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SECTION 41

REMOTE SENSING OF SOILS, LAND FORMS, AND LAND USE IN THE NORTHERN GREAT PLAINS IN PREPARATION FOR ERTS APPLICATIONS[1]

by

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ORIGINAL CONTAINS COLOR ILLUSTRATIONS

INTRODUCTION

Information about soil limitations is necessary to determine the capability and suitability of an area for different land uses. The various types of soil limitations, according to the Soil Conservation Service (SCS, 1961), are erosion, wetness, soil rooting zone and climate. This information is normally derived from interpretation of detailed soil surveys. The primary sources of soil surveys are the USDA Soil Conservation Service and the cooperative soil survey which is composed of agencies, both state and federal, who compile and use soil survey information for land use planning. Following are two examples illustrating the use of information about soil limitations for land use decisions. A detailed soil survey is the first requirement of a farm conservation plan by the Soil Conservation Service. Based upon the soil survey, the capability of each piece of land is planned for a particular land use. One of the first items the Bureau of Reclamation needs for the proposed irrigation plan of an area is a detailed land classification indicating the suitability of the land for irrigation. Examples such as the above can be cited for practically any agency involved in land use planning.

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With present techniques this type of information will not be available for all of the United States until the 1990's. For instance, South Dakota has current soil surveys for slightly less than one-third of the 65 counties. Using present techniques soil scientists are not producing this needed information as fast as it is being demanded. More detailed and accurate information is essential for the more intensive land uses of the future. Hopefully, remote sensing is a tool that can help satisfy this problem. However, considerable research will be necessary to determine the exact role of remote sensing for providing soil limitation data.

The long range objective of this research is to establish principles for recognizing and mapping soil limitations using remote sensing techniques. The present concept for using remote sensing to collect data about soil limitations encompasses using multispectral and temporal data from spacecraft and aircraft. The satellite imagery will be interpreted by standard techniques of photo interpretation for delineation of general soil areas. The aircraft imagery will be used to identify and map the component parts of the general soil areas.

With this concept in mind the objectives for the study in 1971 were:

1. To determine proper timing and wave lengths for identifying and mapping soil limitations.
2. To establish rangeland test sites for determining the usefulness of ERTS imagery.

The first objective relates to studying a proposed irrigation project of an area of fairly intensive agriculture where detailed information about soil limitations is needed. With the present predicted resolution of ERTS imagery, this level of information is not expected to be obtained from the use of ERTS data. The second objective relates directly to potential ERTS applications. The type of soils data needed for rangeland areas is more general and ERTS type imagery should be able to provide a major part of this information.

LOCATION AND DESCRIPTION OF STUDY AREAS

OAHE

The study area established in 1969 (Frazee et al., 1970, 1971) includes soils and land uses typical of the proposed Oahe irrigation project and the adjacent glacial drift area (Figure 1). This area was selected for remote sensing research because of the large amount of ground truth data available. The South Dakota Agricultural Experiment Station in cooperation with the Soil Conservation Service has conducted a detailed soil survey of the area (Westin et al., 1954). The Bureau of Reclamation furnished detailed land classification maps of the portion of the flight line that lies in the proposed Oahe project. A unique advantage of studying this area is the opportunity of using remote sensing to follow the development of an irrigation project from initial land classification to actual water use and the eventual effects of irrigation on land use.

The Oahe project encompasses most of the Lake Dakota Plain (Flint, 1955), the site of a glacial lake late in the Wisconsinan glacial period. The surface of the Lake Dakota Plain is extremely flat, except where shallow stream channels occur, ranging in elevation from 1295 to 1310 feet above sea level. The soil parent materials are laminated lacustrine silt and clay deposits varying in thickness from 3 to 35 feet (Westin, 1970). The climatic environment is cool-temperate with irregular and usually deficient rainfall.

The flight line may be separated into two broad physiographic units, the Lake Dakota Plain and the Williams Loamy Plain (Frazee et al., 1971). The soils vary from friable silt loams with no limitations other than climate to soils with dense subsurface horizons (claypans) close to the surface which are not suited for irrigation.

The primary soil limitations are:

1. erosion of convex upland slopes
2. wetness in depressional or alluvial areas
3. soil rooting zone limitations
    a. claypans of varying density and thickness occurring at varying depths from the surface
    b. stoniness
    c. slowly permeable substratum

Additional information about the study area may be found in Westin et al., 1954 and Westin, 1970.

BENNETT COUNTY

Bennett County lies in the Missouri Plateau subdivision of the Great Plains physiographic province which is covered by Tertiary sediments (Fenneman, 1938). This area was selected because of the large amount of ground truth available (Collins, 1959, 1960; Chamberlin and Radeke, 1971). The county is part of the Pine Ridge Indian Reservation with about 300,000 out of the 761,000 acres managed by the Bureau of Indian Affairs. The major land uses are ranching (75%)

and winter wheat farming (23%).

The climate of Bennett County is semiarid and continental with large variations in seasonal temperatures and precipitation. Approximately three-fourths of the county is covered with native mid- to short-range grasses. The soil parent material consists primarily of silty to sandy sediments with associated alluvium.

The major soil limitations are:

1. erosion of sloping upland soils
2. wetness of depressional or alluvial areas
3. soil rooting zone limitations
   a. claypans of varying depths and thickness
   b. shallow depth to gravel
   c. shallow sandy and silty soils
   d. shallow depth to bedrock

Additional information about Bennett County and the study area may be found in Chamberlin and Radeke, 1971, and Collins, 1959, 1960.

EXPERIMENTAL METHODS AND PROCEDURES

Flights by the Remote Sensing Institute aircraft were conducted along the Oahe flight line during the 1970 crop growing season for the purpose of collecting photographic imagery within the ERTS wave length bands for studying soil limitations (Figure 1, Table I). NASA aircraft flights (RB-57 and C-130) were requested but none were obtained. Ground truth information on the various land use and soil conditions was recorded at the time of overflight. The film transparencies from these flights were evaluated for image quality (American Society of Photogrammetry, 1960) and prints were made of selected areas for laboratory and field study. Camera, film and filter data for imagery studied in detail are listed in Table I.

To help interpretation of the film transparencies listed in Table I, a density slicing system (Figure 2) which color encoded the various film density levels (Spatial Data Datacolor 703-32)[3] was used by experienced soil surveyors in order to identify and map soil limitations. The resultant color encoded representation was photographed and an enlarged print was made for field checking.

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[3]Trade name is included only for benefit of reader and does not imply endorsement or preferential treatment.

The density slicing system analyzes the variation in tone of transparencies and displays the color encoded density levels on a color television screen. The system has the following components identified in Figure 2:

1. light box to illuminate the film transparencies
2. precision monochromatic television camera
3. electronic color analyzer which separates the shades of gray and color codes the signal for each gray level into as many as 32 levels
4. color television monitor for displaying either the color analysis or an image from the original transparency
5. electronic planimeter that measures the percent area of each color encoded density level
6. control keyboard

A standard step wedge may be used to calibrate the color levels to optical densities. Spectral filters may be used on the television camera to enhance the data received from the three spectral sensitive layers of color films.

The Bennett County flight line (Figure 1) was established in 1970 to study remote sensing of soil limitations in rangeland areas in preparation for ERTS applications. Camera, film, and filter data for imagery collected for the study area are listed in Table I. The major effort during this reporting period consisted of locating areas to be used as test sites for research using ERTS data and interpreting the imagery collected for features expected to be identifiable on ERTS imagery. Thematic maps were produced using aerial photo analysis for land use and drainage patterns. These will be used as ground truth for studying the potential of ERTS data for detecting soil limitations, identifying landforms, and determining land use.

RESULTS AND DISCUSSION

TEMPORAL ANALYSIS

Description of Photographs

Color infrared and black and white photographs taken on six different dates during the 1970 growing season were studied to evaluate the usefulness of seasonal information for mapping soil limitations (Table I). Two aspects were considered, the best time to obtain the photographic information and the value of using information from more than one time to study soil limitations. Several fields of the major crops grown in the Oahe area were studied. One 32 hectare field showing representative seasonal changes of the spring grains, which are the major crops of the area, will be discussed and illustrated (Figure 1).

Four different situations were observed for the six flight dates available for study (Figure 3). The ground features on the photographs from the May, June and July dates were all different whereas the ones from the August, September and November dates were similar but different from the above times.

A more or less random pattern of different tones is shown on the May image (Figure 3). The field was planted to spring wheat, which was 5-10 cm high. The resulting pattern is produced primarily by the soil surface. The lightest tones are severely eroded areas whereas the darkest tones are areas with wetness limitations (Frazee et al., 1970). This same pattern would be expected if the field were fallowed or unplanted. However, the effect of the wheat crop is to change the density or color value of the tones of the surface features. Therefore although the photographic pattern of this field and a fallow field may be the same, in order to map the soil limitations of these fields different signatures would be necessary.

By June 25 the wheat had grown to full height, 80 cm, and was weedy (Figure 3). The soil surface pattern of the May image is almost completely masked. The pattern consists of varying levels of infrared reflectance with distinct circular light spots which are weeds. Some of the severely eroded areas can be identified.

On July 21 the spring wheat was 80 cm high, 90% mature, and weedy. The photographic pattern is due almost entirely to differences in the vegetation. Very few distinct differences in reflectance are noted (Figure 3). A few areas with wetness limitation are evident (Figure 3).

The August 12, September 10 and November 5 photographs were taken after the spring wheat was harvested. A stubble 15 cm high with weeds masked the soil surface and is responsible for the photographic pattern. Of these data, only the November photographs are illustrated (Figure 3).

DENSITY SLICING ANALYSIS

The Spatial Data System (Figure 2) was used to enhance the photographic density differences present for the different dates. The color encoded May and June images represent primarily soil and vegetation modified soil features, while the July and November images show some cultivation or cultural effects.

The color encoded representation of the May image is best for obtaining information about soil limitations. The severely eroded areas are shown in yellow, the areas with slight to moderate erosion hazard are green, the red color portrays the normal soils, and the wet areas are blue on the May image (Figure 4). This color encoded representation was field checked and was found to correlate with the soil limitations actually present (Frazee et al., 1971).

The density slicing analysis of the June image is somewhat different (Figure 4). Although most of the severely eroded areas are color encoded yellow, the other soil limitations are not represented. The spring wheat has masked the soil surface except for the severely eroded areas and the resulting vegetative cover does not reflect or show the other soil limitations present. This is the major problem of using vegetation as an indicator of soil limitations in cultivated areas. The crop grown is normally selected to minimize the effects of soil limitations or is not affected every year.

The primary feature shown on the color encoded July image is a somewhat rectangular area in the middle of the field (Figure 4). This feature is interpreted to be the result of the farmer's cultural or cultivation practices.

A similar feature is illustrated on the November image (Figure 4). However, the location of the area is different.

On the basis of this analysis, the May 26 image was best for identifying and mapping soil limitations. The reason being that the soil surface pattern was most apparent at that time. Therefore, the optimum time for obtaining imagery to study soil limitations in the study area is when the soil surface pattern can be sensed or photographed. In the Oahe area this is May. The percent of fields along the flight line for which soil limitations could be adequately mapped using this criteria (observable soil surface patterns) for the various times studied is: May 26, 59%; July 21, 20%; August 13, 18%; September 10, 18%; and November 5, 21%. These results suggest that to map soil limitations of the study area by remote sensing techniques, imagery from more than one time or year will be required.

COMPARISON OF DENSITY SLICING ANALYSIS WITH SOIL SURVEY

The density slicing analysis of the best seasonal image for detecting soil limitations was compared with the existing soil survey map of this field (Westin et al., 1954) to analyze the value of density for mapping soil limitations (Figures 5 and 6). The soil map shows two mapping units which differ in slope and composition (Figure 6). The No. 67 mapping unit is Williams-Bowbells loams, undulating (3-5% slope). The No. 23 mapping unit is Bowbells-Williams loams, nearly level (0-2% slope). At first glance the density slicing analysis bears little resemblance to the soil map (Figure 6). There is a higher percentage of yellow and green color encoded areas in upper left of the image. These colors are associated with the soils occurring on more sloping areas. The color encoded representation shows the complex of four soils better than the original soil map. The density slicing analysis was checked in the field and correlates with the soils found in this field (Figure 5).

Additional and more accurate information about the boundaries delineating areas of similar soil limitations is obtainable from the density slicing analysis than from the existing soil map. There are two major reasons for this. First, the density slicing system is extremely fast and efficient at measuring film density and grouping areas of the same densities. This allows for many more observations than a human could feasibly make in a reasonable length of time. The other reason is related to the quality of the photograph which the soil scientist used to make the soil survey (Figure 7). The photograph was a standard ASCS photograph taken with panchromatic film with minus blue filter in August, 1939. The soil surface was covered almost completely by a crop and very little information could be derived from photograph by the soil scientist to make inferences about the soils present in this field (Figure 7). This is the problem of using standard ASCS photographs for mapping soils. ASCS photographs are taken primarily to locate and measure cropped field boundaries for compliance with government farm programs. The ASCS photographs are normally taken in mid-summer, which, as shown in the previous analysis (Figures 3 and 4), is not the optimum time for obtaining photographs for soil surveys in cultivated areas. The most important immediate use of remote sensing for soil surveys would be to provide the soil surveyor with an image or photograph taken specifically for soil survey.

FILM QUALITY

The film transparencies obtained from the 70 mm Hasselblad cameras using black and white films filtered for the green and red portions of the spectrum and black and white infrared film were evaluated for the film quality characteristics of tone contrast and sharpness, (American Society of Photogrammetry, 1960) (Table I). The purpose was to evaluate imagery collected in similar wavebands as will be used in RBV television cameras on the ERTS satellite for observing soil patterns. From this simple analysis, the RBV camera filtered for the red portion of the spectrum appears most useful for studying soil (Table II). The soil patterns were nearly always observed easiest on the Plus-X or Tri-X film filtered for the red portion of the spectrum because of greater tone contrast and image sharpness.

BENNETT COUNTY

The mosiac of the Bennett County flight line is shown in Figure 8. The primary features are the sandy rangelands, southern part of south half of flight line, cultivated areas in the middle of the flight line, and the silty and loamy rangelands on the north half of the flight line (Figure 8). This flight line was established to collect data for testing the usefulness of the ERTS satellite for studying soil limitations.

Drainage pattern and land use have been interpreted for the flight line. A representative area of the flight line will be used to illustrate the nature of the test data.

The drainage pattern of the northern half of the flight line correlates with land use boundaries (Figures 9 and 10). The areas suitable for cultivation are not dissected by drainageways or have very few drainageways. The density of the drainage pattern has some correlation with slope (Figure 9).

The land use boundaries were determined primarily by observing the presence of regular patterns or field boundaries (Figure 10). Of the land use categories, rangeland and cropland appear to be easily separated, but the cropland and hayland areas are hard to distinguish from each other.

SUMMARY

Research to determine the optimum time or season for obtaining imagery to identify and map soil limitations was conducted in the proposed Oahe irrigation project area in South Dakota. The optimum time for securing photographs or imagery is when the soil surface patterns are most apparent. For cultivated areas similar to the study area, May is the optimum time. The fields are cultivated or the planted crop has not yet masked the soil surface features. Soil limitations in 59 percent of the field of the flight line could be mapped using the above criteria. The remaining fields cannot be mapped because the vegetation or growing crops did not express features related to soil differences. This suggests that imagery from more than one year is necessary to map completely the soil limitations of Oahe area by remote sensing techniques. Imagery from the other times studied is not suitable for identifying and mapping soil limitations because the vegetative cover masked the soil surface and did not reflect the soil differences.

The density slicing analysis of the May image provided additional and more accurate information than did the existing soil map. The soil boundaries were more accurately located. The use of a density analysis system for an operational soil survey has not been tested, but is obviously dependent upon securing excellent photographs for interpretation. The colors or densities of photographs will have to be corrected for sun angle effects, vignetting effects, and processing to have maximum effectiveness for mapping soil limitations.

Rangeland sites were established in Bennett County, South Dakota to determine the usefulness of ERTS imagery. Imagery from these areas was interpreted for land use and drainage patterns.

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TABLE I. CAMERA, FILM AND FILTER DATA FOR STUDY AREAS

January 1, 1970 - December 31, 1970

Mission	Date	Altitude AGL Ft.	Time of day-hrs.	Sensor	Film type	Filter	Wavelength μ	Roll or tape No.
				Oahe Study Area				
104	5-26-70	14,000	14:56-15:19	*Hass.70mm camera A	8403 Tri-X	58	.465-.620	70-144
				Hass.70mm camera B	8403 Tri-X	25A	.580-.710	70-145
				Hass.70mm camera C	8443 EK-IR	15G/30M	.510-.900	70-146
				Hass.70mm camera D	2448 EK-MS	HF3+4	.375-.710	70-147
				K-17 9x9in camera	8443 EK-IR	15G/30M	.510-.900	70-157
112	6-25-70	14,500	12:48-13:11	Hass.70mm camera A	8403 Tri-X	58	.465-.620	70-191
				Hass.70mm camera B	8403 Tri-X	25A	.580-.710	70-192
				Hass.70mm camera C	8443 EK-IR	15G/30M	.510-.900	70-193
				Hass.70mm camera D	2424 BW-IR	89B	.680-.900	70-194

*Hasselblad 500 EL

TABLE I. CONTINUED

Mission	Date	Altitude AGL Ft.	Time of day-hrs.	Sensor	Film type	Filter	Wavelength μ	Roll or tape No.
121	7-21-70	14,500	15:45-16:17	Hass.70mm camera A	8403 Tri-X	58	.465-.620	70-224
				Hass.70mm camera B	8403 Tri-X	25A	.580-.710	70-225
				Hass.70mm camera C	8443 EK-IR	15G/30M	.510-.900	70-226
				Hass.70mm camera D	2424 BW-IR	89B	.680-.900	70-227
				Thermal Scanner			4.5-5.5	5847
140	8-13-70	14,000	12:07-12:35	Hass.70mm camera A	2402 Plus-X	58	.470-.610	70-263
				Hass.70mm camera B	2402 Plus-X	25A	.590-.710	70-264
				Hass.70mm camera C	8443 EK-IR	15G/30M	.510-.900	70-265
				Hass.70mm camera D	2424 BW-IR	89B	.680-.900	70-266

TABLE I. CONTINUED

Mission	Date	Altitude AGL Ft.	Time of day-hrs.	Sensor	Film type	Filter	Wavelength μ	Roll or tape No.
				Thermal Scanner			4.5-5.5	5858
157	9-10-70	14,500	11:51-12:04	Hass.70mm camera A	2402 Plus-X	58	.470-.610	70-316
				Hass.70mm camera B	2402 Plus-X	25A	.590-.710	70-317
				Hass.70mm camera C	8443 EK-IR	15G/30M	.510-.900	70-318
				Hass.70mm camera D	2424 BW-IR	89B	.680-.900	70-319
				Thermal Scanner			4.5-5.5	5923

TABLE I. CONTINUED

Mission	Date	Altitude AGL Ft.	Time of day-hrs.	Sensor	Film type	Filter	Wavelength μ	Roll or tape No.
171	11-5-70	13,500	11:25-12:06	Hass.70mm camera A	2402 Plus-X	58	.470-.610	70-368
				Hass.70mm camera B	2402 Plus-X	25A	.590-.710	70-369
				Hass.70mm camera C	2443 EK-IR	15G/30M	.510-.900	70-370
				Hass.70mm camera D	2424 BW-IR	89B	.680-.900	70-371
				Thermal Scanner			4.5-5.5	5910

C.6

TABLE I. CONTINUED

Mission	Date	Altitude AGL Ft.	Time of day-hrs.	Sensor	Film type	Filter	Wavelength µ	Roll or tape No.
Bennett County Study Area								
166	10-15-70	12,000	12:15-13:03	Hass.70mm camera A	2402 Plus-X	58	.470-.610	70-347
				Hass.70mm camera B	2402 Plus-X	25A	.590-.710	70-348
				Hass.70mm camera C	2443 EK-IR	15G/30M	.510-.900	70-350
				Hass.70mm camera C	2424 BW-IR	89B	.680-.900	70-349
				Thermal Scanner			4.5-5.5	5895

TABLE II. FILM QUALITY ANALYSIS OF OAHE STUDY AREA
January 1, 1970 - December 31, 1970

Mission	Date	Film No.	Filter No.	Tone	Sharpness	Film Characteristics
112	6-25-70	70-191	58	2	2	all imagery suitable for
		70-192	25A	1	1	interpretation
		70-194	89B	3	3	
121	7-21-70	70-224	58	3	3	all imagery suitable for
		70-225	25A	1	1	interpretation
		70-227	89B	2	2	
140	8-13-70	70-263	58	3	3	all imagery suitable for
		70-264	25A	1	1	interpretation
		70-266	89B	2	2	
157	9-10-70	70-316	58	3	3	all imagery suitable for
		70-317	25A	1	1	interpretation
		70-319	89B	2	2	
171	11-5-70	70-364	58	3	3	all imagery suitable for
		70-365	25A	1	1	interpretation
		70-367	89B	2	2	

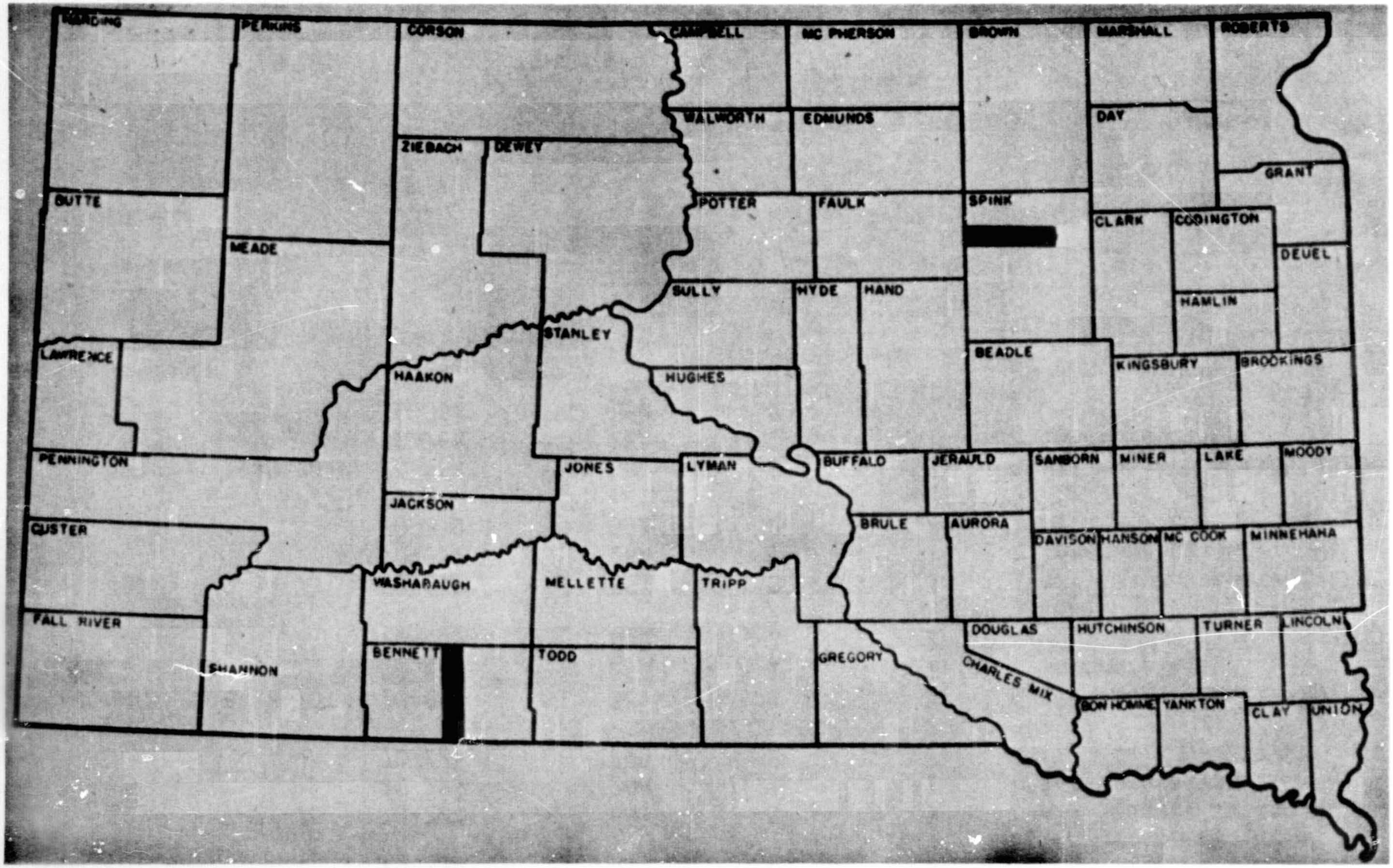


Figure 1.- Oahe and Bennett County Study Area.

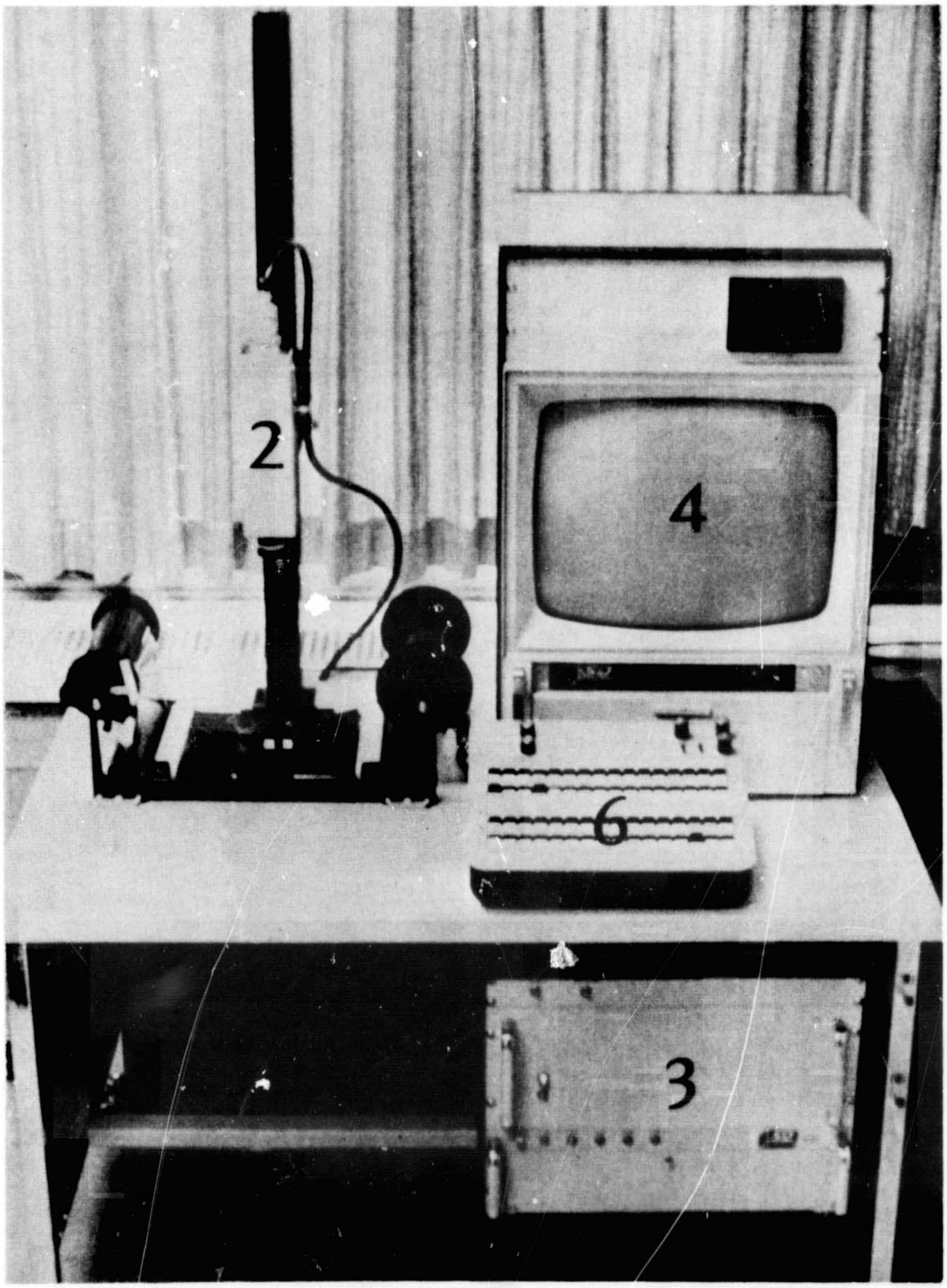


Figure 2.- Spatial Data Datacolor 703-32 density slicing system.

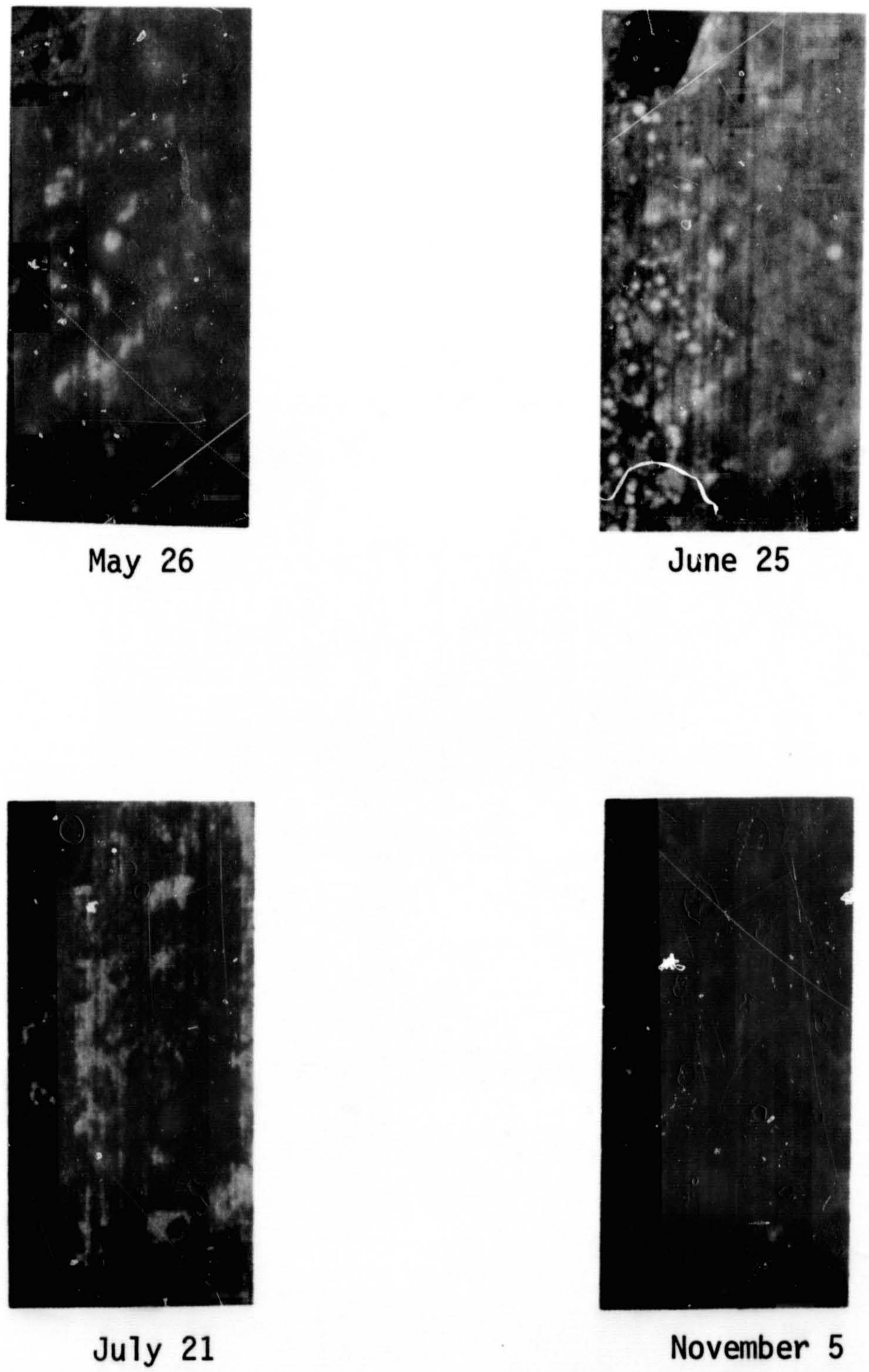
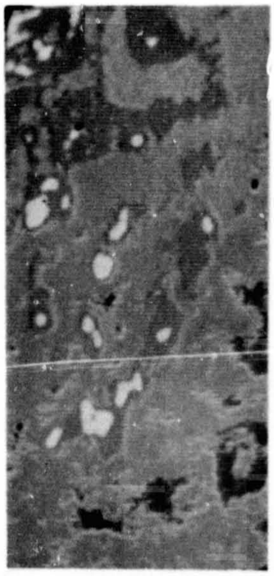
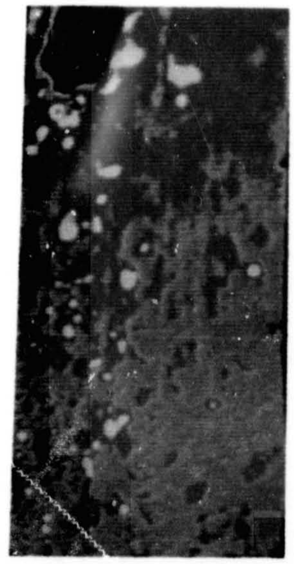


Figure 3.- Color infrared photographs of 1970 time analysis. T118N, R65W, Sec. 3, NE 1/4. Crop is spring wheat. Scale = 1:12,675.

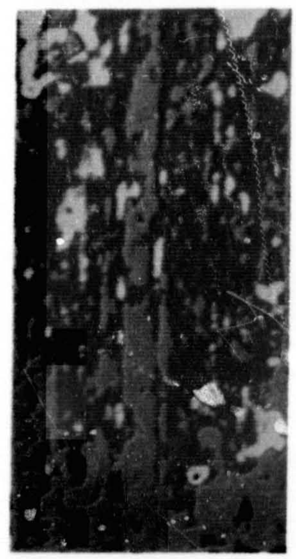


May 26



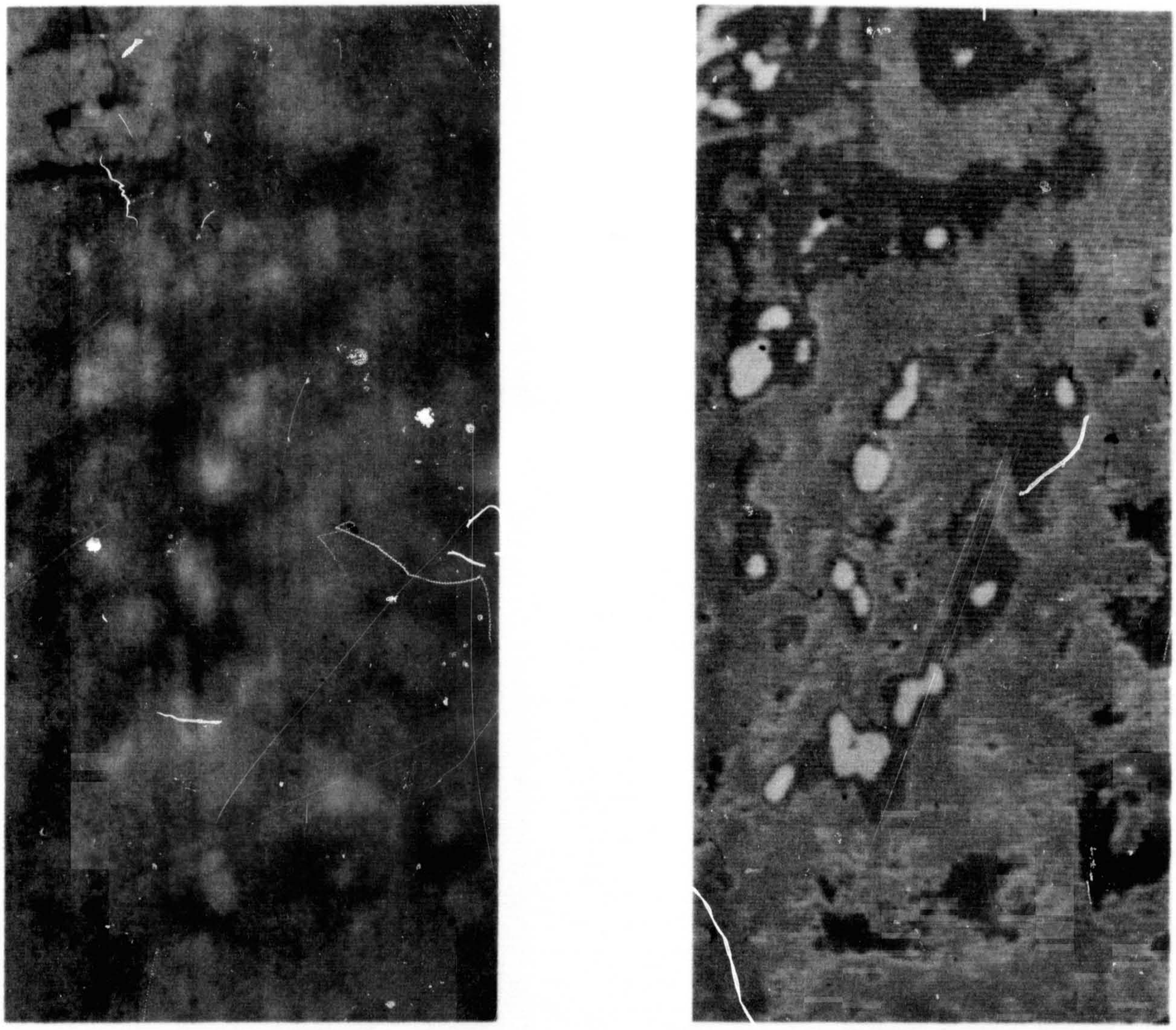
June 25

July 21



November 5

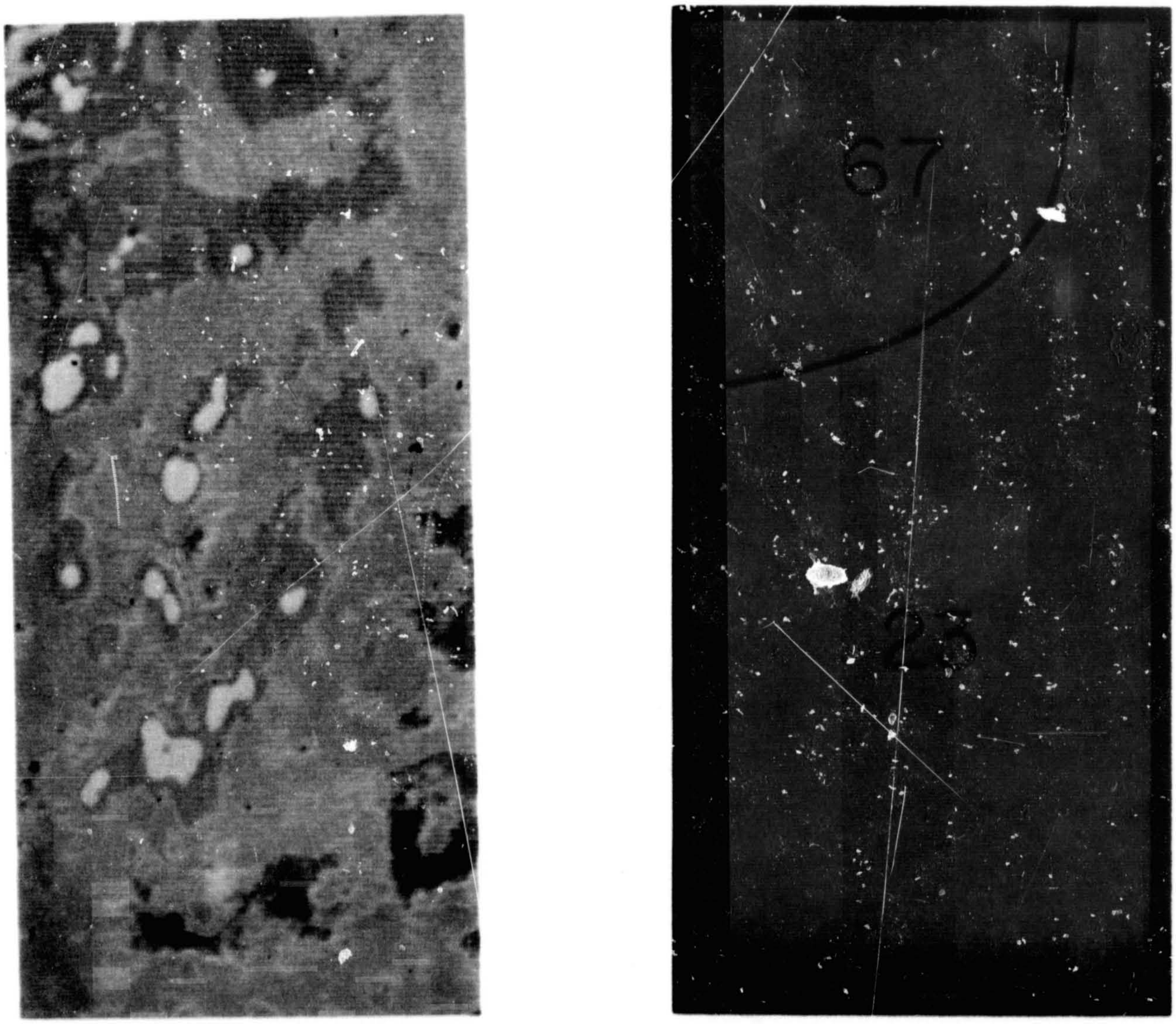
Figure 4.- Color encoded representation of Figure 3.



Color infrared imagery May, 1970

Density slicing analysis

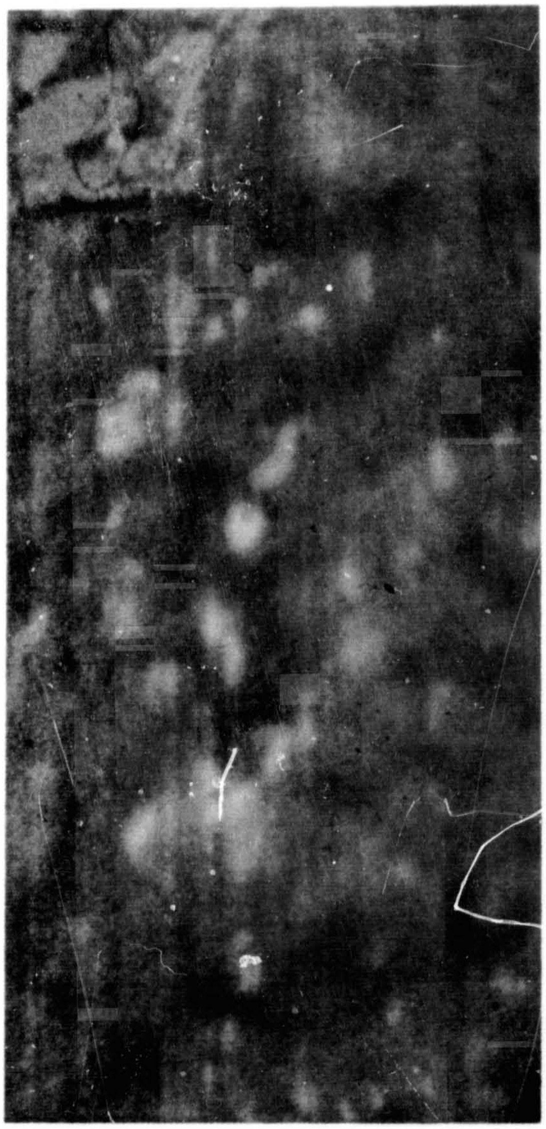
Figure 5.- Density slicing analysis of best seasonal image of 1970 for detecting soil limitations. T118N, R65W, Sec. 3, NE 1/4. Scale = 1:6,330.



Density slicing analysis

Existing soil map

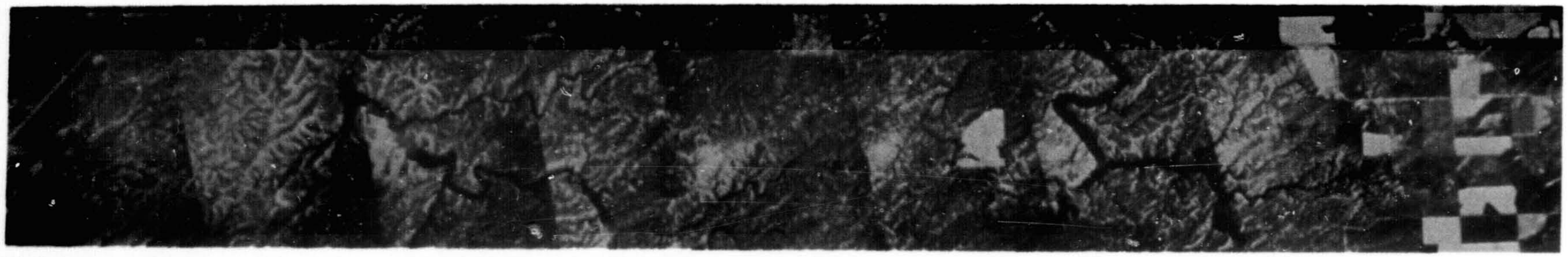
Figure 6.- Comparison of density slicing analysis with existing soil survey map. T118N, R65W, Sec. 3, NE 1/4. Scale = 1:6,330.



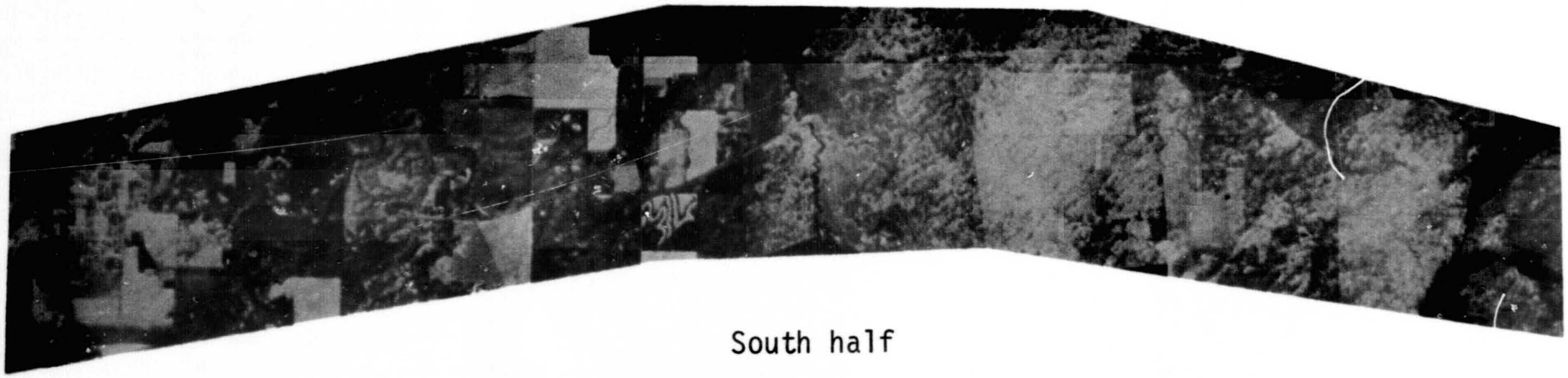
Color infrared
imagery May, 1970

Panchromatic film
August, 1939

Figure 7.- Comparison of remote sensing photograph with photograph used by soil scientists for soil survey. T118N, R65W, Sec. 3, NE 1/4. Scale = 1:6,330.

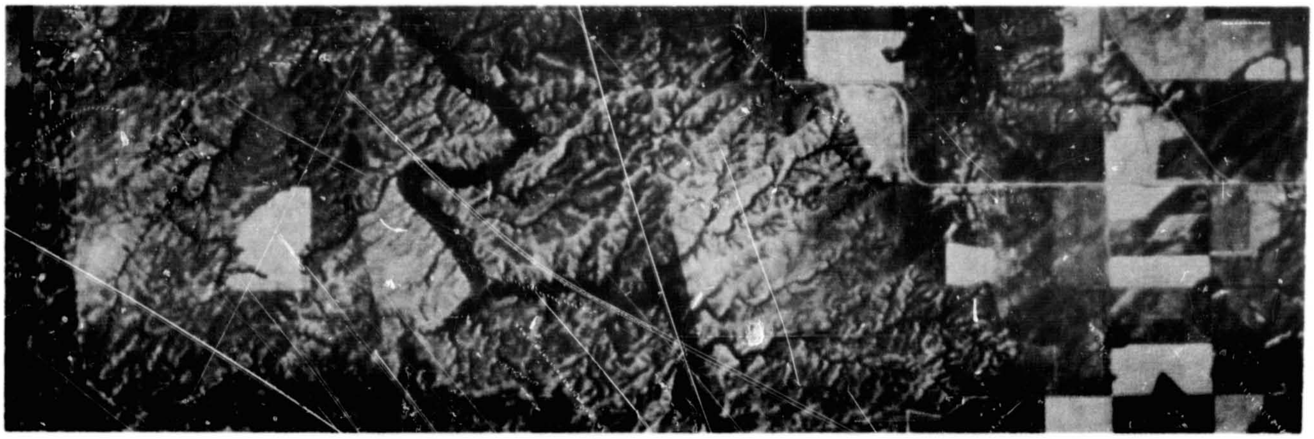


North half

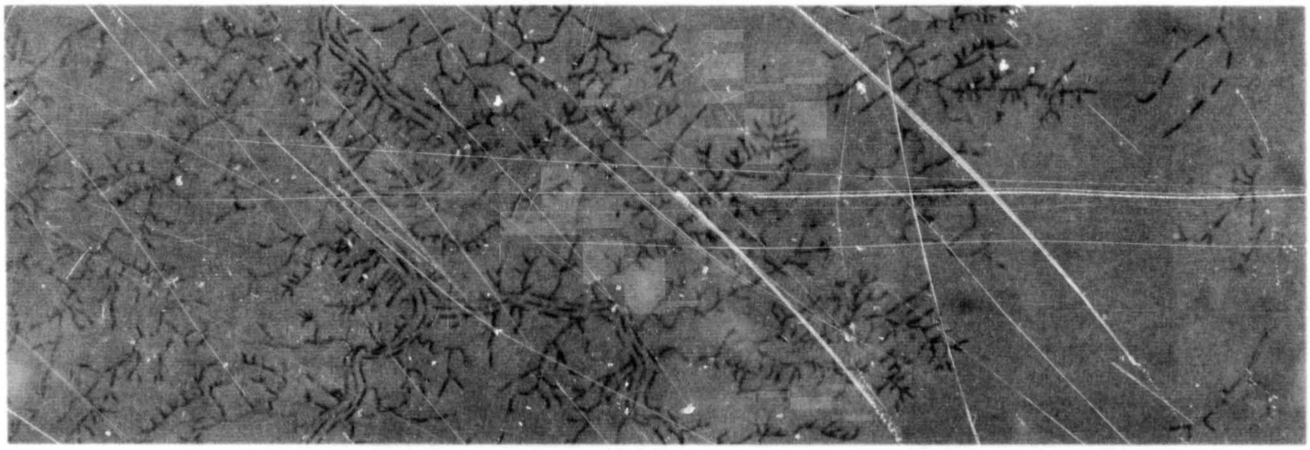


South half

Figure 8.- Bennett County flight line mosaics. Plus-X film with 25A filter. June, 1971. Scale = 1:125,000.

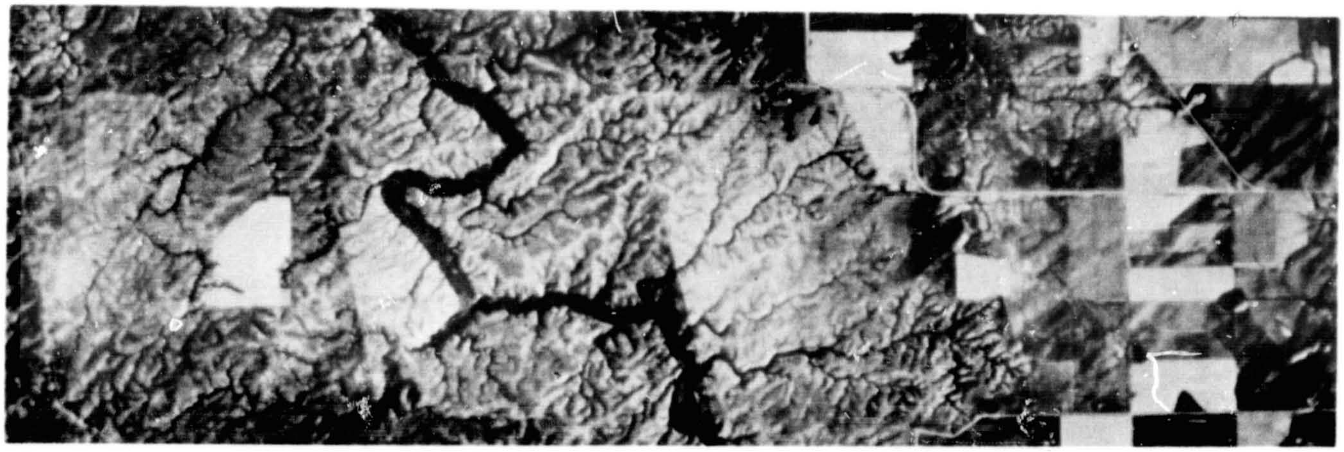


Plus-X film with 25A filter, June, 1971

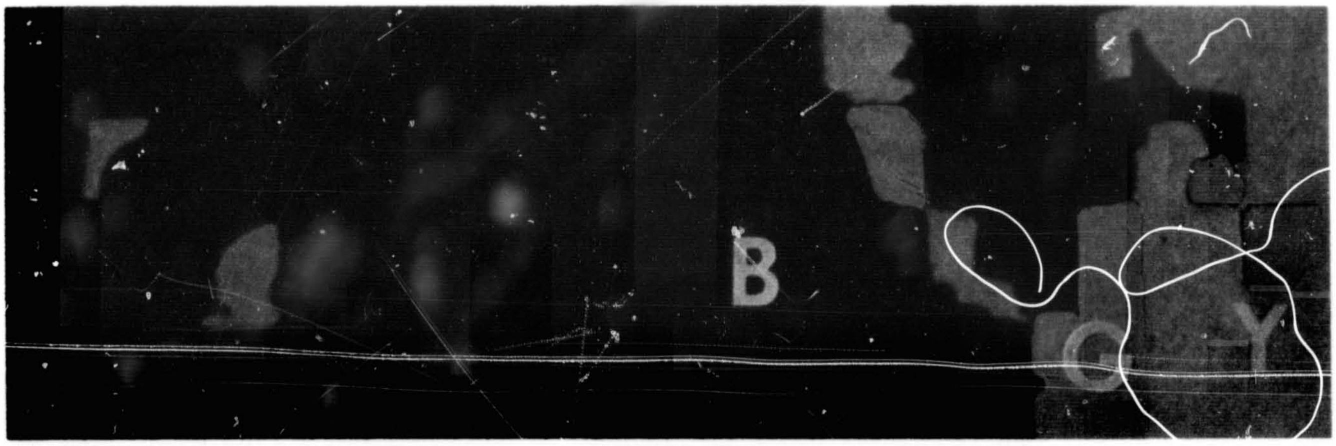


Drainage pattern

Figure 9.- Drainage analysis of a representative area of the northern half of the Bennett County flight line. Scale = 62,500



Plus-X film with 25A filter, June, 1971



Land use

Figure 10.- Land use analysis of a representative area of the northern half of the Bennett County flight line. Scale = 62,500. Yellow = cropland, Green = hayland, Brown = range or pasture.