REMOTE SENSING FOR DETECTION OF SOIL LIMITATIONS IN AGRICULTURAL AREAS

by

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INTRODUCTION

Research is needed to establish remote sensing techniques for recognizing and mapping soil limitations in order to take full advantage of the imagery which will be transmitted back to earth from the earth resources satellite. Rapid automatic scanning procedures also must be developed in order to interpret the vast amount of data which can be obtained very quickly by remote sensing techniques.

As agriculture becomes more intense, as in irrigation, soil limitations become more restrictive. Approximately 84 percent of the 45.5 million acres expected to be irrigated by 1975 have soil limitations. These limitations may be evaluated according to (1) erosion susceptibility, (2) excess water, (3) adverse climate, and (4) unfavorable soil or rooting zone characteristics.

Information about soil limitations is needed by the users of soil survey data. In South Dakota, some of the agencies using this type of information are:

1. Soil Conservation Service for farm planning and conservation decisions,
2. Bureau of Reclamation for land classification and irrigation recommendations,
3. Bureau of Indian Affairs for land use planning,
4. U.S. Forest Service for recommendations about land use in forested and non-forested areas,
5. Department of Revenue for taxation purposes.

The value of the management decisions by the above users is determined by the quality of data available.

Agricultural areas throughout the world could be defined in terms of soil limitations. Remote sensing from spacecraft using broad survey methods and from aircraft using more detailed interpretations offers promise not only for identifying soil limitations but also for monitoring corrective measures.

The objectives of the study for this year are:

1. To establish remote sensing principals for identifying and mapping one or more soil limitations to land use in a potentially irrigable area.
2. To develop rapid scan, automatic identification techniques using color and multispectral photographic transparencies.

This report will deal mainly with the first objective. The second objective will be dealt with in another report entitled: "Pattern Recognition at South Dakota State University," by G. D. Nelson.

LOCATION AND DESCRIPTION OF STUDY AREA

The area selected for study spans the boundry between the proposed Oahe irrigation project and the adjacent glacial drift area (Fig. 1). The Oahe project encompasses most of the Lake Dakota Plain, the floor of a glacial lake late in the Wisconsinan glacial period. The ultimate size of the Oahe project is 495,000 acres.

The lake plain is rimmed by glacial deposits which in the study area occur as an undulating to rolling, loam, textured drift plain with complex slopes. Many closed depressions are present which collect most of the surface runoff. The elevation of the area ranges from 1300 to 1400 feet above sea level.

The crops grown in this area are determined by the climatic environment which is cool-temperature with irregular and usually deficient rainfall. The mean annual precipitation is 19.2 in. (Westin et al, 1954).

The study area may be divided into two broad physiographic units, the Lake Dakota Plain and the Williams Loamy Plain.

The soil limitations present in the soils of the study area are:

1. Unfavorable texture (claypan or sandy)
2. Topography
3. Shallow depth to lime
4. Saline conditions
5. Stoniness
6. Wetness
7. Slowly permeable substratum

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

EXPERIMENTAL METHODS AND PROCEDURES

Initally three flight lines were established traversing typical soil areas in Spink County, South Dakota (Fig. 1). These flight lines were two miles wide. Flights made by the Remote Sensing Institute and the NASA RB-57 overflight for Mission 101, Site 195, are shown in Table I. Prints were made of selected areas.

Ground truth information was obtained for all flights. The information recorded on base maps is:

1. Plant type
2. Plant height
3. Row spacing
4. Row direction
5. Soil series
6. Soil moisture
7. Soil color
8. Condition of soil surface
    a. Clod size
    b. Amount of trash
9. Amount of weeds

In addition any other pertinent information is recorded. Interpretation of photographic and scanner transparencies was made with densitometers, visual methods, and an automatic color TV density slicing system (Spatial Data).

RESULTS AND DISCUSSION

SOIL PATTERNS

Bare Soil Surfaces

The soil patterns observed are different for the Lake Dakota and the Williams Loamy Plain. This difference is due to topography differences between the two physiographic units. The Lake Dakota Plain is extremely flat with simple slopes; whereas, the drift plain is undulating to rolling with numerous microdepressions and short complex slopes.

The soil limitations of the Lake Dakota Plain which can be identified are dense subsoil (claypan) (Fig. 2), unfavorable topography (convex sloping areas (Fig. 3) or depressional areas). The above are the major soil limitations to irrigation of the Lake Dakota Plain (Oahe project). The claypan areas are characterized by a pattern with a texture of different densities (Fig. 2) which is not present in soil areas which do not have this limitation (Fig. 4). This pattern is caused by varying amounts of the lighter colored (10YR6/1,dry) A2 horizon being mixed with the darker colored (10YR4/1,dry) Ap horizon by cultivation. The convex sloping areas are noted by a narrow band of lighter value along the slope change (Fig. 3). This lighter value is due to lighter colored calcareous material being exposed by water erosion or mixing with the overlying soil horizons. The soils occurring on these convex slope areas are usually very shallow. The depressional areas vary in size. They are somewhat circular in shape and if large enough, disrupt the normal field pattern. The depressions in cultivated areas are usually small and shallow. The small shallow depressions are associated with the claypan areas and may or may not be separable from the claypan areas.

The important soil limitations of the Williams Loamy Plain which can be observed are unfavorable topography (convex sloping areas or depressional areas) (Fig. 5). The topography of the drift plain is reflected by a random pattern of different densities. The areas of higher density are the soils on the flatter areas or in the concave areas which have darker colored A horizons. The areas of lower density are the eroded portions of the short complex slopes which are present. As with the lake plain the lighter colored areas are calcareous material close to the surface.

The depressional areas in cultivated areas appear as larger somewhat circular bodies with a density intermediate to the other topographic areas.

Vegetated Areas

The soil patterns for vegetated and bare soil areas are the same until the vegetative cover masks the soil surface. The optical densities will be changed due to the effect of the growing vegetation. Once the vegetation covers the surface, the soil pattern is masked unless the crop is affected by the particular soil limitation present.

Under conditions of plant stress the crop in the claypan area reflects the pattern found in bare soil areas for claypan limitation. Similar conditions are true for the topographic limitation. The depressional areas show in vegetated areas as areas of different density than surrounding areas due to more vegetation or different type of vegetation because of the additional water collected in the depressional areas from runoff. Also, in the spring after heavy rainfall, these areas may have standing water present or may have the bare soil surface exposed if the crop has been drowned out.

AUTOMATIC ANALYSIS OF SOIL PATTERNS

Two approaches for automatic analysis of the multispectral imagery listed in Table I have been utilized. The first was to measure optical densities of 9x9 inch EK-IR imagery with the four filter options available on the Macbeth optical densitometer. The other involves the use of an automatic color TV density slicing system (Spatial Data). The soil interpretations will be discussed in this part of the report while the details of obtaining the density data and classification problems are discussed in the report entitled: "Pattern Recognition at South Dakota State University," by G. D. Nelson.

The area selected for densitometer measurements consists of sandy soils ranging in drainage from excessively drained to poorly drained. The initial problem was to distinquish the poorly drained soils from the better drained soils. According to the confusion matrix generation by the pattern recognition group, this task could be accomplished 319 out of

320 times. The difference in the red chroma being the most important distinguishing factor. The Spatial Data system cannot make this separation without filters because it color codes only the value component of color. This type of analysis with the present equipment available is extremely slow because of the large amount of time needed to take the densitometer readings. Also, no stipulation for constructing a soil map is presently available.

Typical examples of soil limitations in the study area were analyzed by the Spatial Data system. A suitable map of a soil limitation can be made by photographing the color coded representation of differences of the value component of color of the area and making a contact print.

The claypan limitation of the Lake Dakota Plain (Fig. 2) may be mapped as shown in Figure 6. The yellow color represents areas of shallow depth to the claypan (<20cm.) whereas the blue color represents areas with greater depths to claypan (>20cm.). The black area is a depressional area which contained water at the time of flight.

Shallow soils on convex slopes (Fig. 3) are mappable also in some instances. Figure 7 shows the Spatial Data encoded image of Figure 3. The areas with erosion susceptibility are white.

On the Williams Loamy Plain, an undulating area with 3-5% slope, low round topped hills interspersed with areas of gentler slopes, flats, and swales was analyzed (Fig. 5). A Spatial Data representation with four colors is shown in Figure 8. The soils interpretation listed in Table II must be checked in the field.

The analyses of Table II indicate the great potential the automatic color TV density slicing system has for identifying and delineating areas of similar soil limitations or other groupings of similar soil. Not only can this type of system identify and map similar soil areas, but also the system can compute the area of each soil, which is extremely important as far as determining the composition of a soil mapping unit. Additional research is needed to define more precisely the uses and limitations of the Spatial Data system.

FACTORS AFFECTING AUTOMATIC ANALYSIS OF SOIL LIMITATIONS

Film-Filter Combinations

Evaluation of NASA RB-57 overflight on August 8, 1969, Mission 101, Site 195.-

Quality of data:

The sensors employed are listed in Table I. Analysis of the film quality and exposure data for the film-filter combinations has been reported (Remote Sensing Institute, 1969). The important results from that report as well as additional points will be discussed here.

The analysis of the exposure data indicates that determining proper exposures is a serious problem which must be solved for multispectral sensing with photographic images. Hopefully, with better mission planning this problem can be eliminated.

The vignetting of all the imagery is so serious that the imagery cannot be used for quantitative density measurements. This problem is most serious for the RC-8 cameras and least serious for the Zeiss camera with the Hasselblad cameras being intermediate. The ranges in optical density due to vignetting cause density contrasts on the imagery that may be much greater than differences associated with vegetation and soil contrasts. Before photographic imagery of this type can be used for automatic data analysis this serious vignetting problem must be solved.

Evaluation of imagery for detecting soil limitations:

Contact prints at scales approximating those used for soil surveys were made of the enlarged imagery for comparison and evaluation of the imageries for soil limitations.

For identifying and mapping soil limitations at this time of year (Aug. 8, 1969), the Ektachrome infrared imagery taken with the Zeiss camera is best. In order of excellence the black and white imagery (70 mm) are listed as follows:

Film	Filter	Comments
3400	58	Good target contrast and resolution
3400	25A	Less contrast than other B&W films and poor detail

Film	Filter	Comments
SO-246	89B	Good contrast, but very poor detail due to extreme graininess of enlargement

Usefulness of the 70mm color films may be ranked as follows:

Film	Filter	Comments
SO-368	2A	Detail limited by blue attenuation
SO-368	12	Detail poor
SO-180	15G	Overexposed, not suitable for use

The 9x9 inch color imagery taken with the RC-8 and Zeiss camera can be ranked as to usefulness as follows:

Film	Filter	Comments
SO-117	Zeiss "B"	Good detail, slightly underexposed
SO-117	500 Micrometer/1.4AV	Detail good, but limited by slight overexposure
2448	HF3/2.2AV	Good detail for this film and time of year.

The above comments may apply only for the conditions for Site 195, Mission 101. Better exposure or different targets may alter the above observations. Additional studies on the above multispectral imageries and additional imagery for other conditions are needed to further answer the question of which film-filter combination is ideal for a particular condition.

Use of Mission 101 Imagery:

The transparencies may be used to make general maps of the study area, both physiographic and soil association maps, by visual analysis. Enlargements of any of the 9x9 inch color imagery to scales used in mapping soils provide a better base map for soil surveys than is presently being used.

The potential value of studying the multispectral imagery from NASA overflight lies in improving the accuracy of present surveys and in speeding up soil survey methods, the latter by permitting the soil surveyor to use remote sensing imagery to do a substantial amount of delineation and interpretation of soil boundaries in the office before going to the field.

Evaluation of RSI flight, Mission 104 on May 26, 1970.-

On May 26, 1970, the Remote Sensing Aircraft flew the Oahe #1 flight line with four 70mm sensors (Table 4) aboard affording another opportunity for comparison of film-filter combinations. For the conditions of this flight, most spring grains emerging from the soil, the sensors may be ranked as follows:

Film	Filter	Comments
2448	HF3+4	Good detail in bare soil areas
8443	15G/30M	Comparable to 2448
8403	25A	Detail limited because of graininess
8403	58	Poor detail, underexposed

Summary of evaluation of film-filter combinations.-

The different target conditions of the August 8, 1969 and May 25, 1969 flights changed the ranking of usefulness of the films. From the above elementary analysis, it can be seen that the film-filter combinations selected for a mission will depend upon the target or time of year.

The film-filter combinations and their exposures need to be carefully selected for each mission according to the conditions of the agricultural scene to be sensed.

Scale

The scale of the image must be large enough to allow automatic analysis of an area. With present techniques, analyzing one field at a time because of vegetative differences, many cultivated areas on the 60,000 ft. 9x9 inch imagery from the NASA RB-57 are too small for analysis. The smallest element which presently can be analyzed is one-half inch square.

SUMMARY AND CONCLUSIONS

Establishing remote sensing principles for identifying and delineating soil limitations to land use in agricultural areas was the subject of research initiated in a potentially irrigable area in South Dakota. Representative patterns of claypan and topographical soil limitations can be identified on bare soil surfaces and on vegetated surfaces if the vegetation is subjected to a stress because of the soil limitation.

Automatic analysis of the soil limitations studied by an automatic color TV density slicing system was accomplished.

This system color codes the density range of the value component of color of an image. Maps of soil limitations or other similar soil groups may be produced by photographing the color coded representation of an area. These maps are comparable or may be superior to present day maps. The planimeter feature of the density slicing system can measure the area of each soil limitation providing information on the importance of a soil limitation in an area.

The results of this first year study suggest that an automatic color TV density slicing system has great potential not only for identifying and mapping similar soil areas, but also for indicating the percentage composition of an area.

TABLE I.- CAMERA, FILM AND FILTER DATA FOR OAHE SITES
July 1, 1969 to June 30, 1970

Mission	Date	Altitude AGL Ft	Time of day	Sensor	Film Type	Filter	Wavelength μ	Roll or Tape No.
27	7-25-69	2,000	11:53-13:11	Thermal IR scanner			8-14	23,23,25
28	7-28-69	2,000	11:43-12:44	Thermal IR scanner			4.5-5.5	26,27
36	8-7-69	14,000	15:06 15:42	Thermal IR scanner			4.5-5.5	37,38
				K-17 9x9in camera	EK-IR	15G/30M	.510-F*	69-99
		6,500	16:02-16:08	Thermal IR scanner			4.5-5.5	38
				K-17 9x9in camera	EK-IR	15G/30M	.510-F*	69-99
101**	8-8-69	60,000	12:03-1:18	Hass. 70mm camera A	EK-MS	12	.495-F*	4
				Hass. 70mm camera B	Pana-tomic-X	58	.465-.620	6
				Hass. 70mm camera C	Pana-tomic-X	25A	.580-F*	7
				Hass. 70mm camera D	BW-IR	89B	.680-F*	4

TABLE I.- CONTINUED

Mission	Date	Altitude AGL Ft	Time of day	Sensor	Film Type	Filter	Wavelength μ	Roll or Tape No
				Hass. 70mm camera E	EKIR	15G	.510-F*	3
				Hass. 70mm camera F	EKMS	2A	.405-F*	5
				RC-8 9x9in camera	EKMS	HF3/2.2AV	.375-F*	2
				RC-8 9x9in camera	EKIR	500μ/ 1.4AV	.500-F*	3
				Zeiss 9x9" camera	EKIR	Zeiss B	.470-F*	4
38	8-12-69	6,000	12:22-13:01	Thermal IR scanner			4.5-5.5	44,45
				K-17 9x9in camera	EKIR	15G/30M	.510-F*	69-100
57	10-21-69	2,000	6:18-7:41	Thermal IR scanner			8-14	62,63,64
60	10-23-69	8,000	10:50-11:14	Thermal IR scanner			8-14	68
				K-17 9x9in camera	EKMS	HF3	.375-F*	69-139

TABLE I.- CONTINUED

Mission	Date	Altitude AGL Ft	Time of day	Sensor	Film Type	Filter	Wavelength μ	Roll or Tape No
103	5-25-70	14,000	12:17-12:29	Hass. 70mm camera A	Tri-X	58	.465-.620	70-144
				Hass. 70mm camera B	Tri-X	25A	.580-F*	70-145
				Hass. 70mm camera C	EKIR	15G/30M	.510-F*	70-146
				Hass. 70mm camera D	EKMS	HF3+4	.375-F*	70-147
104	5-26-70	14,000	14:56-15:19	Hass. 70mm camera A	Tri-X	58	.465-.620	70-144
				Hass. 70mm camera B	Tri-X	25A	.580-F*	70-145
				Hass. 70mm camera C	EKIR	15G/30M	.510-F*	70-146
				Hass. 70mm camera D	EKMS	HF3+4	.375-F*	70-147
				K-17 9x9in camera	EKIR	15G/30M	.510-F*	70-157
112	6-25-70	14,500	12:48-13:11	Hass. 70mm camera A	Tri-X	58	.465-.620	70-191

TABLE I.- CONCLUDED

Mission	Date	Altitude AGL Ft	Time of day	Sensor	Film Type	Filter	Wavelength μ	Roll or Tape No
				Hass. 70mm camera B	Tri-X	25A	.580-F*	70-192
				Hass. 70mm camera C	EK-IR	15G/30M	.510-F*	70-193
				Hass. 70mm camera D	BW-IR	89B	.680-F*	70-194

* F-sensitivity of film

** Supplied by NASA RB57 flight, Mission 101, Site 195. All other data obtained by Remote Sensing Aircraft.

TABLE II.- INTERPRETATION OF SPATIAL DATA ANALYSIS OF AN UNDULATING DRIFT PLAIN.

Color	Area %	Interpretation
Yellow	5.6	Rolling, eroded, shallow soils. Excessively drained. Severe water erosion potential.
Green	34.0	Undulating, shallow soil, well drained, water erosion potential.
Red	49.6	Nearly level, well drained soils.
Blue	10.0	Concave to level, moderately well drained soil. Collect runoff from surrounding sloping areas.

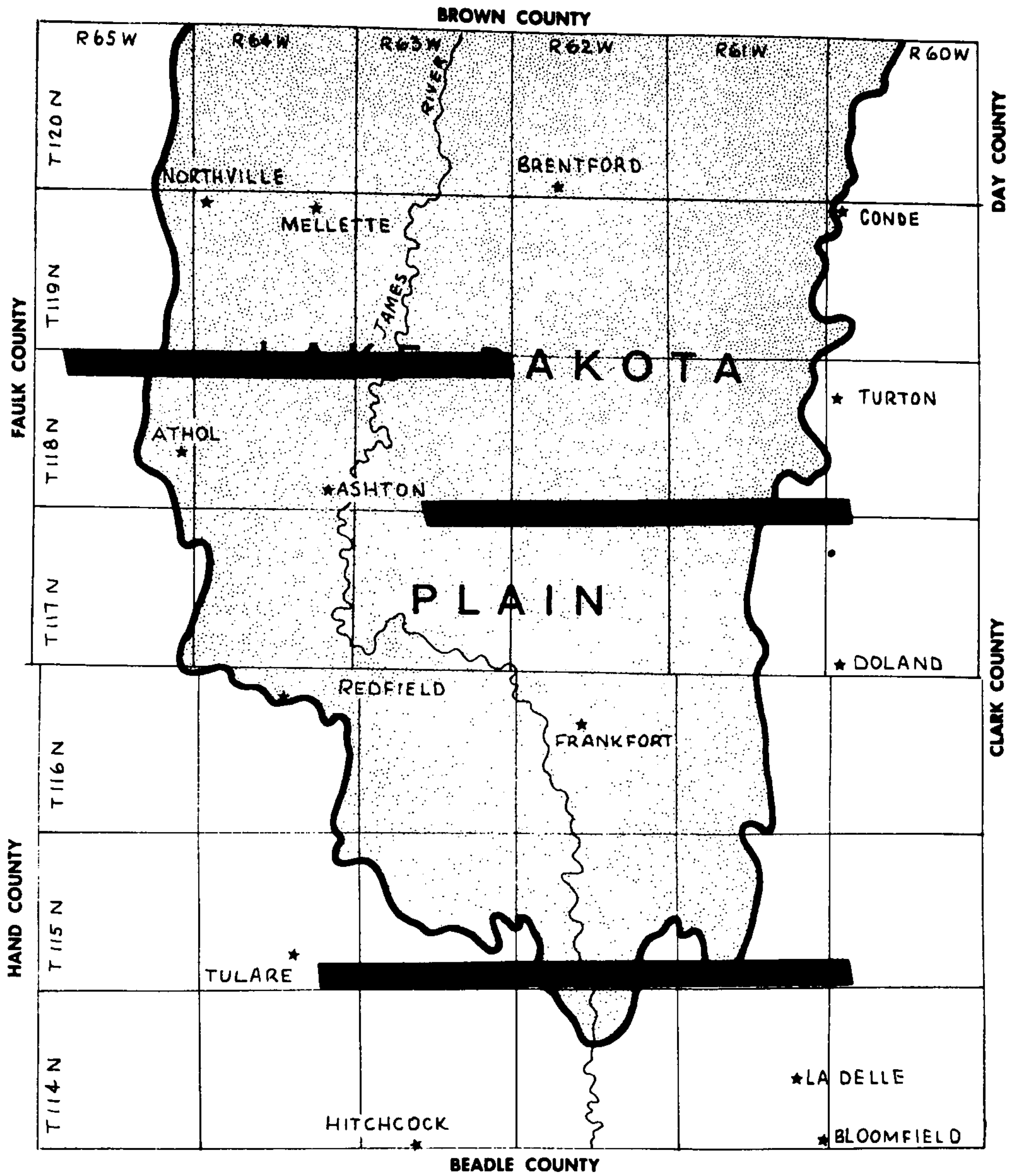

FIG. 1 LOCATION OF STUDY AREA IN SPINK COUNTY, SOUTH DAKOTA

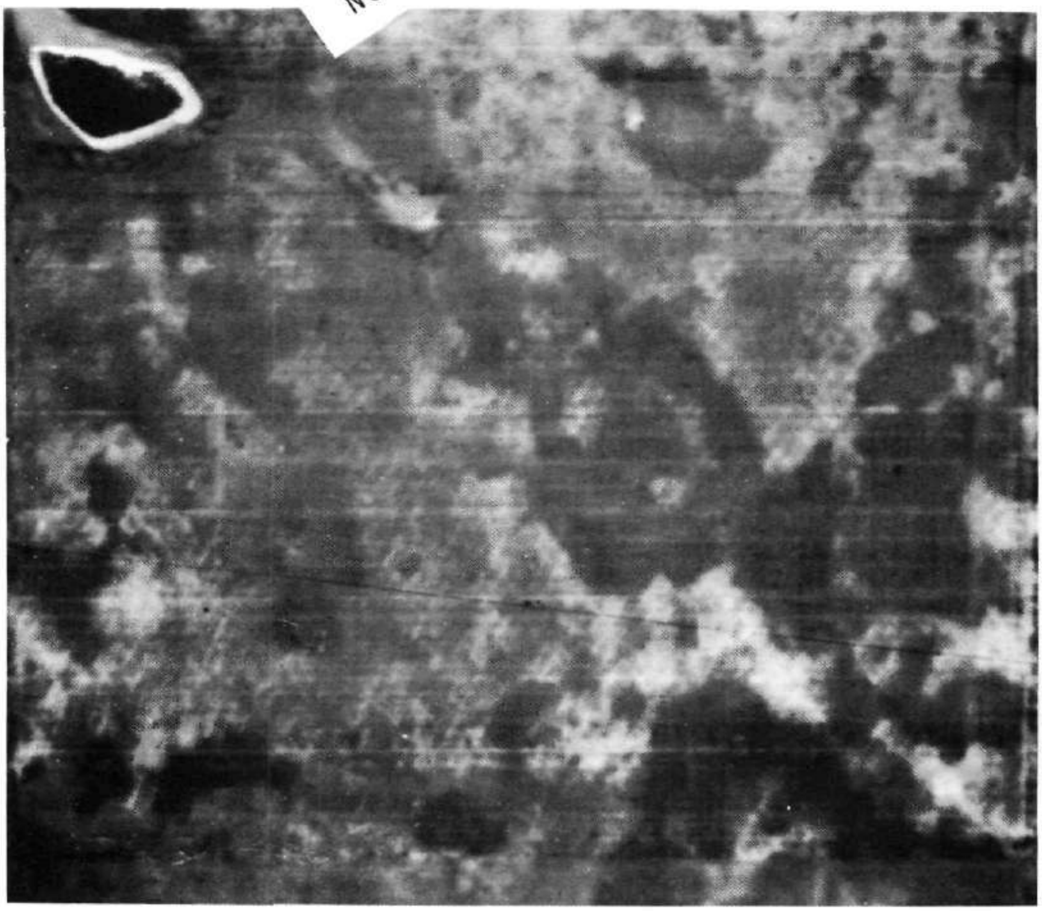

Figure 2. Claypan limitation, Lake Dakota Plain, T118N, R64W, Sec. 11, NE 1/4. RSI Mission 104. Scale - 1:4800. Crop is spring wheat, 5cm. high.

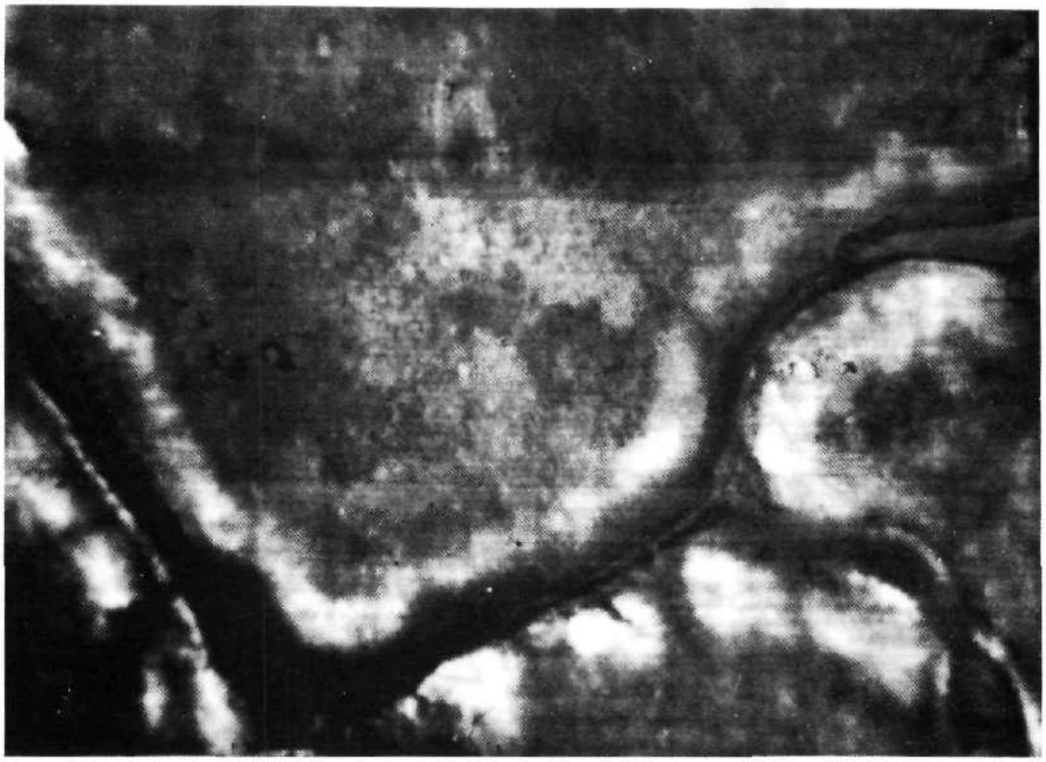

Figure 3. Topography limitation, Lake Dakota Plain, T118N, R63W, Sec. 10, SE 1/4, RSI Mission 104. Scale - 1:6000, Crop is spring wheat, 8cm high.

NOT REPRODUCIBLE

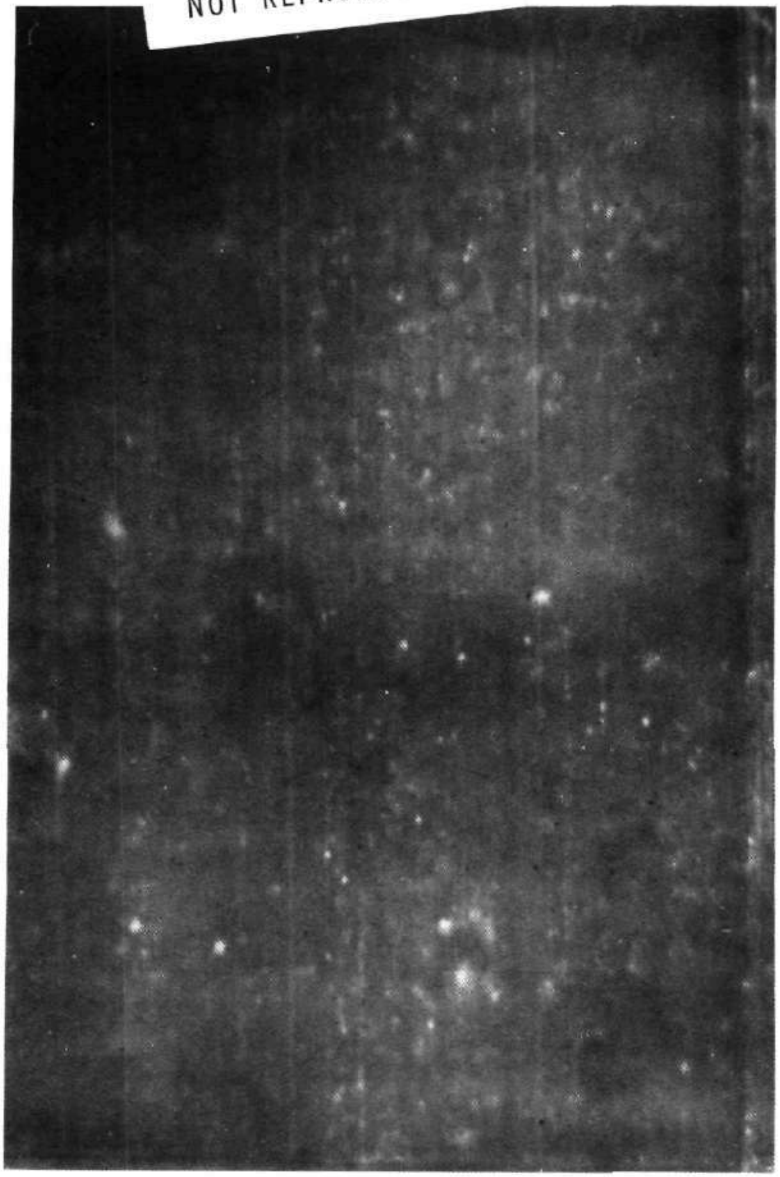

Figure 4. Soil areas without claypan, Lake Dakota Plain, T118N, R64W, Sec. 8, SE 1/4, RSI Mission 104. Scale - 1:6000 Fallow field.

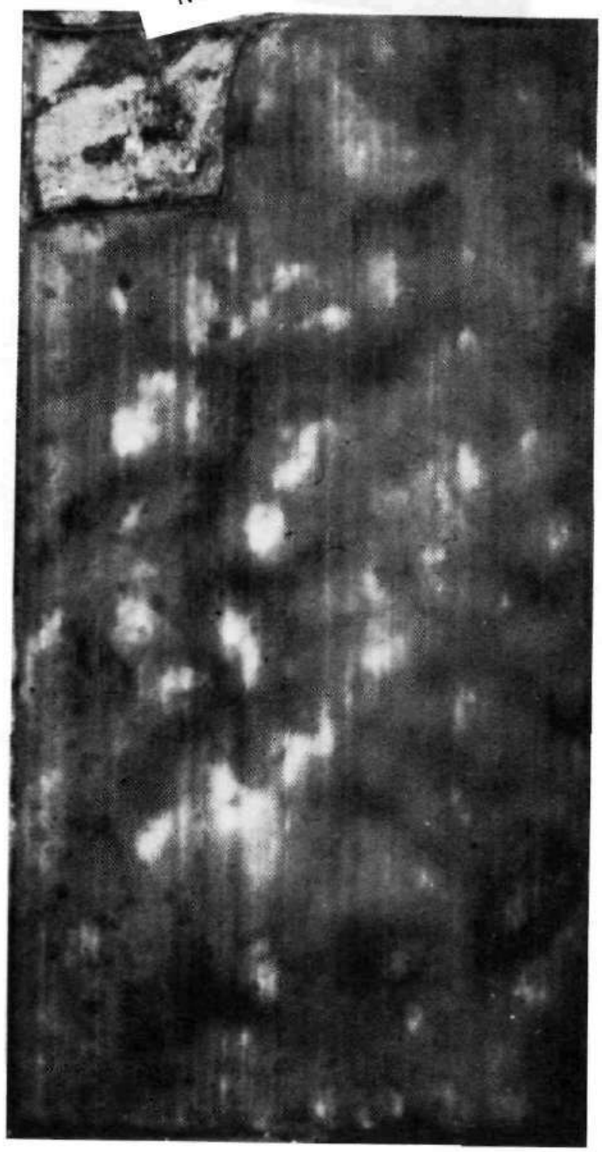

Figure 5. Undulating drift plain, Williams Loamy Plain, T118N, R65W, Sec. 3, NE 1/4. RSI Mission 104. Scale - 1:6000. Crop is spring wheat, 8cm high.

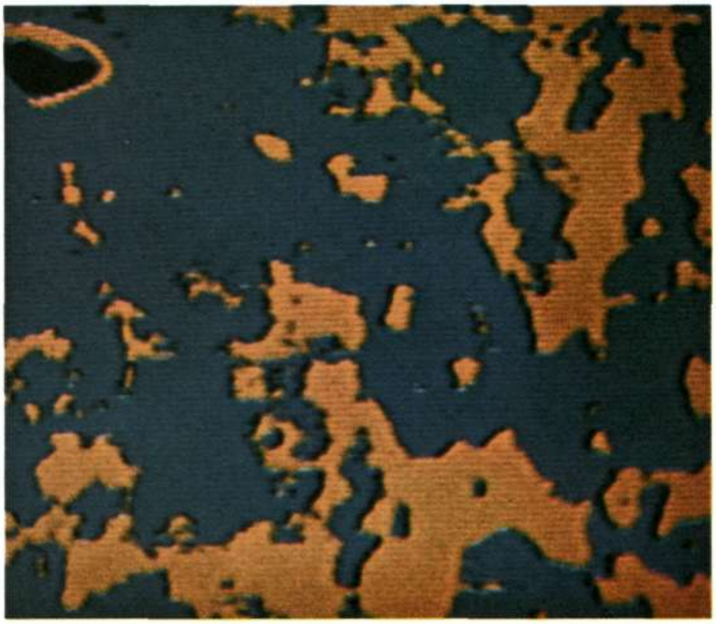

Figure 6. Color coded representation of Figure 2.

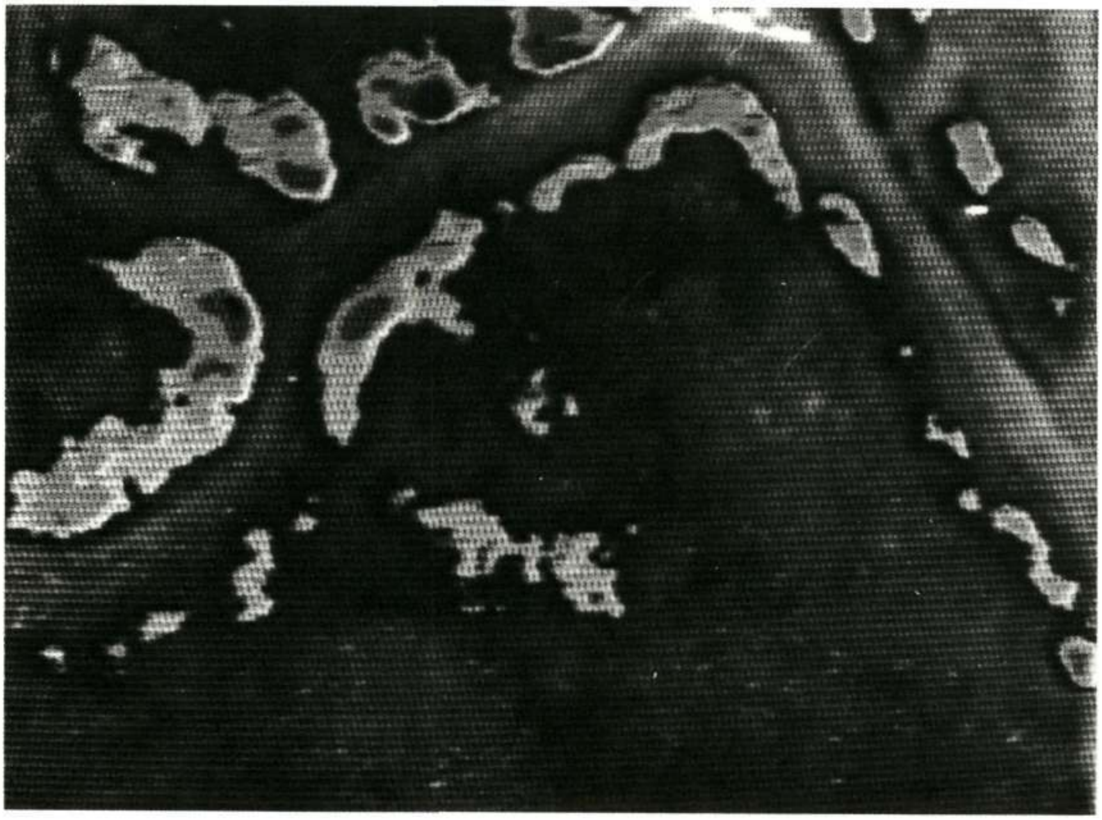

Figure 7. Color coded representation of Figure 3.

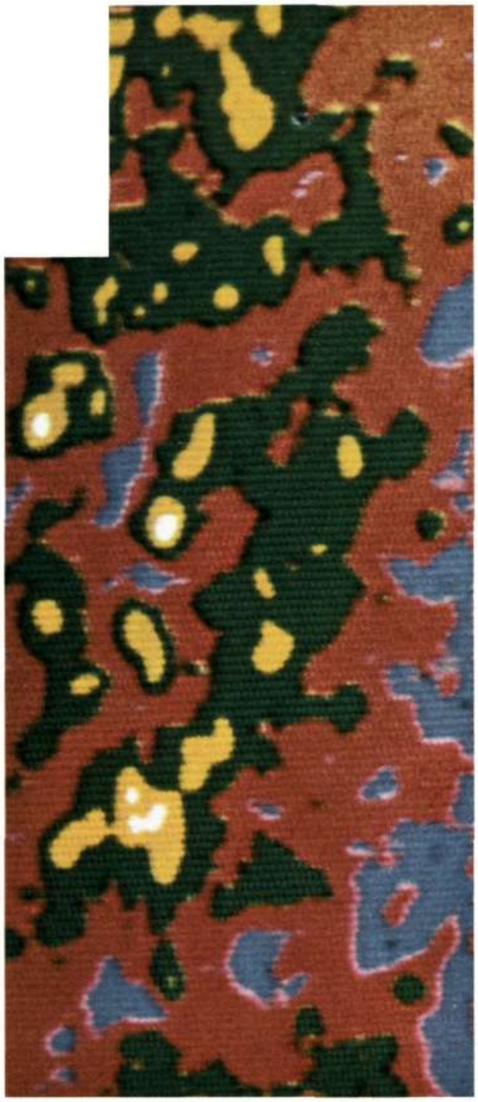

Figure 8. Color coded representation of Figure 5.