72 19.1/6 U-1-K-E-Y
*****
53 C *****
54 C SEARCH THE CATEGORY MATRIX 'ILABEL' AND CLASSIFY THE FIELDS.
55 C *****
56 C DJ 3 III=1,NIMAGE
57 I=IDJM(III, )
58 JJ=IDJM(III,2)
59 WRITE(6,103)IFILE(III),ILABEL(II,JJ)
60 103 FORMAT(1H0,'THE IMAGE NUMBER',I3,' WAS CLASSIFIED AS A ',A6,' FILE
61 $0')
62 / CONTINUE
63 C *****
64 C PRINT AND PUNCH THE RESULTS.
65 C *****
66 C DJ / KKM=1,NIMAGE
67 WRITE(45,107) IFILE(KKM),IDJM(KKM,1),IFILE(KKM),IDJM(KKM,2)
68 WRITE(6,107) IFILE(KKM),IDJM(KKM,1),IFILE(KKM),IDJM(KKM,2)
69 107 FORMAT(1X,' HH FIELD NO. ',I3,' MEAN=',I5/,
70 1X,' V FIELD NO. ',I3,' MEAN=',I5)
71 / CONTINUE
72 RETURN
73 END
*****
23659 WORDS OF MEMORY USED BY THIS COMPILATION

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```

1 C JMEAN J-M-E-A-N
2 SUBROUTINE JMEAN(IARRAY,N,EVEL,NROW,NCOL,NROWN,NCOLM,II,IMIN,IMAX
3 $,GMEAN,KKK, IMAGE,I MEAN)
4 *****
5 C THIS SUBROUTINE FINDS THE MEAN OF EACH IMAGE AND THEN
6 C ACCORDING TO THE OPTION 'II' TRANSFERS THE CALL TO A APPROPRIATE
7 C SUBROUTINE.
8 C *****
9 C DIMENSION IARRAY( NCOLM)
10 C *****
11 C FIND THE MEAN OF THE IMAGE BY ADDING JP ROW AT A TIME
12 C *****
13 NUM=0
14 C NIMES IS THE COUNT OR NUMBER OF CALLS TO JMEAN1
15 NIMES = NROW
16 NNCOL = NCOL
17 POINTS = NROW*NNCOL
18 RETURN
19 C *****
20 C ENTRY J-M-E-A-N-1
21 C *****
22 ENTRY JMEAN1
23 C SUM UP ELEMENTS IN ONE ROW ON EACH CALL, MUST BE CALLED NIMES
24 C FOR EACH FIELD.
25 DO 1 J=1,NC L
26 1 NIM = NUM + IARRAY(J)
27 NIMES = NIMES - 1
28 I-(NIMES,NE,0) RETURN
29 GMEAN=(FLOAT(NUM))/POINTS
30 WRITE(6,101) GMEAN
31 101 FORMAT(1X,F9.2)
32 C *****
33 C ACCORDING TO OPTION II GO TO PROGRESS IMAGE
34 C *****
35 I-(II,E0.1) CALL EQINT(N,EVEL,IMIV,IMAX,GMEAN)
36 I-(II,E0.2) CALL SLINIC(GMEAN,KKK,NIIMAGE,I MEAN)
37 RETURN
38 END

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88662 01 07-11-72 19.186

E-Q-I-N-I

```
1 C=0INI E-Q-I-N-I
2 SUBROUTINE POINT(NLEVEL,IMIN,IMAX,GMEAN)
3 *****
4 C THIS SUBROUTINE QUANTIZES THE MEAN INTO NLEVEL CLASSES, USING AN
5 EQUAL INTERVAL QUANTIZATION.
6 C FIND THE INTERVAL SIZE
7 C
8 C INT=(IMAX-IMIN)/NLEVEL
9 C *****
10 C NOW RE-EVALUATE THE VALUE OF GMEAN
11 C *****
12 DO 1 I=1,NLEVEL
13 ALEVEL=INT#1
14 I=(GMEAN-I.ALEVEL) GO TO 2
15 GO TO 1
16 2 GMEAN=I
17 GO TO 3
18 1 CONTINUE
19 3 WRITE(6,101) GMEAN
20 101 FORMAT(1X,INEN GMEAN=F.5,2)
21 RETURN
22 END
```

23658 WORKS O. MEMORY USED BY THIS COMPILATION

88552 01 07-11-72 19.190

S--I-I-N-T

```

1  C$LIST          S-L-I-I-V-I
2  S$ROUTINE SLINI (G$EAN,K$M,V$AGE,I$EAN)
3  C *****
4  C THIS SUBROUTINE IS USED TO INPUT REDETERMINED CLASS
5  C INTERVALS FOR THE MEANS OF THE HH AND HV FILES
6  C *****
7  I=(K$M,LE,N$IMAGE) GO TO 101
8  C *****
9  C DETERMINES IF FILE IS AN HH OR HV FILE AND DIRECTS TO
10 C PROPER INTERVAL GROUPING
11 C CONVERTS HV MEAN TO INTEGER USING PREDETERMINED INTERVAL
12 C *****
13 IF(G$EAN.GT.0..AND.G$EAN.LT.65.) I$EAN = 1
14 IF(G$EAN.GT.65..AND.G$EAN.LT.90.) I$EAN = 2
15 IF(G$EAN.GT.90..AND.G$EAN.LT.115.) I$EAN = 3
16 IF(G$EAN.GT.115..AND.G$EAN.LT.120.) I$EAN = 4
17 IF(G$EAN.GT.150..AND.G$EAN.LT.220.) I$EAN = 5
18 GO TO 102
19 C CONVERTS HH TO INTEGER WITH PREDETERMINED INTERVAL
20 101 IF(G$EAN.GT.0..AND.G$EAN.LT.70.) I$EAN = 1
21 IF(G$EAN.GT.70..AND.G$EAN.LT.102.) I$EAN = 2
22 IF(G$EAN.GT.102..AND.G$EAN.LT.140.) I$EAN = 3
23 IF(G$EAN.GT.140..AND.G$EAN.LT.190.) I$EAN = 4
24 IF(G$EAN.GT.190..AND.G$EAN.LT.220.) I$EAN = 5
25 102 RETURN
26 END

```

23601 WORDS OF MEMORY USED BY THIS COMPILATION

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SAMPLE PROGRAM OUTPUT

THE IMAGE NUMBER 3 WAS CLASSIFIED AS A SCYGHM FIELD

THE IMAGE NUMBER 4 WAS CLASSIFIED AS A SCYGHM FIELD

THE IMAGE NUMBER 5 WAS CLASSIFIED AS A RDTJIL FIELD

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