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LANDSAT-1 DATA, ITS USE IN A SOIL SURVEY PROGRAM

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ABSTRACT

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There were three objectives for this study. First, to investigate the unique characteristics of LANDSAT imagery as they aid in recognizing soil survey boundaries. Second, to explore the use of LANDSAT imagery for low intensity soil surveys. And third, to investigate LANDSAT imagery as a base map for publishing thematic soils maps.

As an aid in recognizing soil boundaries, the following characteristics of LANDSAT-1 imagery have a bearing on the use of the imagery in a soil survey program. First, each scene covers such a large area that a synoptic view of soil associations is possible. An area of 3.5 million hectares can be studied where sun angle, condition of soil, stage of vegetative growth and other features are recorded at nearly the same moment. The influence of climate and vegetation, soil parent material and topography on soils can be detected. Second, the scenes are near-orthographic. Thus LANDSAT scenes join one another with very little distortion so that mosaics can be constructed. Moreover, LANDSAT scenes fit controlled base maps such as the USGS maps and thus maps showing geologic, topographic, soils, cultural and other features can be superimposed as transparencies over LANDSAT scenes. Third, since LANDSAT passes occur every 9 days, scenes can be selected for the time of the year best suited for soil survey. Moreover, the changes in vegetation and use of soils as well as the soils themselves can be observed as they change with time. Fourth, the data are recorded in four distinct parts of the electromagnetic spectrum. Since both soils and vegetation reflect differently in different parts of the electromagnetic spectrum, the use of four bands increases the chances for unique signatures for identification of vegetation and soils. Fifth, computer compatible tapes, on which the reflectances of the four bands are digitized, are useful to quantify the data of each scene.

Using many of the characteristics of LANDSAT imagery, a low intensity soil survey of Pennington County, South Dakota was completed in 1974. This study was supported in part by NASA Office of University Affairs, Grant No. 42-003-007. In South Dakota a law was passed in 1970 requiring that agricultural land be assessed for taxation according to the ability of land to produce agricultural crops or native grass. A method based on soil survey data and land sales was developed at South Dakota State University for use by assessors. Soil Survey data necessary to use this method are available for only 41 of the 67 counties in South Dakota. Low intensity inexpensive soil surveys can provide the data needed to evaluate agricultural land for the remaining counties until detailed soil surveys are completed.

LANDSAT color composite transparencies, single band transparencies and enlargement prints were interpreted to produce a soilscape map for

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400,000 hectares. Areas of similar photographic characteristics were delineated on mylar over a color composite. The field checking was done by a resource team of soils, geology and range science specialists.

The time necessary to map and field-check the soil associations for 400,000 hectares using LANDSAT-1 imagery was four to six weeks. The total cost for this low intensity soil survey was about 2¢ per hectare. The soilscape map plus land sales data were used to prepare a land value map for the county.

In using LANDSAT imagery as a base map for publishing thematic soil maps, the first step was to prepare a mosaic. Twenty LANDSAT scenes from several late spring passes in 1973 were selected and made into a mosaic of scale 1:1,000,000. Two state LANDSAT mosaics containing soils information have now been published. They were funded in part by NASA No. 5-21771 and NASA Office of University Affairs, Grant No. 42-003-007. On the first, the soil associations are keyed to information on land sale prices from 1967-1972 and the result is a land value map on a LANDSAT mosaic. On the second, the soil associations are keyed to soil test results in South Dakota of the last 25 years for organic matter, P_2O_5, K_2O and pH. Also given for each soil association is relief and texture. Each of these publications cost about $400 for 5000 copies.

INTRODUCTION

Aerial photographs of the earth have been used as a soil survey tool since the 1930's. Since July of 1972, imagery of the earth from the Earth Resources Technology Satellite (LANDSAT) has been available. LANDSAT data are multispectral, temporal, synoptic and near orthographic. Thus they have properties not previously available in photographs taken from airplanes. Limits of LANDSAT data include lower resolution than aircraft imagery, atmospheric attenuation and, since data are taken at fixed intervals, there is no chance of avoiding cloudy or stormy weather. Since imagery is a tool of soil survey, this study was undertaken to evaluate LANDSAT imagery in a soil survey program.

The following characteristics of LANDSAT imagery have a bearing on use of the imagery in a soil survey program.

First, each scene covers such a large area that a synoptic view of soil associations is possible. An area of 3.5 million hectares can be studied where sun angle, condition of soil, stage of vegetative growth and other features are recorded at nearly the same moment. The influence of climate and vegetation, soil parent material and topography on soils can be detected.

Second, the scenes are near-orthographic. Thus LANDSAT scenes join one another with very little distortion so that mosaics can be constructed. Moreover, LANDSAT scenes fit controlled base maps such as the USGS maps. Such maps, showing geologic, topographic, soils, cultural and other features, can be superimposed as transparencies over LANDSAT scenes.

Third, since LANDSAT passes now occur every 9 days, scenes can be selected for the time of year best suited for soil survey. Soil surveyors have had very little control as to flight scheduling for acquiring aerial photographs and have had to accept photographs taken usually in midsummer when the soils are mantled with vegetation.

Fourth, the data are recorded in four distinct parts of the spectrum. Since both soils and vegetation reflect differently in different parts of the electromagnetic spectrum, the use of four bands increases the chances for unique signatures for identification of vegetation and soils.

Fifth, computer compatible tapes containing digital data relating to reflectances in each of the four spectral regions are useful to quantify the data of each scene.

Much of the literature concerning LANDSAT-1 research is available in NASA Symposium Results. Freden and Mercanti (1) have summarized the Third Symposium in three volumes. The work done in soils with LANDSAT-1 appears generally under the discipline heading "Agriculture, Forestry and Range Resources". So far, the information extracted from LANDSAT-1 data in soil survey is by direct photointerpretation or by automatic data processing techniques.

METHODS AND RESULTS

The three objectives for this study were: to investigate the unique characteristics of LANDSAT imagery as they apply to recognizing soil survey boundaries, to explore the use of LANDSAT imagery in low intensity soil surveys, and to investigate LANDSAT imagery as a base map for publishing thematic soil maps.

USE OF LANDSAT TO RECOGNIZE SOIL SURVEY BOUNDARIES

Synoptic View

Soil boundaries caused by climatic and vegetative differences usually can not be observed on conventional air photographs. No one photograph covers enough area to show evidence of these soil differences due to climate and vegetation changes since at best these boundaries are diffuse. The LANDSAT scenes, however cover an area large enough to observe climatic boundaries.

Figure 1 is of eastern South Dakota and western Minnesota along latitude 45°15'. Shown are negative prints of scale 1:500,000 of part of one scene. The tonal difference of the east and west parts is due to reflective differences of soils and vegetation. In this area the climate gradually becomes more humid toward the east. The western part of the scene receives about 21 inches of annual precipitation, while the eastern part receives about 25 inches. More small grain crops and alfalfa are grown in the drier

western part of this area, while more corn and soybeans are grown in the more humid eastern part. On June 17, 1973, the date of this scene, the small grain and alfalfa are near their peak of green growth, thus showing dark tones on this negative print of MSS-7, while the corn and soybeans do not yet cover the ground and the light tones are those of nearly bare soil. In this approximate area the line is drawn between Udoll soils on the east and Ustoll soils on the west.

While soil boundaries caused by climatic and native vegetation differences are diffuse, boundaries due to different parent materials generally are sharp. Figure 2 is a negative print at a scale of 1:500,000 of MSS-7 data from southwestern South Dakota. Loess (Area A), sand (Area B), and calcareous sandstone (Area C) soil parent materials all are apparent on the scene. Stream patterns, image tone, land-use characteristics, and land types all give clues for these separations.

Soil boundaries on the Great Plains caused by relief differences are especially apparent on imagery in areas of fine textured soils. Most of the rain falling on soils of this texture runs off because of the low soil infiltration rates. The result is a network of closely spaced drains. These drains fill with snow in the winter, thus relief differences are accentuated. Figure 3 includes negative prints of MSS-7 data of scale 1:250,000 from the Cretaceous Pierre shale area in central South Dakota. Both summer and winter scenes are shown.

Temporal Character

Figure 4 includes parts of two LANDSAT scenes from western South Dakota taken about 2 years apart. A change in use of some of the soils of the Great Plains from grass to wheat has been brought about by the increase in the price of wheat. This change in the use of soils with time can be studied with LANDSAT imagery since bare land and wheatlands are easily distinguished from grasslands.

In figure 4, two negative prints of scale 1:500,000 taken about 2 years apart, the newly cultivated land is light-toned, grassland is a medium gray tone and wheat is very dark gray.

These changes in land use can be quantified through use of the computer compatible tapes which are discussed in a later section.

Figure 5 includes MSS-7 prints of the same area of southeast South Dakota of two dates. Both scenes are negative prints of scale 1:250,000. Two principal soil associations are shown: A, a nearly level, immaturely dissected, glacial plain of silty soils formed in a thin loess cap over till; and B, a dissected plateau having rolling, deep loessial soils. The association of rolling soils(B) is easily distinguishable on the May 30 scene but is less easy to see on the August 28 scene. Vegetation, and the lack of it, which changes with time, plays a large part in distinguishing these associations. The rolling Area B is characterized by two features - considerable erosion and more close-growing crops - alfalfa, grass and small grain. This causes a mottled tone. The mostly dark areas in

these negative-print MSS-7 data are crops, and the splotches of white are the light colored, eroded soils. The flat soils of A in late May are bare or only partially covered with the recently planted corn and soybeans. Thus they appear light-toned in geometric shapes on this negative print. In the late August scene the two soil association areas appear almost uniformly dark-toned since practically all the soils are mantled with some kind of growing vegetation on this date. The May scene thus is superior to the August scene to show these soil association boundaries.

Multispectral Capabilities

One advantage in having energy recorded in four spectral bands is that unique signatures for water and for various agricultural uses of soils can be developed. Figure 6 shows 4 sections of land in western South Dakota (Sections 1-4, T106N, R77W Lyman County) as they appear in negative prints of two bands - MSS-5 in the visible spectrum and MSS-7 in the near infrared. The scale is 1:100,000. On MSS-7, fallow fields appear nearly white (have high reflectance), grass is in light gray tones, while very dark tones are of growing vegetation - milo or wheat. The type of growing vegetation is difficult to distinguish on MSS-7 in mid or late summer. However, on MSS-5, milo reflects nearly white while wheat appears dark gray at this time. Thus, using MSS-5 and 7 in combination, water, fallow, grass, milo and wheat can be separated. These are the main uses of agricultural land in this area.

A crop calendar for the region under study as well as detailed ground truth information on the date of the LANDSAT overpass are essential for land use studies.

Dark, shale-derived soils occur in central South Dakota on slopes leading down to the Missouri reservoir. These soils occur on steep slopes and in places are actively eroding. The black eroding soil in small gullies adjacent to grass-covered interfluves occurring on gentler slopes provides an energy contrast recorded on MSS-7 but not on MSS-5. Figure 7 shows MSS-5 and 7 prints of scale 1:250,000 of the same area. The eroding soils, labeled \, appear as a white fringe on the negative print of MSS-7. Thus these eroding areas can be detected on MSS-7 but not on MSS-5.

Soil surveyors are concerned about separating open water from marshland. The panchromatic film used for most soil survey base maps records energy in the visible spectrum comparable to MSS-4 and 5 of LANDSAT. Panchromatic images of emergent vegetation in marshes and open water reflect about the same on MSS-5, but open water is easily identified on MSS-7 and separable from marshland. Figure 8 is an example from glaciated eastern South Dakota. These are negative prints of scale 1:500,000. What appear to be four lakes on MSS-5 are shown to be two lakes and two marshes on MSS-7.

Near-Orthographic Character of LANDSAT Images

The geometric quality of LANDSAT MSS images is such that mosaics of adjacent images join with very little distortion. Moreover, overlays of controlled base maps fit LANDSAT images. Overlays can be prepared for geology, soils, cultural features, drainage and the like to assist users in orienting themselves on LANDSAT images for planning purposes.

Computer Compatible Tapes

Most of the work with LANDSAT data has been with photographs converted from the electronic signals received by the multispectral scanner. However, the digital data themselves are considered to have more dynamic range than can be accommodated by a photograph.

In digital processing the amount of light reflected by the smallest area recorded by the scanner on tape is given a digit. The MSS bands 4, 5 and 6 have a range of digits from 1 to 128 while MSS band 7 has a range of digits of 1 to 64. Thus the range of reflectance for the 4 bands is divided into many more categories than can be distinguished by eye from a photographic image of the scene. Each LANDSAT scene has 3,240 columns and 2,340 lines. Since each scene is 185 km square, each digit records data for about 0.45 hectares (or 1.1 acres). A histogram is prepared for each scene recording the number of times each digital value is printed, so that the acreage of each signal can be computed.

Machine processing of computer compatible tapes (CCT) is just developing. Until computer augmentation is more fully developed and generally accessible, soil surveyors still can make considerable use of the CCTs, with only simple computer software and hardware.

This is the procedure used in this study. The CCT as received from the EROS Data Center, Sioux Falls, S.D. has 2 pixels of MSS-4, 2 pixels of MSS-5, 2 pixels of MSS-6 and 2 pixels of MSS-7 printed together, followed again by 2 pixels of MSS-4, 2 of MSS-5 and so on.

Our procedure is to reformat the tape so it is compatible for use on the IBM 370/145 computer. In this procedure each band is printed separately. The first step is to get a photographic print of one band, usually 7, of an entire LANDSAT scene at a scale of 1:500,000. This is superimposed on a USGS base map of the same scale over a light table to locate the 4 corners of the LANDSAT scene on the base map. The area of study - a township or county usually - is located on the base map and lines connecting the corners of this are drawn to the left side and top of the located LANDSAT scene. Since each tape has 3,240 columns and 2,340 lines, a small area of study can be located as is shown in figure 9. On a map of 1:500,000 the LANDSAT scene measures 36.8 cm on a side. Therefore 36.8 divided into 2,340 lines indicates that there are 63.8 lines per cm. In the same manner it is determined that there are 88.2 columns per cm. The distance from the upper left corner of the LANDSAT scene is measured to the intersection of the lines connecting the 4 corners of the study area. This is converted

into columns and lines, and thus only the part of the tape encompassing the study area is printed out. The entire LANDSAT tape can be dumped but this would result in a large volume of paper and the histogram summaries would be meaningless unless the investigator wished to summarize data by LANDSAT scene. We also have found that printing every other line and column reduces printout size and although there also is some reduction in accuracy, the resolution is suitable for our agricultural applications. The reflectances of MSS-5 and MSS-7 usually are printed out and the digits are converted to alphanumeric form so one symbol utilizes one space.

The tapes printed out in this manner are not rectified. Rectification can be accomplished but requires additional computer manipulation, increasing computational time requirements. As printed out in our procedure the sections are parallelograms but not squares. Figure 10 is an example of a section of land from western South Dakota printed for MSS-5 and MSS-7 data. After locating a study area and correlating reflectances on MSS-5 and 7 with ground truth data from test sites, the combinations of reflectances on the two bands that correspond to a land use such as fallow or wheat or grass can be determined. Thus on MSS-5, figure 10, the fallow field corresponds mostly to M and N while on MSS-7 the fallow field corresponds to E and F. A second printout can be prepared for the study area assigning a unique symbol to all areas where M and N appear on MSS-5 and E and F appear on MSS-7. A histogram for the area can be prepared summarizing the separations in terms of hectares, acres or percent.

Although not sophisticated, this procedure permits inexpensive access to the quantitative data on the tapes for soil survey purposes.

USE OF LANDSAT FOR A LOW INTENSITY SOIL SURVEY

In South Dakota a law was passed in 1970 requiring that agricultural land be assessed for taxation according to the ability of land to produce agricultural crops or native grass. A method based on soil inventory data and land sales was developed by Westin et al. (2) for use by assessors in South Dakota. Soil inventory data necessary to use this method are available for 41 of the 67 counties in South Dakota. General soils information such as low intensity soil surveys which are inexpensive to make, can provide the data needed for the remaining counties until detailed soil surveys are completed.

Using many of the characteristics of LANDSAT-1 imagery, a low intensity soil survey of Pennington County, S.D. was completed in 1974. Frazee et al. (3) have prepared a detailed report on the work which was supported by the Plant Science Department and the Remote Sensing Institute of South Dakota State University and NASA under contract 42-003-007.

LANDSAT-1 color composite transparencies, single band transparencies and enlargement prints were interpreted to produce a soilscape[1] map for

[1] The term "soilscape" is a contraction of "soil landscape" described in Buol, Hole and McCracken in Soil Genesis, p. 300 as the assemblage of soil bodies on a land surface in a particular landscape.

400,000 hectares. Areas of similar photographic characteristics were delineated on mylar over a color composite using a light table and a three-power magnifying glass. The field checking was done by a resource team of soil, geology and range science specialists.

The color composite transparency was adequate for locating most of the boundaries between soilscape areas. The time necessary to map and field check the general soils for 400,000 hectares using LANDSAT-1 imagery was 4 to 6 weeks. The soilscape map and land sales data were used to prepare a land value map for the portion of Pennington County east of the Black Hills.

The color composite transparencies were most useful for interpretation of boundaries between soilscape areas. The interaction between the individual bands provided useful clues for interpretations. Most of the boundaries were delineated very well on the LANDSAT-1 imagery. Areas such as flood plains which were too small to delineate using the color composite transparency at a scale of 1:1,000,000 were mapped using the 1:250,000 enlargement prints.

The map with major soil boundaries interpreted in the office by photo-interpretation of the color composite transparencies, single band positive transparencies, and enlargement prints is shown in part in figure 11. Table 1 is the legend for this preliminary interpretation. This map (figure 11) was transferred to the USGS 1:250,000 scale topographic map for field checking. Each area delineated was visited and the soil, vegetation and geologic materials were described as well as the surface features responsible for the reflectance patterns apparent on the LANDSAT imagery.

Examination of the LANDSAT imagery in the field indicated several additional boundaries. These were delineated and the final map prepared (figure 12). Table 2 is the complete legend. Figure 13 is a line map enlargement of figure 12. Figure 14 is the current soil association map of Pennington County by Westin and Bannister (4). It can be noted that more soil areas are delineated on the soilscape map (figure 12) than on the current soil association map.

The major differences between the two maps are in the areas with soils formed from the Fox Hills Formation, the White River Sediments and terraces overlying the Pierre Shale. Area No. 32 on the Soils Association map, figure 14, the Ralph-Cabbart-Regent Association, was divided into 4 areas using slope and land use data. The Badlands area labeled under 69 was divided into three segments using color and color pattern interpretations. The terraces, Caputa Association, 36, were separated into three parts.

The features or characteristics observable on the LANDSAT color composite transparency which were used for interpreting the soilscape boundaries were tone, color, land use patterns and drainage patterns.

The soilscape map of Pennington County was interpreted to give the Director of Equalization general guidelines for land evaluation. This is shown in figure 15. In this process a crop and grass yield rating was calculated for each soilscape and related to sales figures from 1967-1973 furnished by the Director of Equalization.

The cost for this low intensity soil survey was roughly 2¢ per hectare. The LANDSAT imagery for the area of the county covered cost $100, and travel was $100. The office interpretation, the field check and the final drafting took about 36 man days.

USE OF LANDSAT IMAGERY AS A BASE MAP FOR PUBLISHING SOIL INFORMATION

Since LANDSAT scenes are near orthographic, adjacent images join with very little distortion. Twenty LANDSAT-1 scenes from several late spring passes in 1973 were selected and made into a mosaic of scale 1:1,000,000 by Jack Smith, Photographic Technician at the SDSU Remote Sensing Institute. It would be unusual for all LANDSAT scenes in a single pass to be cloud free and so it was necessary to utilize several passes. Some scenes were joined which differed in date by 18 days and although this was undesirable, it could not be avoided. It would take about 30,000 conventional air photos to cover South Dakota. The expense of constructing a state mosaic from conventional air photos would be impractical.

For this mosaic, negative prints of MSS-7 were used. For our materials, negative prints were one generation closer to the original and hence were sharper than positives. Band 7 was selected because all water bodies are well defined, and bare soil contrasts sharply with cultivated land and grass and trees. A LANDSAT photographic background for soil related information greatly enhances its use since much can be deduced about hydrology and land use.

Two state LANDSAT mosaics have been published, Westin (5) (AES No. 5), and Westin (6) (AES No. 7). AES No. 5 shows 53 soil associations to which are keyed information on land sale prices from 1967-1972, general agricultural use, relief, soil texture and soil parent material. A portion of AES No. 5 is shown in figure 16. AES No. 7 has 30 soil associations to which are keyed soil test results since the 1950's for organic matter, P_2O_5, K_2O and pH. Also given for each soil association is relief and texture. Small maps of the state printed in the margins show annual precipitation and temperature, elevation, soil parent material, growing degree days, physical divisions, and approximate farm size. Each of these publications cost about $400 for 5000 copies.

AES No. 5 was intended for users interested in land prices, while AES No. 7 was intended for users interested in the nutrient status of their soils and to assist in planning herbicide rates of application which depend on the soil texture, organic matter content and pH. In both pulications, the soils data presented are more meaningful because the LANDSAT photographic image permits the user to see the general use of the soils.

AES No. 5 was funded in part by NASA 5-21774 and AES No. 7 by NASA Office of University Affairs, Grant No. 42-003-007.

South Dakota Agricultural Experiment Station Journal Article Number 1342

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Table 1. Legend for Preliminary Interpretation.

A. Soilscapes from White River Sediments

A1 -- Badland walls and basins, steep
A2 -- Badland uplands, nearly level to undulating

B. Soilscapes from Pierre Shale

B1 -- Shale Breaks, steep
B2 -- Shale Plains, gently rolling
B3 -- Shale Plains, undulating
B4 -- Terraces, nearly level
B5 -- Alluvium

C. Soilscapes from Fox Hills Formation

C1 -- Sandstone Breaks, Steep
C2 -- Sandstone Uplands, gently rolling
C3 -- Sandstone Uplands, nearly level

D. Soilscapes from Black Hills Footslope

D -- Uplands, gently rolling

Table 2. Soilscapes of Eastern Pennington County

Unit	Land Form	Geologic Material	Soil	Range Site	Land Use	LCS*	Ground Water**
A	Soilscapes from White River Sediments						
A1	Hilly to very steep barren badlands	Siltstone and shale	None	None	Non-Agricultural	8s	None to Poor
A2	Undulating to gently rolling uplands	0-5' of terrace alluvium over White River Sediments	Shallow to Moderately Deep Clayey Soils	Clayey-Shallow	Rangeland	4e-6s	Poor
A3	Nearly level to undulating badland basins	Clayey alluvial sediments	Shallow to Moderately Deep Clayey Soils	Clayey-Shallow	Rangeland	4e-6s	Poor
A4	Nearly level to undulating table lands	5-20' of terrace alluvium and aeolian deposits over White River Sediments	Deep Silty and Loamy Soils	Silty-Sandy	Cropland Rangeland	3c-3e-4e	Fair
B	Soilscapes from Pierre Shale						
B1	Steep shale breaks	Pierre Shale	Shallow to Moderately Deep Clayey Soils and Shaleland	Shallow	Rangeland	7s-6e-8s	None to Poor
B2	Undulating to rolling sideslopes	Colluvium from Pierre Shale	Shallow, Moderately Deep to Deep Clayey Soils	Clayey	Rangeland	6e-4e-6s	Poor
B3	Undulating to gently rolling plains	Colluvium from Fox Hills Sandstone and Pierre Shale	Deep Clayey and Thin Claypan Soils	Clayey-Claypan	Rangeland	4e-6s	Fair to Good
B4	Undulating plains	Thick colluvium from Pierre Shale	Moderately Deep to Deep Clayey Soils	Clayey	Cropland	4e	Fair

Table 2. Continued

Unit	Land Form	Geologic Material	Soil	Range Site	Land Use	LCS*	Ground Water**
B5	Undulating to rolling dissected terraces	5-10' of terrace alluvium over Pierre Shale	Moderately Deep to Deep Loamy Soils	Clayey-Thin Upland	Rangeland	4e-6e	Fair
B6	Undulating to gently rolling terrace remnants	5-10' of terrace alluvium over Pierre Shale or White River Sediments	Deep Loamy Soils	Clayey	Rangeland-Cropland	3e-4e	Fair
B7	Nearly level to undulating terrace remnants	5-50' of terrace alluvium over Pierre Shale	Deep Loamy Soils	Clayey	Cropland	3c-3e	Fair
B8	Nearly level terraces	5-20' of terrace alluvium over Pierre Shale	Deep Silty and Loamy Soils	Silty-Clayey	Cropland	3c	Fair to Good
B9	Nearly level terraces	0-5' of terrace alluvium over Pierre Shale	Moderately Deep Loamy Soils	Silty	Rangeland	4s	Fair to Good
C	Soilscapes from Fox Hills Formation						
C1	Hilly to steep breaks	Fox Hills Sandstone and Shale	Shallow to Moderately Deep Loamy Soils	Shallow	Rangeland	7s	Fair
C2	Rolling uplands	Colluvium from Fox Hills Sandstone and Shale	Shallow, Moderately Deep to Deep Silty Soils	Silty-Shallow	Rangeland	6e-6s	Fair to Good
C3	Undulating to Gently rolling uplands	Colluvium from Fox Hills Sandstone and Shale	Deep Silty Soils	Silty	Cropland	3e-4e	Fair to Good
C4	Nearly level to undulating uplands	Colluvium from Fox Hills Sandstone and Shale	Deep Silty Soils	Silty	Cropland	3e-3c	Fair to Good

Table 2. Continued

Unit	Land Form	Geologic Material	Soil	Range Site	Land Use	LCS*	Ground Water**
D	Flood Plains						
D1	Flood plains of Cheyenne and white Rivers	Sands and fine textured alluvium	Deep Clayey and Thin Sandy Soils	Clayey-Overflow	Rangeland-Hayland	4s-4e-6w	Excellent
D2	Flood plains of Rapid, Box Elder, and Spring Creeks	Medium textured alluvium	Deep Silty Clay Loam Soils	Overflow	Hayland	3c-6w	Excellent
E	Soilscapes from Black Hills Footslopes						
E1	Rolling uplands	Colluvium from Carlisle, Greenhorn and Niobrara Formations	Moderately Deep Clayey and Loamy Soils	Thin Upland-Clayey	Rangeland	6e-4e	Fair to Poor
E2	Rolling uplands	Clayey colluvium and bedrock from Graneros Group	Shallow to Moderately Deep Clayey Soils	Shallow-Clayey	Rangeland	6s-6e	Fair to Poor

* LCS Land Capability Subclass
** Potential for development of household wells

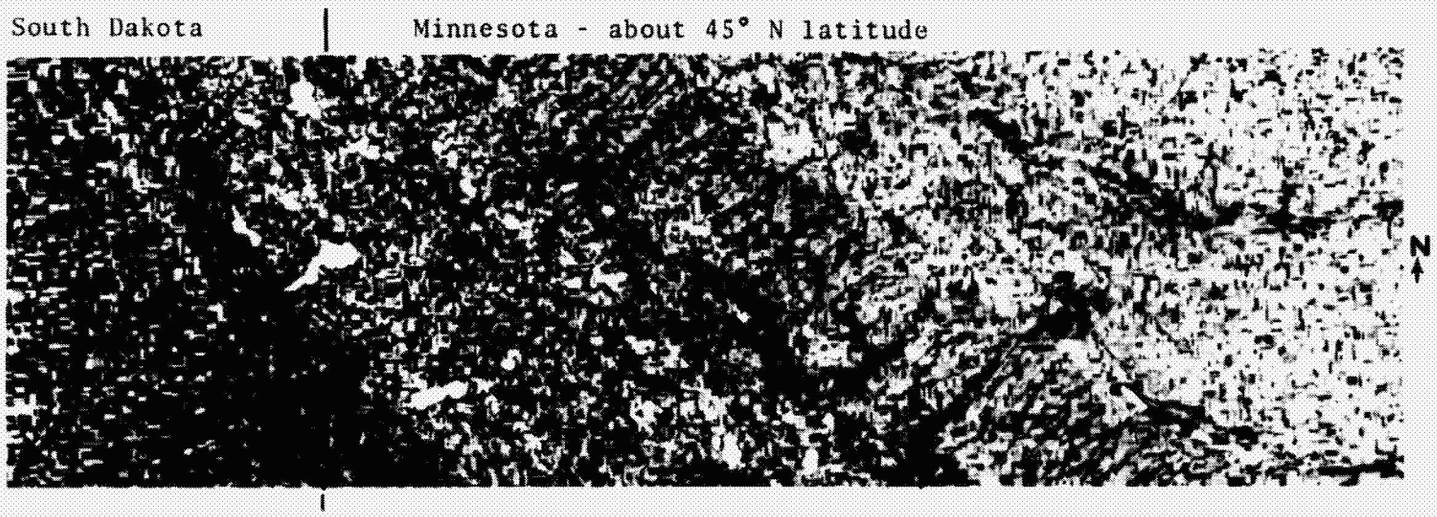

Figure 1. Diffuse boundary due to climatic change separating soil associations. LANDSAT scene of 17 June 73 1329-16440-7 Scale 1:500,000. Soils at eastern edge of scene (on the right) receive more moisture and thus are used primarily for corn and soybeans, neither of which mask the soil surface at this date. These lands thus have low reflectance and gray tones on this negative print. Soils at the western edge of the scene receive less moisture hence are used more extensively for crops like small grains which require less moisture. On this June date these small grains are reflecting strongly in the infrared and thus have dark tones on this negative print.

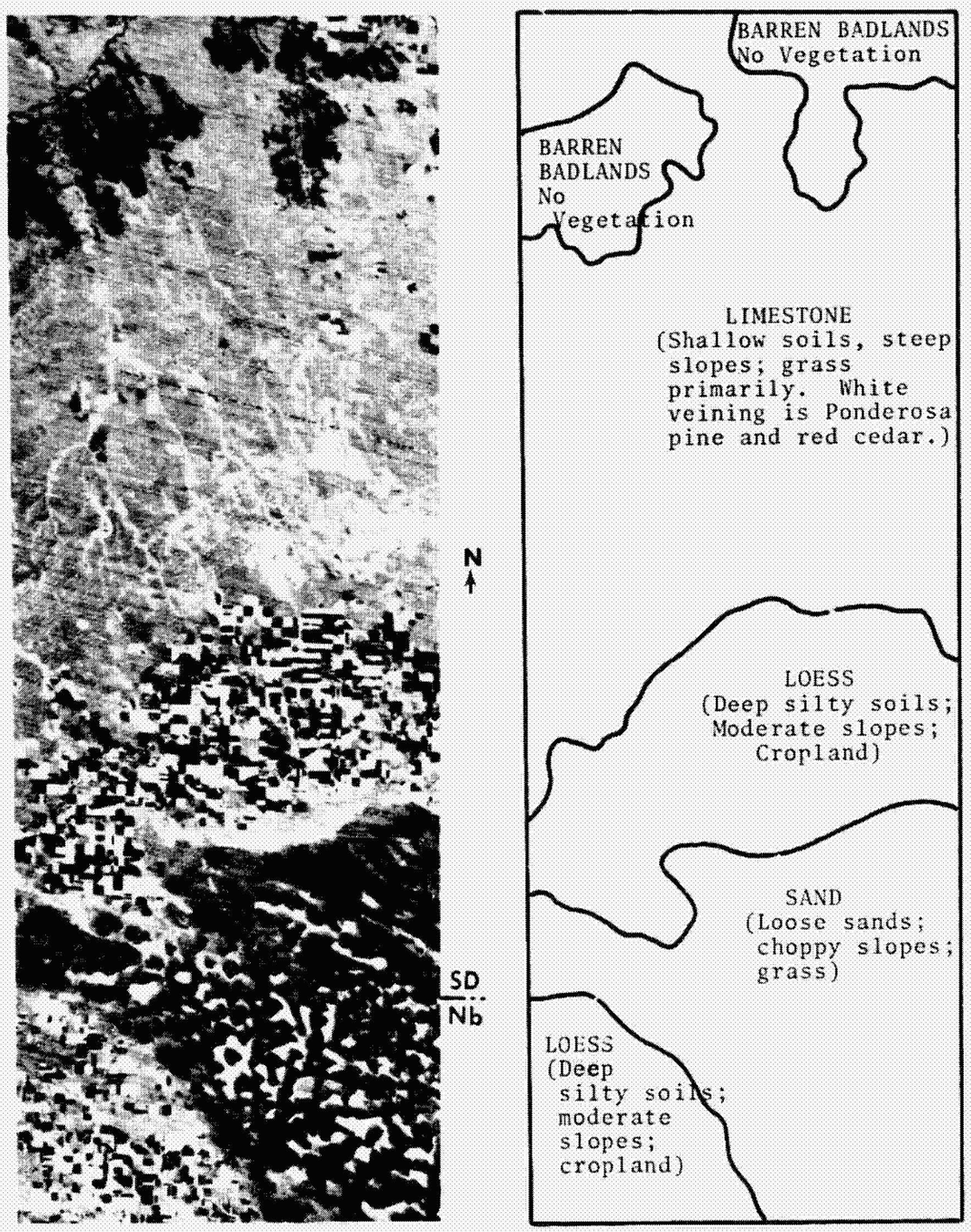

Figure 2. Sharp boundaries due to soil parent material differences, Southwest South Dakota. LANDSAT scene of 3 June 73, 1315-17073-5 Scale 1:500,000. Negative print.

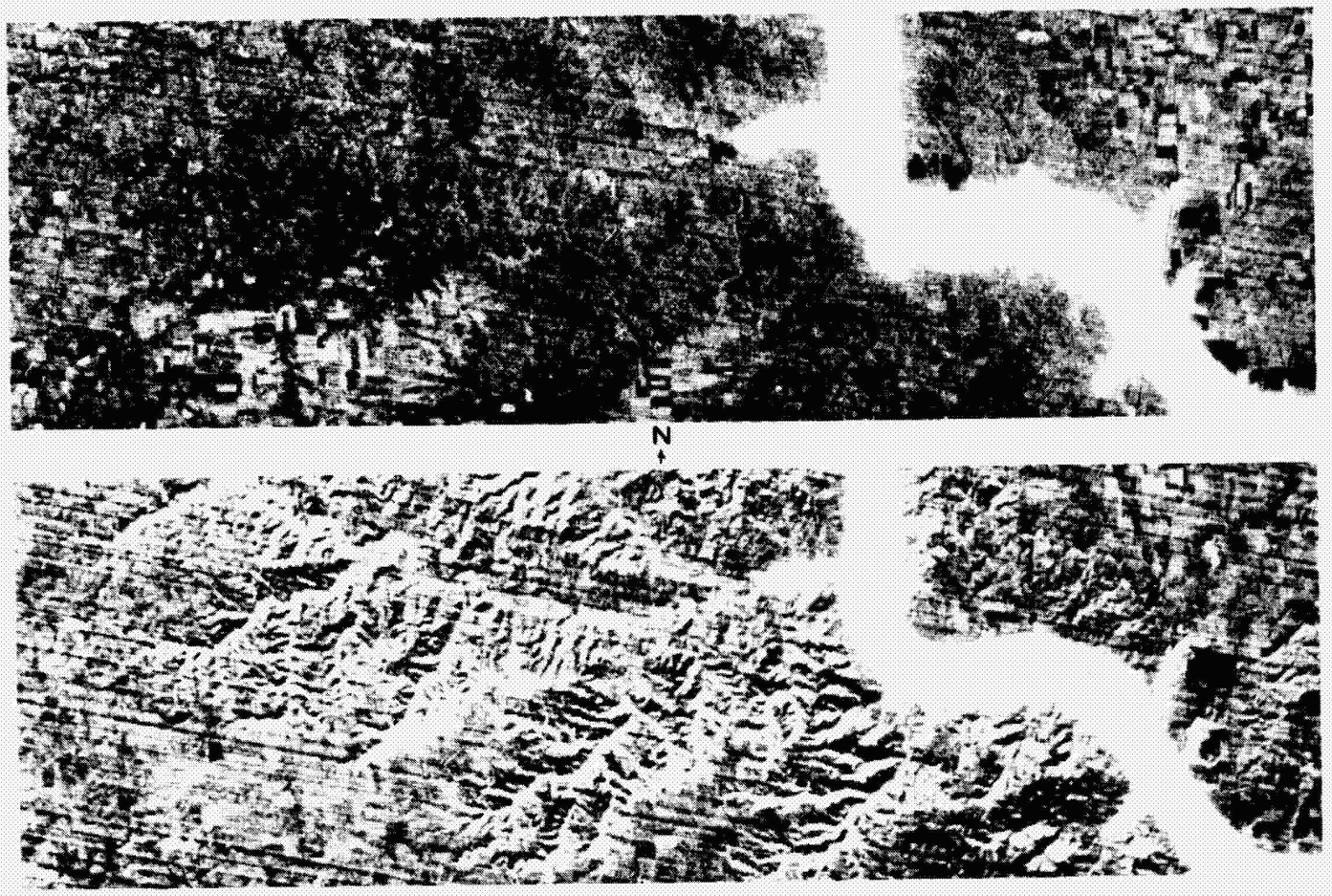

Figure 3. Soil Association boundaries caused by topography differences as seen during June and December. The top scene is of 19 June 74 1726-16414-7. The lower of 10 Dec 74 1870-16364-7, on both the scale is 1:250,000 and both are from along the Missouri River Reservoir in Central South Dakota above Fort Randall Dam. Snow etches the drainageways and assists in topographic delineation.

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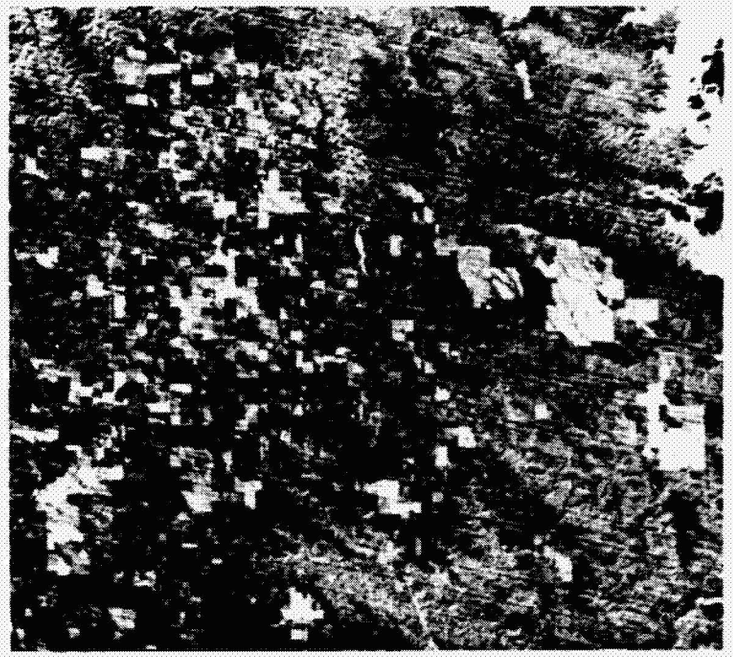
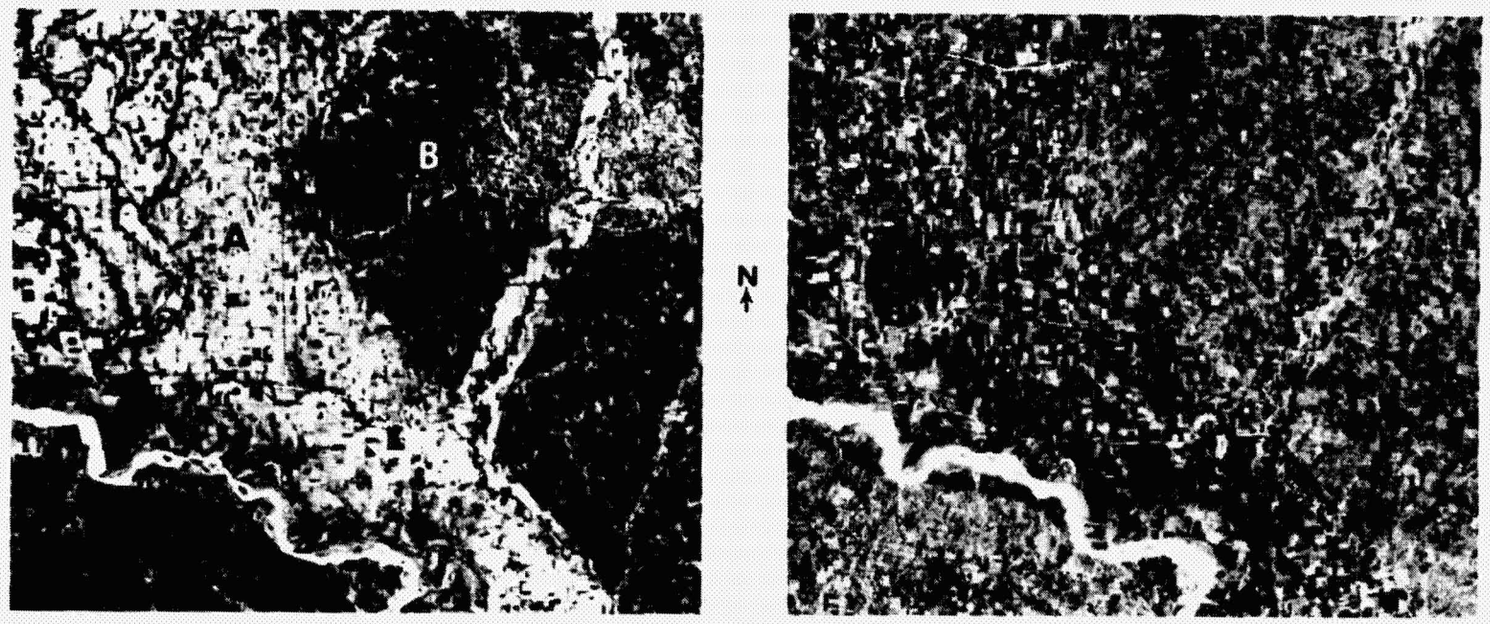
5 Sept 72 1044-17004-7
Scale 1:500,000

N ↑



24 Nov 74 1854-16483-7
Scale 1:500,000

Figure 4. Temporal changes in use of soils. Both scenes are negative prints of the same area just west of the Oahe Reservoir in central South Dakota. The reservoir is visible on the northeast corner of the scene. The light gray geometric areas are fallow fields, the dark ones mostly winter wheat or alfalfa. The intermediate gray tones are grass and the small white specks especially noticeable in the 1972 scene are stock ponds. Note the number and size of the new fields on the 1974 scene, some in failow and some in winter wheat. These clay soils in the Great Plains area of South Dakota generally are not cropped unless slopes are nearly level. The network of drains in the newly cultivated areas indicate they occur on sloping areas subject to erosion.



30 May 73 1311-16444-7
Scale 1:250,000

28 Aug 73 1401-16433-7
Scale 1:250,000

Figure 5. Temporal change useful in identifying soil associations. Both scenes are negative prints of the same area in southeast South Dakota. The Missouri River is the large river in the lower left. The Big Sioux River is the stream on the right part of the scene. On the May scene the flat soils (A) were recently planted to corn and soybeans but still reflect mainly bare soil and are light gray and sharply separated on MSS-7 from the rolling and sloping areas (B) used primarily for small grains, grass and other close growing crops. In August the separation of the soil associations boundaries is less distinct since nearly all of the area is vegetated and reflecting strongly on MSS-7. Thus, for detecting soil boundaries in this area the May scene offers a distinct advantage.

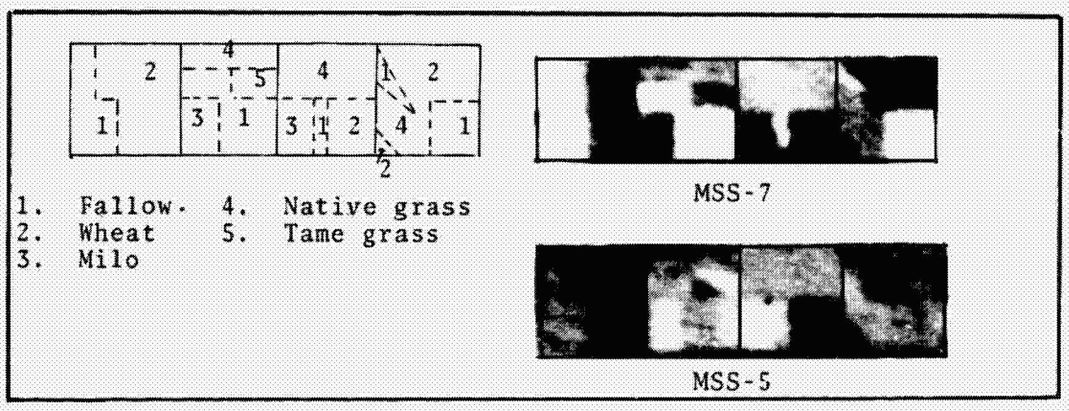


Figure 6. Multispectral differences of the same land use. Negative print of sections 1-4, T106N, R77W, Lyman County, South Central South Dakota. 17 Aug 72 1025-16551.

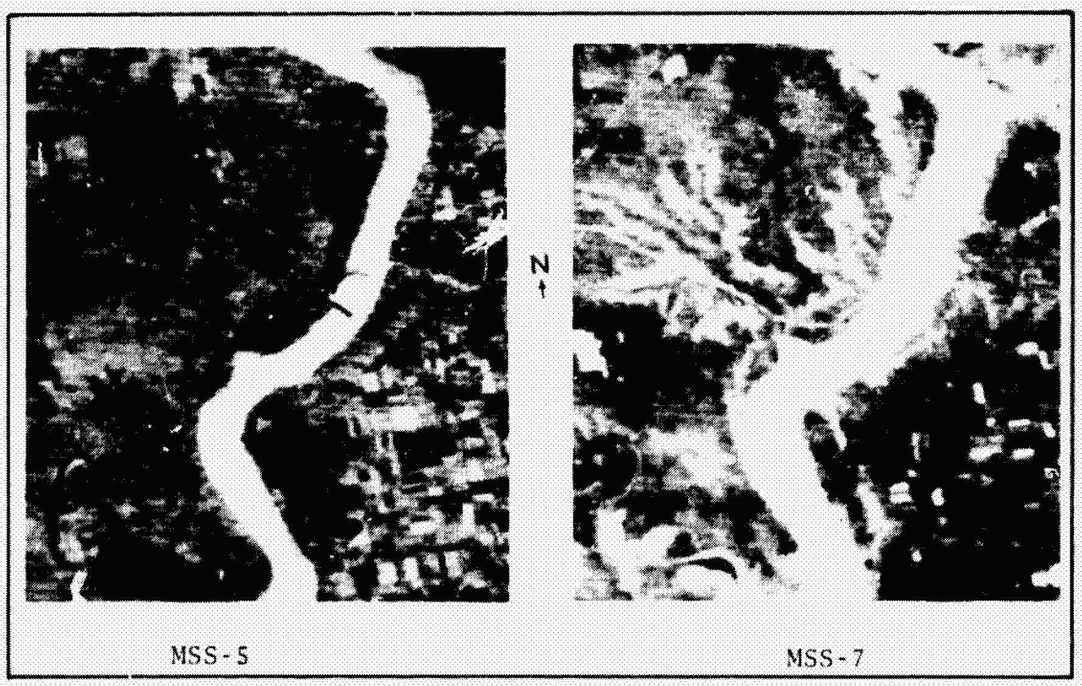


Figure 7. Multispectral differences of the appearance of erosion above the Missouri River Reservoir in south central South Dakota. The white fringe on MSS-7 identified by an arrow is bare eroding soil. Negative prints of 17 Aug 72 1025-16551.

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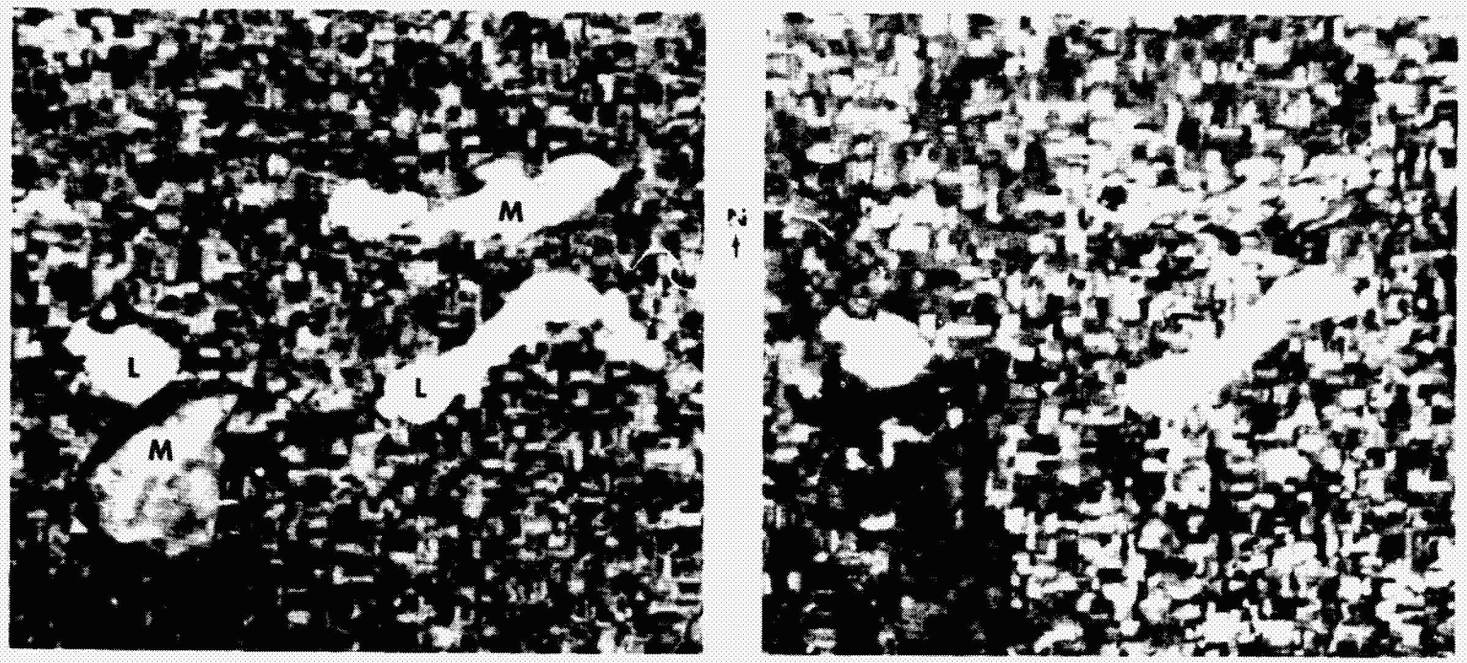

MSS-5 MSS-7

Figure 8. Multispectral differences in the appearance of lakes (L) and marshes (M) on LANDSAT scene of 21 Sept 72 1060-16491. Scale 1:250,000.

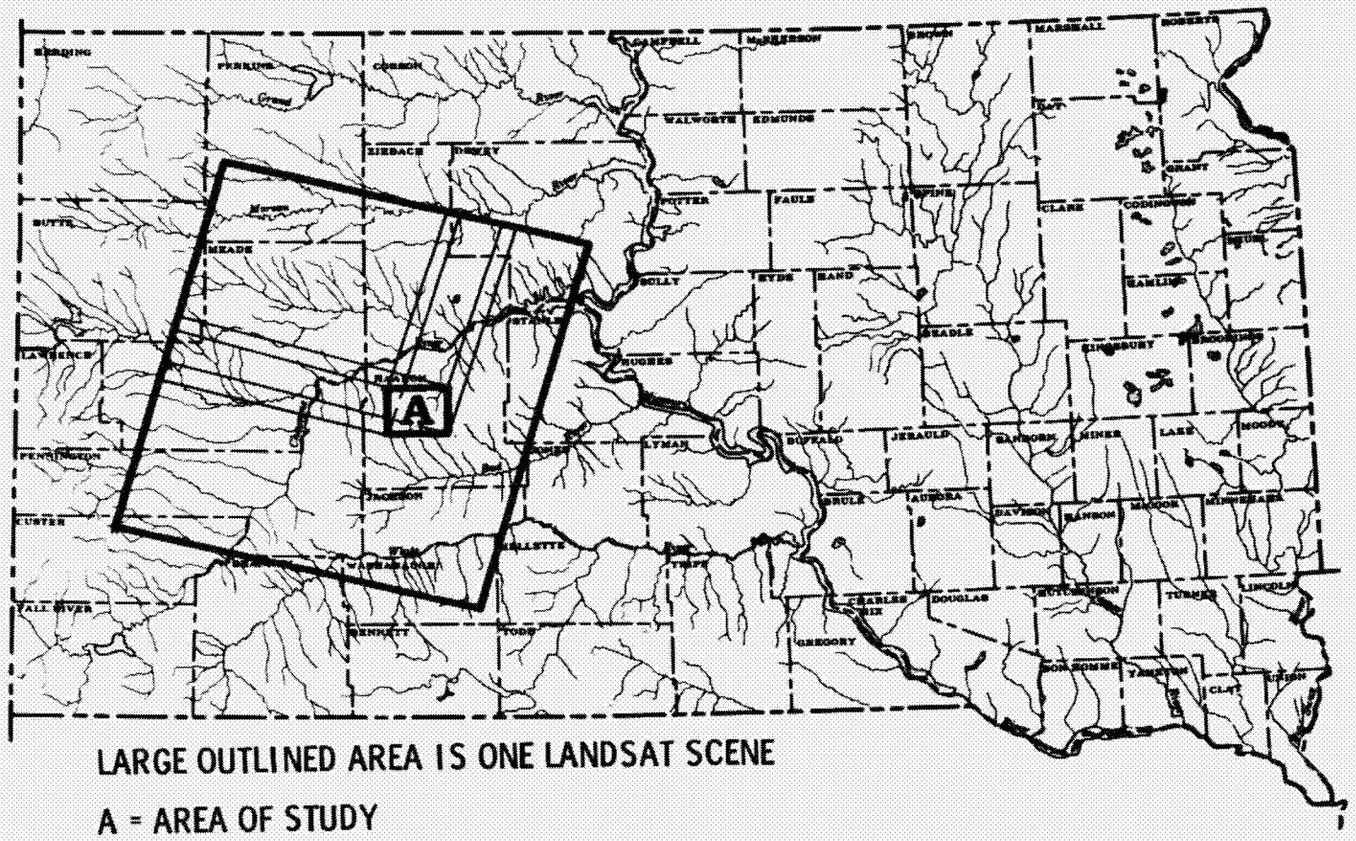

Figure 9. Location of a LANDSAT scene in South Dakota.

Figure 10.

LANDSAT-1 19 Aug 72
COMPUTER COMPATIBLE TAPE, BANDS 5 AND 7
SECTION 32, T37N, R26W, BENNETT COUNTY, S.D.

BAND 5

```
        ONONNRRPNN
    RPMIIHNNOMNQQNM
QIIJJGFFLNOPMRQQM
PKJJKIFGJOPQQRRON
 NIJJGFIGLNMJNQQQM
 NMMMFFGGJNNPKKRPM
 ONSEIKLNOSSRSQMKMN
  NMMMMLNMPSRRQPROK
  NMNNMLMMNQTQTQRRK
  PONNNMNNNONNNPOQK
   ONNMMMMMMLLKJKKML
   NONNLLMOJJJKJNLKK
   OPWPPPOQM
```

BAND 7

```
      NQJIJIIHHIG
   JKIIIKNQJIJIIHHIG
   JKJKKQSRLJJJIHHIJ
   JJIKJMRQMIIIJHHISE
   IIKJLPRQRKJJIJEHGF
    FKKKTSRQNIIJJIJJF
    GIIIPMIFFIJJJIIHF
     GGFFFEFFIJJJJKJH
     GNFFFEFFGKKKJJJKI
       IFFFFFEFIJIJJIJI
       IIFFFFFFGIJLNCKK
        IEFGHIIHNNNONNM
        KIIHII
```

One-quarter section (160 acres) of fallow outlined.

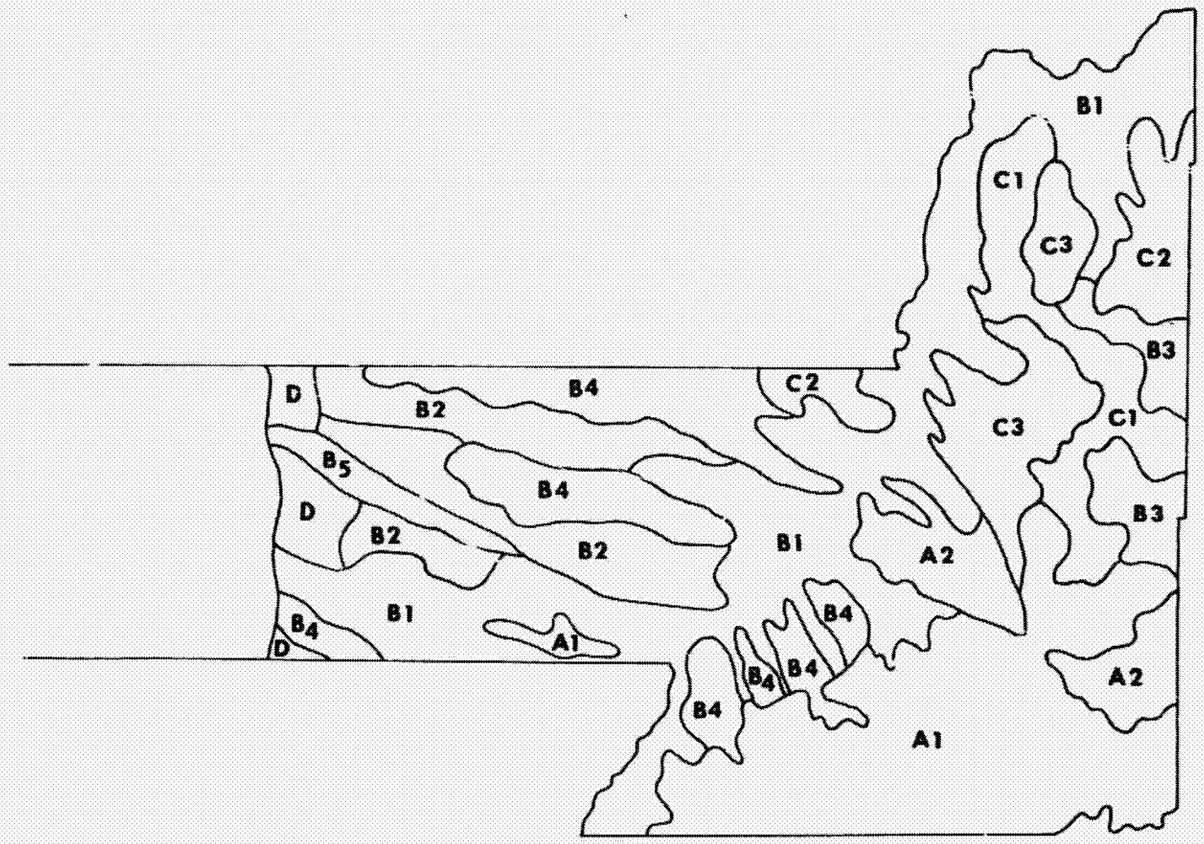

Figure 11. Preliminary interpretation of LANDSAT-1 imagery of eastern Pennington County, South Dakota.

Figure 12. LANDSAT color composite of Pennington County, South Dakota with soilscape map on Plains portion. Scale about 1:1,000,000. The western third, roughly, of the county is in the Black Hills and out of the study area. The legend for the map is table 2. Figure 13 is an enlarged line drawing of this map.

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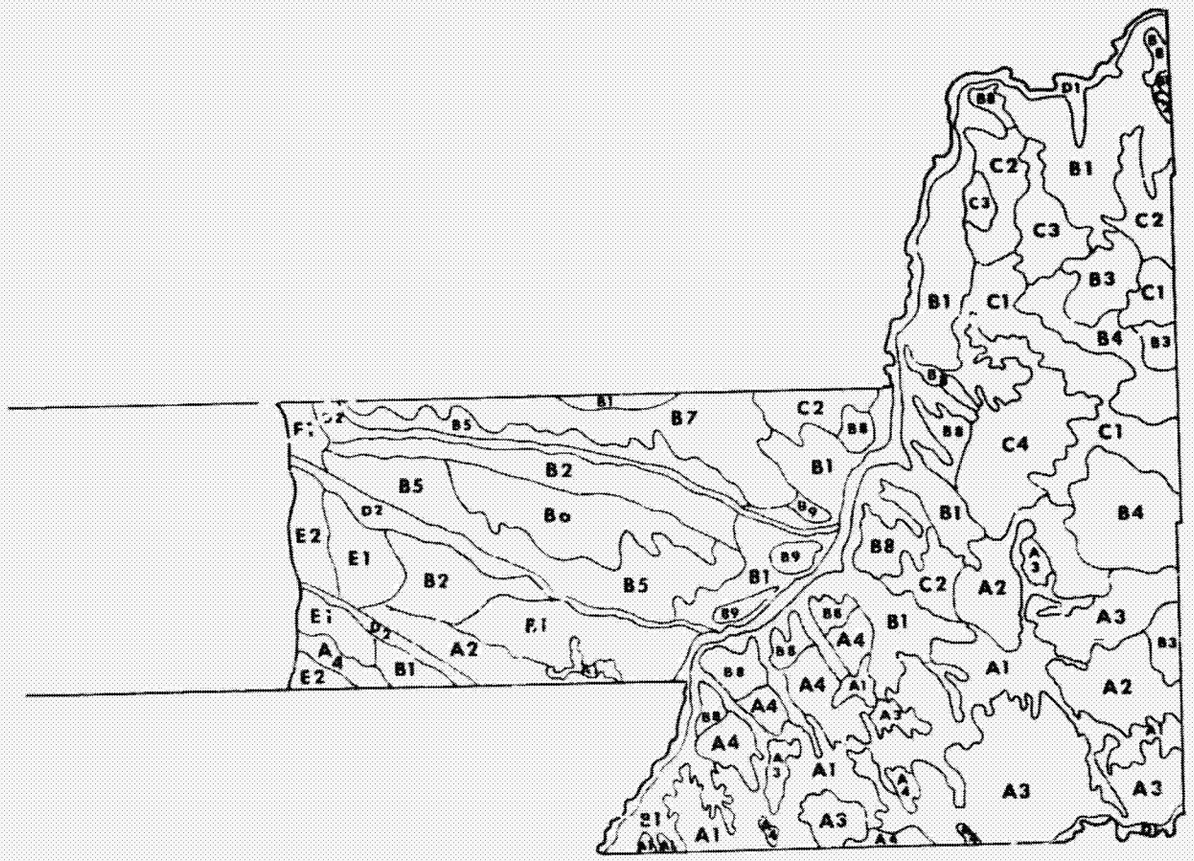

Figure 13. Soilscapes of eastern Pennington County

Legend for Pennington County Soil Association

5 Nevee-Spearfish
6 Spearfish-Nevee
7 Butche-Canyon
8 Canyon-Butche
32 Ralph-Cabbart-Renent
36 Caputa-Satanta
37 Ree
39 Satanta
43 Penrose-Minnequa
44 Pierre-Kyle
47 Pierre-Samsil
48 Grummit
50 Samsil-Lismas-Pierre
60 Wanblee
62 Glenburg-Haverson
63 Haverson
64 Loamy alluvial land
65 Bankard-Kyle
69 Badlands

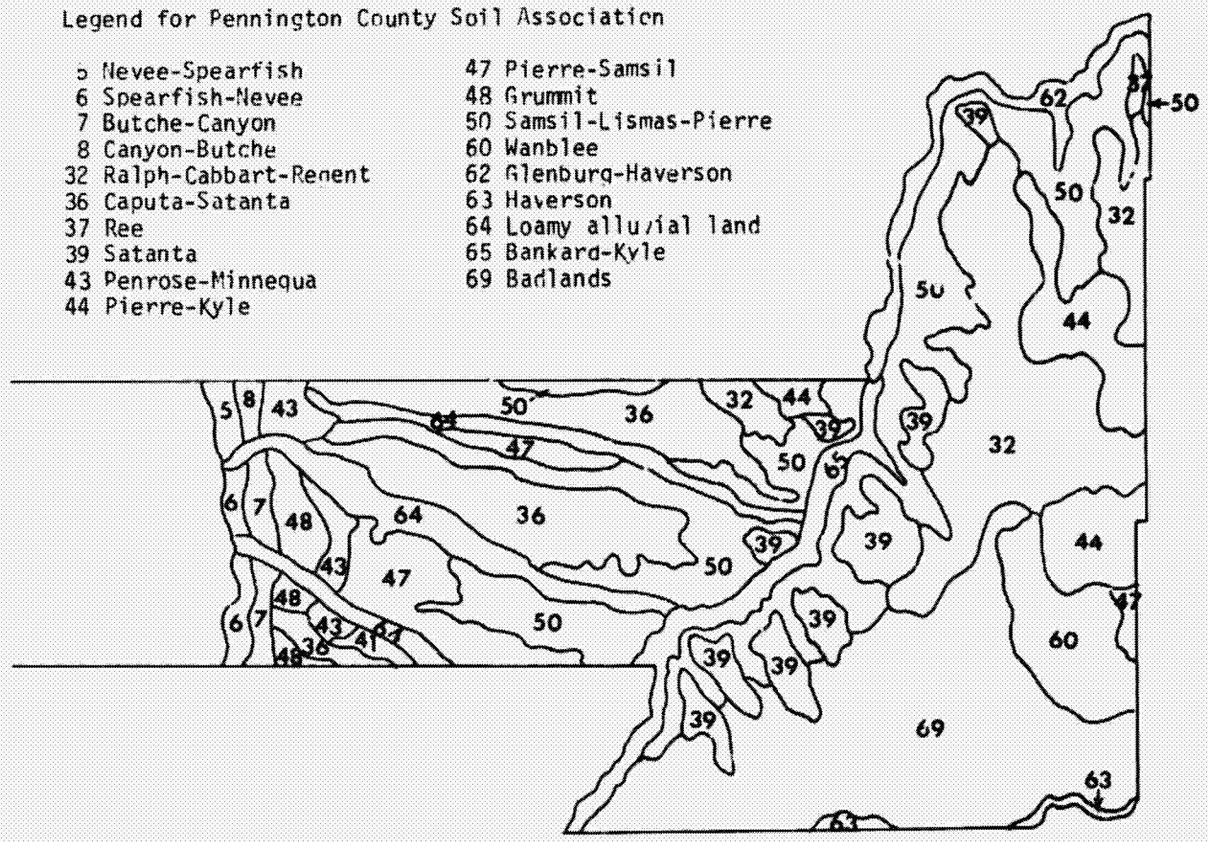

Figure 14. Current soil association map of eastern Pennington County (Westin and Bannister, 1971). Original scale = 1:500,00.

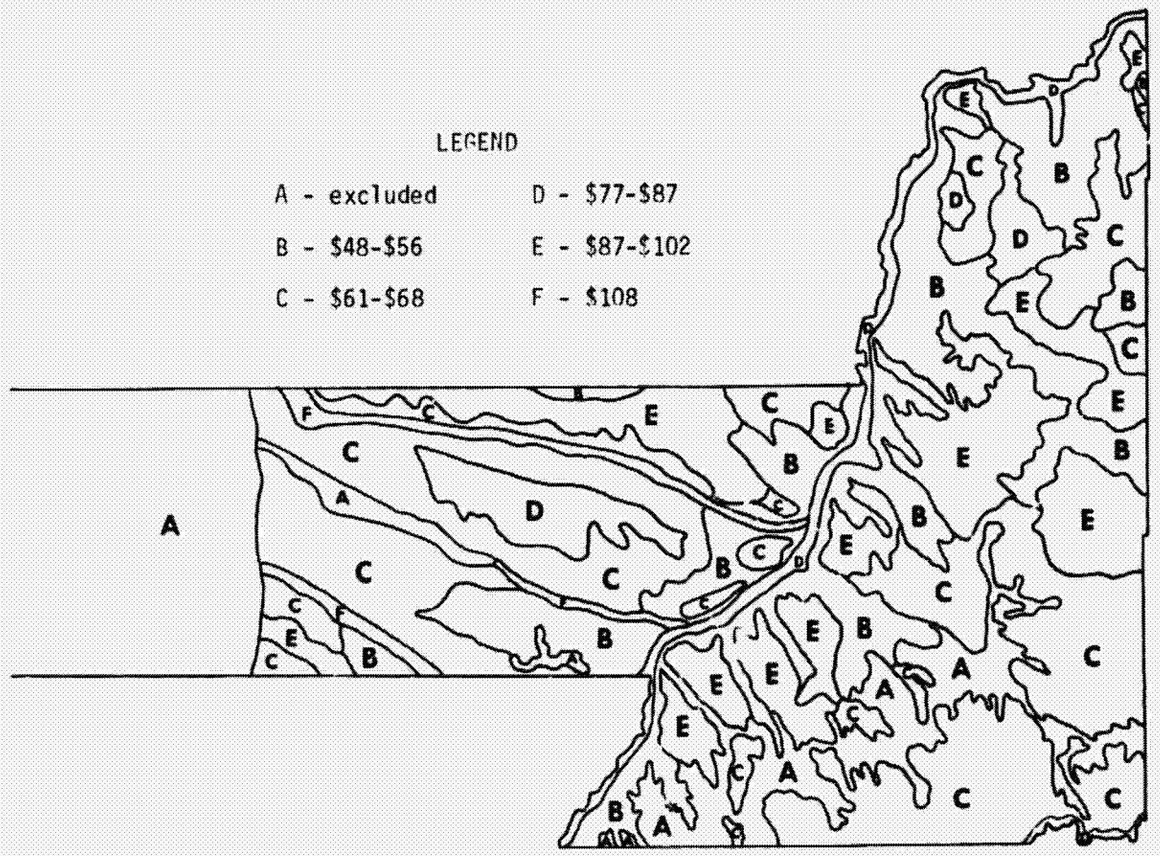

Figure 15. Land value map of eastern Pennington County.

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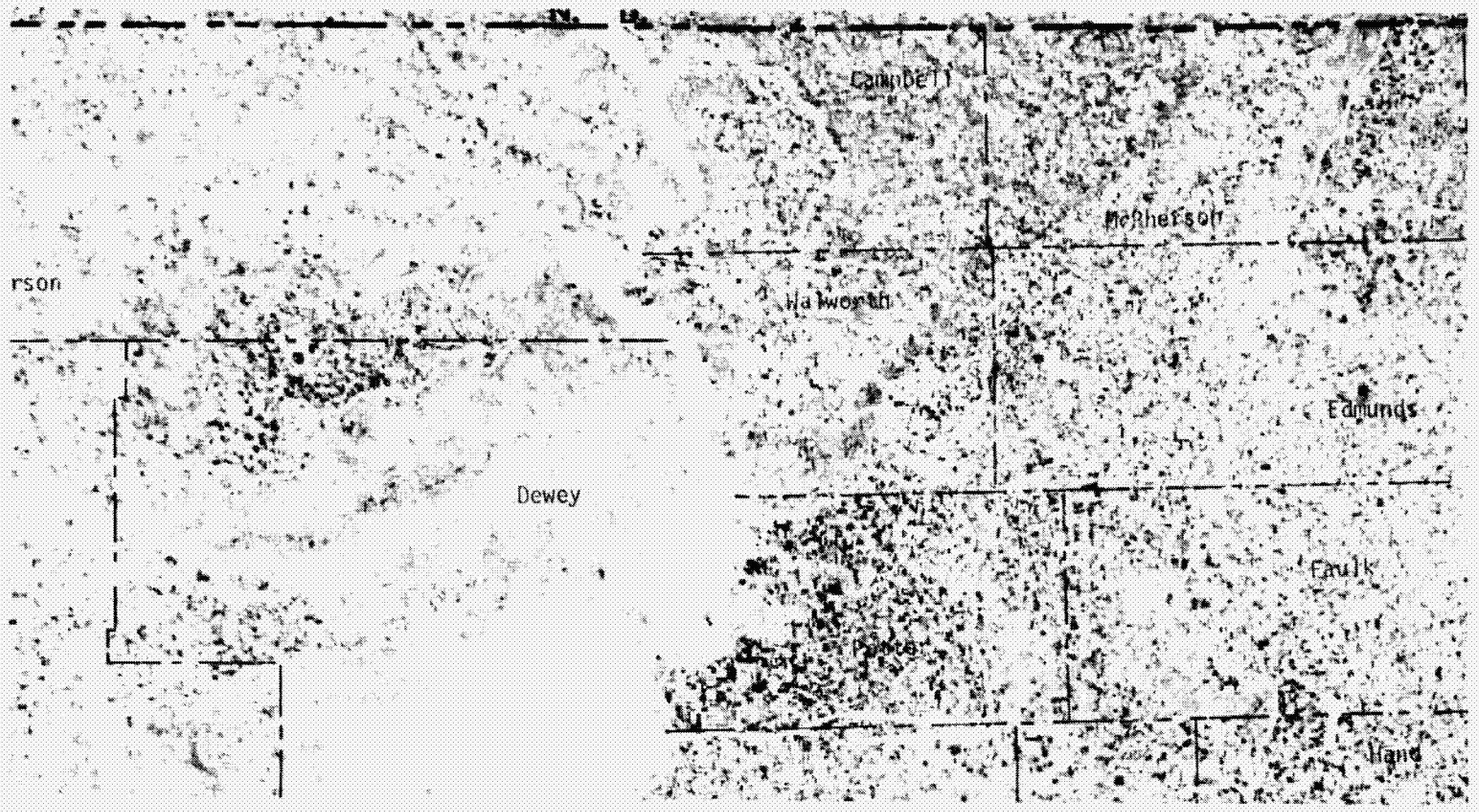

Figure 16. Part of LANDSAT-1 mosaic with soil association boundaries-north central South Dakota. Negative print. Scale about 1:1,000,000.