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Correlation of Spectral Classes Derived from Landsat MSS Data to Soil Series and Soil Conditions for Jasper County, Indiana

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Abstract

The process of soil survey has been an on-going program in the United States since the early 1930's with aerial photography greatly increasing the speed and accuracy of the survey. Recent innovations in remote sensing techniques have offered the soil scientist a tool to aid in surveying the soils of this country and the world.

The launch of the Landsat satellites has prompted numerous investigations into the applicability of the satellite spectral data to soil survey and mapping. Recent work utilizing computer-aided analysis of Landsat MSS data resulted in a spectral soils map of Jasper County, Indiana. This map displayed fifty-two spectral classes which represented the soils found within six distinct parent material areas.

A correlation of the spectral classes with the soils and soil conditions was achieved by inventorying soils on twenty-eight 160-acre randomly chosen sites. The soils data and spectral data were manually overlaid and a dot grid count was made to determine the relative percentages of soils within each spectral class. From these percentages a descriptive legend was developed identifying the dominant soils represented by the spectral class as well as soils that represent significant inclusions.

In addition to developing a legend for each spectral class, various factors involved in the analysis and interpretation of remotely sensed data for soil survey were identified. These factors included: soil-vegetation complexes, crusting of the surface soil, subhorizon exposure, soil surface moisture, organic matter content, texture, and free sand on the surface. Of these, soil-vegetation complexes presented the most widespread problem in interpreting the spectral data. The other factors all altered the spectral response of the soil to some degree, but their influence appeared rather localized.

The results of the spectral classification with the associated correlation will be used along with the aerial photography for the soil mapping investigation. These additional data will conceivably aid in auger placement and soil boundary delineations, hence reducing the time and expense of the soil survey.

INTRODUCTION

Soil surveys have become an increasingly used data input to agricultural, land use and resource planning decisions (4). As population and growth pressures increase, so does the need for timely and accurate soils data.

Soil surveying began in the 1900's by using plane tables to draw both a base map and a soil map (56). In the late 1920's aerial photography was instituted to aid in soils mapping (13). These photos were used by the soil surveyor for ground location and as an additional source of information by using the technique of photointerpretation. They were also used as a base map for drawing soil boundaries. They are still so used today.

Drawing such boundaries on the photography is, however, a subjective procedure. Boundary placement depends on field investigations, the quality of the photograph and the experience of the soil surveyor. If there was some technique that could reduce the subjectivity of boundary placement, the accuracy of the soil survey could be greatly enhanced. If this same technique could aid in the placement of soil auger borings, the number of borings as well as the area traversed by the surveyor would be minimized. The borings could be placed in areas that were relatively homogeneous hence representative of the dominant soil conditions in the area. Transitional zones and confusing areas would be recognized, therefore, aiding in making decisions on the soil unit to be placed on the map. Soil inclusions and complexes would be readily mapped. This would be of great benefit to the user of soil survey information since it is reported that presently the economically feasible level of mapping leaves 30 to 40% soil inclusions within map units. This is significantly higher than the normally accepted 15% level (50). Other studies support this by reporting that many delineations do not adequately represent conditions as stated in the map unit description (2, 38).

Previous investigations have demonstrated the utility of Landsat imagery in the preparation of soil association maps at the county and state level (33,45,53,58,68,69). Other studies have shown promise in identifying such soil parameters as natural, internal drainage characteristics, organic matter differences, textural differences, and differing cultural practices (31,58,59).

Few studies have investigated the use of Landsat data for delineating soils at a more detailed level. Kirschner, et al. (29) concluded that, for a study site in Indiana, digital analysis of Landsat data provided an additional source of information for the soil surveyor and promises to be an aid in the placement of soil borings and for delineating inclusions. Kaminsky (26) investigated various techniques for producing a detailed soils map by digital analysis of Landsat data. Such digital analysis of the multispectral Landsat data results in unique spectral classes. These classes can be separated into soil and not-soil classes by various techniques (26). Prior to correlation, these spectral classes have very little soil information associated with them hence rendering them virtually useless for interpretation and planning purposes. It was the purpose of this study, therefore, to investigate methods by which these spectral soils classes can be correlated to the actual soils occurring in the area. The spectral soils map and the resulting correlation is not meant to replace the traditional process of soil survey. It will, hopefully, be used as an aid by the field soil surveyor to increase the accuracy and decrease the subjectivity of the soil survey.

To achieve this soils correlation, a previously produced map delineating the spectral characteristics of the soils for the six parent material areas of Jasper County, Indiana was used. A methodology was developed that promises to be the basis of a rapid way of correlating soils to spectral data over a relatively wide geographic area. This technique will determine the basic soils correlation which will provide the soil scientist and resource planner with a basis for making soil related decisions. In addition, some of the problems in using Landsat data for soil survey were investigated. Finally, the method that was developed may lead to a more intensive investigation into methods for estimating the accuracy of maps produced from remotely sensed data for soils and other purposes.

LITERATURE REVIEW

Soil can be defined as a collection of natural bodies on the earth's surface, in places modified or even made by man of earthly materials containing living matter and supporting or capable of supporting plants out-of-doors (57). Soils have a unique combination of both internal and external characteristics that have definable ranges (56). Soils, therefore, are individuals that are related as a continuum, with each individual occupying a three dimensional piece of landscape. After these soil individuals are identified and their relationship to the environment and each other defined, the actual boundary can usually be drawn by careful observation of the landscape (56).

The soil survey has been an ongoing program in the United States since the early 1900's. At the beginning, soil surveys were made using a plane table to draw both a base map and a soils map (51). With the advent of aerial photography taken expressly for soil survey (13), the accuracy of such boundary placement and landscape observations have been greatly improved. Since the late 1940's aerial photography has been used by the field soil scientist to extrapolate detailed field observations to large areas and has greatly increased the economics of effort required to obtain soil information (20). Because of the use of aerial photos ground mapping of soils has progressed to the point that more than twenty million hectares are mapped annually at a cost of approximately one billion dollars (19).

Many types of aerial photography have been investigated as to their use in soil mapping. Black and white photography offers the advantage of a stereoscopic view of the terrain but has the disadvantage of having a limited range of photographic tones (8). Color and color infrared photography has been investigated for such soil properties as color, internal drainage, and moisture as well as soil boundary delineations (21,32,42,46,47). It has been determined that color and color infrared photos are better than black and white because tonal problems are less severe (18). Soil boundaries are more accurately delineated on color than black and white aerial photos. Even though improvement has been noted for some soil characteristics, a comparison of color, color infrared, and black and white for distinguishing such parameters as soil series, land types, drainage, and organic matter showed no significant differences between these products (18).

Multi-emulsion and multiband photography have also been investigated for their applicability to remote sensing surveys. In multi-emulsion photography densities in the three emulsion layers are measured in order to quantitize the tonal variations. From these variations interpretations are made. Differing filter and film combinations result in multiband photography which display information in discrete wavelength bands. Microdensitometer measurements of such photography reveal that soils have a relatively high spectral response in the thermal infrared, a varied response in the visible portion of the spectrum, and a low response in the reflective infrared.

Digitization of photography has also been investigated. When compared to conventional photointerpretive techniques, however, there was no significant improvement due to the digitization of the photography (5).

In recent years non-photographic remote sensing devices have been investigated to determine their utility to the process of soil survey. Results using radar, an active system, indicate that the most important variables are moisture (which affects the dielectric constant) and surface roughness. Conclusions are that actual pedological information cannot come solely from radar imagery but from collateral information such as field surveys and knowledge of the soil scientist. The greatest promise for radar systems appears to be in the arid or semi-arid environments because of the relative lack of interfering vegetation or the perennially cloudy tropic and arctic zones because radar can penetrate such clouds.

The increasing need for soil surveys has led to the investigation of other non-photographic remote sensing systems such as the optical-mechanical scanners. These scanners range from aircraft borne scanners of twelve, thirteen, or even twenty-four channels to the four channel scanners on board the Landsat family of satellites. The advantages of the multispectral sensors are that the information gathered is sampled in discrete bands and recorded on computer compatible magnetic tapes. This allows for quantitative information extraction unlike typical photointerpretation.

The multispectral data collected by the Landsat satellites provide spectral information in four wavelength bands: 0.5-0.6, 0.6-0.7, 0.7-0.8 and 0.8-1.1 micrometers, with each data point representing 0.45 hectares. These data are collected in a sun-synchronous polar orbit and allow repetitive coverage of the globe. Such satellite data, therefore, allow relatively rapid assessment of large areas and detection and enhancement of relatively subtle spectral variations among features using statistical analysis techniques (35).

There have been two avenues of research in multispectral remote sensing as it applies to soils. First is the investigation of the inherent spectral properties of soil such as the effect of clay and organic matter on reflectance. The second is investigating the use of multispectral data for soil inventory using both image interpretation and digital processing of the data. It is the intent of these two avenues of research to reach a common ground so that the knowledge of how the properties of soil affect spectral response can be applied to soil mapping using multispectral scanners.

In an overall study of the spectral properties of soils Condit (16) attempted to classify the spectral reflectance curves of one hundred and sixty soils sampled from various places within the United States. Condit measured the spectral reflectance of the soils from 0.32 to 0.80 micrometers using a Cary Recording Spectrophotometer Model 14 and from 0.8 to 1.0 micrometers using a Beckman DU Spectrophotometer. He was able to classify the resulting spectral curves into three general shapes according to the 1938 classification systems: 1) chernozems, 2) pedalfer-type silts and 3) red quartz and calcite sands.

Many of the basic components of soils such as color, moisture, clay and organic matter have been found to affect the spectral properties of soils. Various investigators have used different techniques to determine these relationships.

Karmanov and Roshov (27) investigated the relationships between the color properties of soil and their physical makeup. They analyzed forty-two samples of cinnamon-brown soils, calcareous clays, and saline gypsum-bearing clay loam. They arrived at three conclusions: 1) close paired and multiple linear correlations exist between the color characteristics and composition of cinnamon-brown soils, 2) color of soils is directly and linearly related to the clay and free iron content and inversely related to the content of humus and carbonates and 3) relative spectral absorption is directly and linearly related to the amount of humus and clay present and inversely related to the carbonate content. Color is, of course, a function of many soil properties.

Organic matter has been found to have a significant effect on the reflectance of soils (1,12,37,40,44). In general, regardless of clay type present, the organic matter appears to lower the magnitude of the spectral reflectance in all wavelengths with no specific absorption bands. Page (44) found that, in the spectral range of his investigation, it was not possible to discriminate between small change in organic matter content by reflectance measurements when organic matter exceeded five percent.

Particle size and structure also has been found to affect reflectance. The conclusions of several investigators (12,41,43) are that reflectance increased with decreasing particle size. Reflectance also increased from those soils displaying weaker structure.

Clay type has been found to affect reflectance (25,37,40,41). The type of clay influences the shape and intensity of the spectral reflectance curve in the 0.5 to 2.6 micrometer range (37). Hunt and Salisbury (25) studied montmorillonite and kaolinite clays. They found the montmorillonite spectral reflectance curve to have absorption bands at 1.4 and 1.9 micrometers due to bound water. A weaker absorption band, possibly due to absorbed water, was found at 1.16 micrometers. Absorption bands for kaolinite were noted at 1.4 and 2.2 micrometers, due to energy absorption by hydroxyl groups located on the clay. Al-Abbas (1) found significant correlation between clay content and spectral reflectance using stepwise multiple regression and polynomial analysis. He was able to map five levels of clay content in a study area in Tippecanoe County, Indiana.

Soil moisture has been found by numerous investigators to decrease the amount of soil reflectance (7,12,14,37,48,61). The soil reflectance decreases significantly with increasing soil moisture content due to darkening of soil color and energy absorption.

Other physico-chemical properties have been found to be correlated with soil reflectance. Montgomery (40), using multiple regression analysis, showed that in addition to clay and organic matter, cation exchange capacity, silt, and Fe_2O_3 were highly correlated with spectral reflectance. Mathews (37) found that organic matter, silt and Fe_2O_3 influenced the intensity of energy reflected by soils in the 0.5 to 2.6 micrometer range. Organic matter and Fe_2O_3 showed a particular influence in the 0.5 to 1.2 micrometer range.

All of the above research has been done in the laboratory using various types of spectrophotometers with the intent of characterizing the reflectance characteristics of soils, hence allowing better mapping of soils through remote sensing techniques. Research in mapping techniques has ranged from image interpretation to computer-aided analysis of multispectral digital data.

Image interpretation started with photographic products as described previously. Interpretation of non-photographic images, such as Landsat images, has been a relatively recent innovation. Soil association maps of single counties up to entire states have been produced with the aid of Landsat images (34,57,68). Westin and Frazee (69) produced a soil association map of South Dakota in approximately five weeks at a cost of $.02/hectare. Longlois, et al. reported that a Landsat image was used as a base for a soil association map of White County, Indiana. More recently, a parent material map delineating six distinct parent materials was produced using a Landsat image as the main data source (28).

Research into the application of computer-implemented pattern recognition techniques for soil mapping has yielded promising results. Early work with aircraft multispectral scanner data showed that such soil parameters as texture, color, moisture relationships, and soil types were distinguishable using pattern recognition techniques (6,36).

Initial investigations were conducted with twelve channel scanner data collected at aircraft altitudes. Mathews, et al. (36) found that limestone, sandstone, and local colluvial soils could be separated with a high degree of accuracy. Erosion classes were also separated to some degree. Kristof (30) found that he could map six different categories of soil surface conditions with reasonable accuracy and felt that these mapped soil categories would be a great aid to professional personnel in soil mapping. His conclusions were that observations of actual surface moisture, erosion, organic matter content, and surface roughness factors would have greatly aided the interpretation of the data. Cipra, et al. (15) found that spectral data collected along a twelve mile aircraft flightline could be divided into three spectrally separable classes. These three classes corresponded to some extent to management groups. Cipra concluded, however, that a one-to-one correspondence between soil survey mapping units and discriminable spectral classes is unlikely for glacial soils of western Indiana.

Kristof and Zachary (31), using aircraft data, were able to identify gross variations in soil features. Variations in soil tone could be seen as well as features related to soil tone such as drainage patterns and organic matter content. They did find problems in extending spectral training samples from one area to another. Kirschner, et al. (29), in a study on a 430-hectare site in Indiana, were able to differentiate soil drainage classes by digital analysis of Landsat data. The conclusion was that correlation of drainage characteristics with soil series allows for the composition of soil map units to be accurately ascertained. Stoner and Horvath (60) found that organic matter content, texture, color, and soil type could be displayed on a computer map of classified aircraft data. Cultural practices such as plowing and disking as well as the amount and kind of vegetative cover were found to affect the multispectral response of surface soils.

Recent work by Weismiller, et al. has shown that combining ancillary data in the form of physiographic boundaries with the classified Landsat spectral data can greatly enhance the usefulness of the spectral data (67). In this study this technique allowed for a better correlation of soils with the spectral classes.

Using the idea of combining ancillary data with spectral data, Kaminsky (26) produced a spectral soil map of Jasper County, Indiana using computer-aided analysis of Landsat data. The county was divided into six parent material areas through image interpretation of Landsat data and the final classification done exclusively within each parent material area. Her conclusions are that these parent material areas contribute to a more representative statistical classification of a county spectral soil map. Drainage characteristics, textural differences, organic matter differences, erosion and scattered vegetation were significant contributors to soil responses. In general, Kaminsky felt that the spectral map produced could be used in the future county soil survey.

It appears, then, that remote sensing products can be a great aid in providing an additional tool for the soil survey process. Of particular promise is the computer-aided analysis of digital Landsat data.

Accuracy Checking of Spectral and Soil Maps

In most instances the accuracy of spectral maps has been evaluated in general ways by comparing spectral classes to broad land use classes. In remote sensing of soils, the comparison was generally made by visually comparing a conventionally prepared soils map with the results of a spectral classification.

More quantitative work has been attempted particularly in the area of land use map accuracy determination. In most instances multistage sampling procedures have been used to sample before and after the spectral classification. This, along with several stages of subsampling using low and/or high altitude photography and/or ground data acquisition was used to rapidly check land use interpretation (63).

Stratified random sampling techniques have also been used as a means of checking land use maps. In a study of a semi-arid area, van Genderen and Lock devised a method to rapidly check a land use classification (63). Their conclusions were 1) stratified random sampling is the most appropriate method of sampling to use; 2) there is no established method for determining the ideal number of sample points, hence they developed a special method to overcome the problem; 3) size of the "sample point" should be established after considering the minimum mapping unit and image resolution. For their investigation, a 250m x 250m sample size was adopted as the size of the sample point.

Other studies have also attempted to quantify remotely sensed map accuracy. Hord and Brooner (23) investigated classification, boundary line placement and control-point placement for land-use maps. They sampled one acre points with replacement, ground checked them and related the results to the photo-interpreters classification for a fifty-six square mile area. They then could calculate a confidence interval for each land use class. Their work was done with aerial photography.

Many investigators have researched means of checking the accuracy of soil maps. The techniques used can be divided into three categories: 1) grid sampling, 2) transect sampling and 3) area sampling.

Soil scientists in the United Kingdom often use grid sampling to check the accuracy of their soils data. Webster and Burrough (64) sampled twenty soil properties at 100 meter grid squares for two rectangular areas 1400 x 1400 meters in size. Beckett (8), in an overview of soil survey in Britain, felt that it is desirable to measure soil properties in a grid survey particularly because a non-professional staff could do the work. Beckett claimed that, at scales of 1:500 to 1:2000, the surveyor can achieve 80 to 90% precision using the grid sampling technique.

Transect methods have also been used by numerous investigators. Transects are either randomly followed in the field, referred to as a free survey by Beckett (8) or they are predetermined transects, i.e., one where the direction is set before the survey begins traversing the field. Predetermined transects have been used to determine such things as kind of mapping unit, intricacy of soil pattern, soil boundaries, and variation in soil parameters (clay, pH, etc.)(9,10,11,64).

Powell and Springer (50) describe two methods of transecting: 1) the line-intercept transect and 2) the point-intercept method. The line-intercept is quicker if the mapper can recognize the kind of soil without boring into it. The point-intercept method is needed if the soil boundaries are not easily observable.

Powell and Springer describe the two methods as follows:

1) In the line-intercept method, the surveyor selects the direction of the transects at random. Starting at one edge of the area he walks along a straight line in a pre-selected direction, counting his steps. He notes the number of steps taken at each boundary between kinds of soil and records the number in a notebook. Upon reaching a pre-selected point, or the far boundary of the study area, he stops, records the total number of steps at this point, and selects at random the direction of his next transect. After several transects have been measured in this fashion, the results are totaled and averaged to obtain the proportions of each kind of soil.

2) In the point-intercept method, the surveyor first selects at random the directions of his transects. Instead of counting steps and noting where the soil changes, he stops at regular intervals such as every fifty steps. At each stop, an auger boring is made and notes taken on the soil. After a number of transects are made, the results are totaled and a proportion of each soil determined.

In their study Powell and Springer used the point-intercept method to transect sixteen randomly selected 160 acre blocks of land to determine the composition and precision of classification of several mapping units. Amos and Whiteside (2) used the same technique to determine the composition of twelve mapping units in south-central Michigan. Transects were taken at 500 foot (152.2m) intervals with observation points at 250 foot intervals (76.2m). They concluded that the naming of series could be refined using this transect technique.

Hajek (22) in a study in Alabama used a random point-intercept method for evaluation of relatively large mapping units (300 acres or greater). He concluded that, at this level of mapping (order two or three--previously referred to as reconnaissance mapping), many mapping units in a survey area can be characterized with less than ten transects at 80% confidence.

Thompson (62) used an offset lateral transect on six 160 acre test sites. Transect lines were 528 feet apart as were the observation points. A soil boring and a complete morphological pedon description were made for each of the preselected observation points.

While the investigators mentioned have utilized the transect methods in their studies, there has been some indication that this method might not be adequate. White (70) calculated that for an area having an average soil map delineation of thirty-two acres, at least 150 miles of transects would be needed to accurately estimate the composition of one mapping unit. This would make the time and cost needed to adequately estimate the composition of one mapping unit prohibitive. Even if the average map unit size is significantly smaller than thirty-two acres, it is obvious that the length of transects needed for accurate determination of mapping unit composition is prohibitive.

MATERIALS AND METHODS

It was the object of this study to correlate the spectral soils classes derived from Landsat data and the soils found county-wide. The ideal method of doing this would, of course, be to check every data point at every soil location, therefore arriving at a one-to-one correspondence. This is, however, an impossibility. The practical way of doing such a correlation is to devise a county-wide sampling plan that will allow for sampling of soils and spectral classes, hence extrapolating over the entire area. This technique, by its very nature, approaches accuracy checking of soils and spectral maps.

Data

The spectral data used for this investigation was that collected over Jasper County, Indiana. These data had been classified using computer-implemented processors as described by Kaminsky (26). For a detailed discussion of the techniques used for the classification the reader is referred to that work.

The Landsat data were collected 9 June 1973 at 10:00 a.m. local time at an altitude of 3,588,090 feet. The data chosen for classification were relatively free of vegetative cover, interfering clouds, and other undesirable features.

Photographic data were collected in May of 1976 at an altitude of 6000 feet. The resulting block of eighty-five photos were at a scale of 1:15,840.

Using these photos as a base, the Landsat data were rectified in a north-south direction and precision registered to ground control points. The spectral data were rescaled to 1:15,840 to make them compatible with the aerial photography. When the scale was expanded, essentially a "rubber sheet stretch," holes appeared in the data. Extra data were created to fill these gaps. For this set of Landsat data a cubic convolution resampling algorithm was used. Kaminsky (26) described it as an algorithm where the intermediate data values were calculated using a Lagragian third order equation that used a 4 x 4 matrix or sixteen spectral points. On the curve of this equation intermediate data values were plotted and used in expanding the scale. This method had the effect of smoothing the image which could contribute to a somewhat less accurate classification but would provide a more suitable map for soil mapping. Classes that are very close spectrally could lose their distinctness because of their calculated intermediate values. The final accuracy resulted in a one foot error in 751 feet in the east-west direction and a one foot error in 1088 feet in the north-south direction. This represents a 0.1% error in registration.

Since the rescaling of these data, a technique has been devised to increase the scale of the final classification map by using an electrostatic printer/plotter. This eliminates the need for rescaling the data prior to classification.

Geology of Jasper County

While glacial deposits from the Kansan and Illinoian age cover all of Jasper County, it is the effect of the Lake Michigan and Erie glaciers of the early Wisconsin age that dominate the surficial geology of the county. Underlying all glacial deposits are tertiary and quarternary bedrock valleys which are filled by quarternary debris. Coral reef domes, possibly of Silurean or Devonian ages are evident in the western part of the county. These domes sometimes occur within one or two feet of the surface (55).

Three distinct glacially deposited parent materials are present in Jasper County: outwash, till, and lacustrine.

The outwash deposits found consist of assorted materials that were deposited by rivers, streams, and lakes that were present during the glacial period. These materials are mostly stratified sand and gravel. Sand ridges, occurring in the northern section of the county were formed by the action of the wind on the outwash material.

The glacial till is the non-assorted material deposited by the glacier. It is generally a mixture of pebbles, sand, and clay and a few large stones. There are three separations of till found in the county. These are: 1) rolling moraine consisting of undulating topography where the slopes are dominantly 4-10%, 2) ground moraine area where Mollisol soils predominate and 3) ground moraine area where Alfisol soils predominate. The ground moraine areas are nearly level to gently sloping with slopes being less than 4%.

The lacustrine area has typically flat topography. Shorelines of what were the larger lakes are characterized by beaches, bars, and sand dunes. The lacustrine soils are underlaid by clays and silts that are distinctly stratified.

A unique area lies in the northeastern part of the county. In this area both outwash and till have come together. This outwash over till area is characterized by having an underlying material similar to the material found in the rolling moraine area. Over the till, outwash deposits of varying thicknesses occur. The result is that the area is predominantly outwash on the surface but is interspersed with knobs of till material showing through where the outwash material is thin. These knobs are generally an acre or less in size.

Organic deposits are interspersed throughout the county, particularly in the outwash areas. They were not extensive enough to be separated.

Classification of Spectral Data

Based on the results from a previous study Kaminsky stratified Jasper County by parent material type and classified the spectral data within each parent material area separately (26). The parent material map had been produced by image interpretation of the Landsat data and verified by field investigation. The lines separating the parent material boundaries were digitized onto the Landsat data, hence allowing for isolation of the spectral data by parent material type. The parent material map is presented in Figure 1.

The spectral data were then classified using computer-implemented processors. The technique used consisted of sampling every fifth line and column in each parent material area which represented about four percent of the spectral data. These samples were analyzed by computer-aided statistical analysis procedures. The resulting statistics deck was used as input to a classification algorithm which classified the spectral data into spectrally separable classes within each parent material area. The resulting classification was used as the spectral map input to this study. For an in-depth description of the parent material stratification and classification procedures, the reader is referred to the work of Kaminsky (26).

Selection of Sample Areas

It was obvious that, due to temporal and fiscal constraints, a sampling plan would have to be instituted. It was decided that a sampling system similar to that used for the 1958-1960 Conservation Needs Inventory (CNI) of the Soil Conservation Service should be employed. In that study, thirty-three quarter sections (160 acres each) were randomly chosen throughout Jasper County by the Iowa Statistics Laboratory. The location and old soil maps of these areas were obtained from the Soil Conservation Service office at Rensselaer, Indiana.

Initially, it was thought that the CNI mapping could be used as an additional source of soils data. However, field investigation revealed that many of the CNI quarter sections did not contain the detail desired in this study.

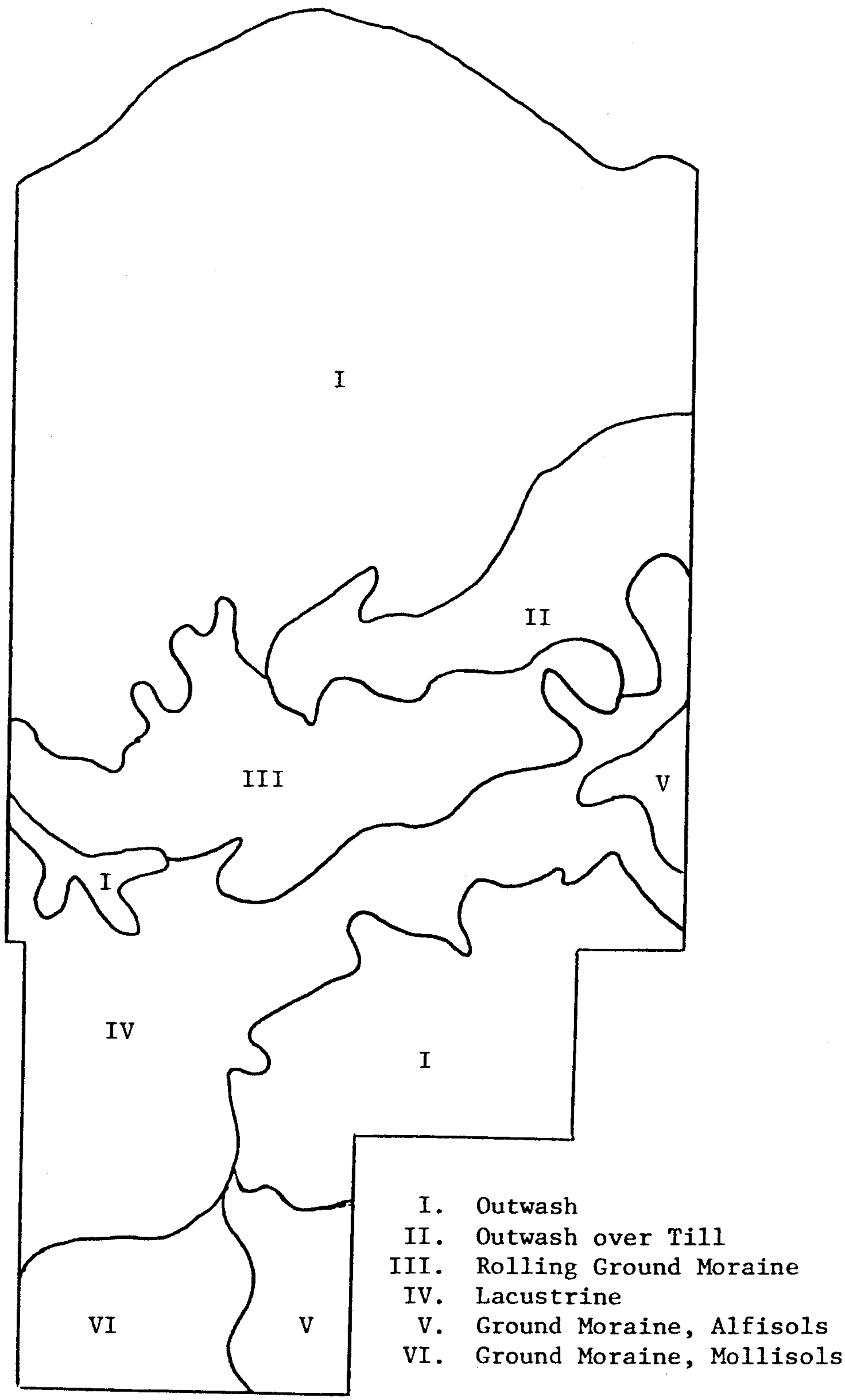


Figure 1. Parent Materials of Jasper County.

In addition, different names of the soils were used when this mapping was done, hence making the conversion to current soil names difficult and unreliable. Field and soil conditions were not evident on the CNI maps, therefore eliminating any means of hypothesizing the differences in soil spectral responses.

A random selection of quarter sections to be mapped was performed in the southern and northern part of the county. To make the sampling area more complete some of the quarter sections that had been selected for the CNI study were selected for remapping. All areas mapped are shown in Figure 2. The total area mapped in this study was 4480 acres which is approximately 1.25% of the county. Table 1 shows a breakdown of quarter sections sampled by parent material area.

Table 1. Acreage of Quarter Sections Sampled.

Parent Material Area	Approximate Acreage	Acreage Mapped	Percent
Outwash	202,040	1600	0.79
Outwash over till	26,880	480	1.79
Rolling moraine	35,840	480	1.34
Lacustrine	63,360	960	1.53
Ground moraine Mollisol soils	16,640	640	3.85
Ground moraine Alfisol soils	14,080	320	2.27
TOTAL	358,840	4480	1.25

The low percentage for the outwash area occurred because of the relatively high amount of acreage of the outwash in the county. The high percentages for the two ground moraine areas occurred because these areas are relatively small; yet it was felt that at least two quarter sections should be mapped for each parent material area.

Once the areas were located on the photos, they were located on the spectral map. This was accomplished by locating the approximate area of the quarter section on the gray scale map, noting the line and column coordinates and printing this portion of the map. This map was then overlaid onto the appropriate photo and the boundaries of the quarter section precisely located on the Landsat data. This was done by comparing distinctive vegetative features, man-made features, and soil patterns.

Collection of Soils Data

The spectral soils information was, as previously indicated, a fixed factor. The soils information gathered was to be compared to this spectral data for correlation of the soil spectral classes with actual soils. Two

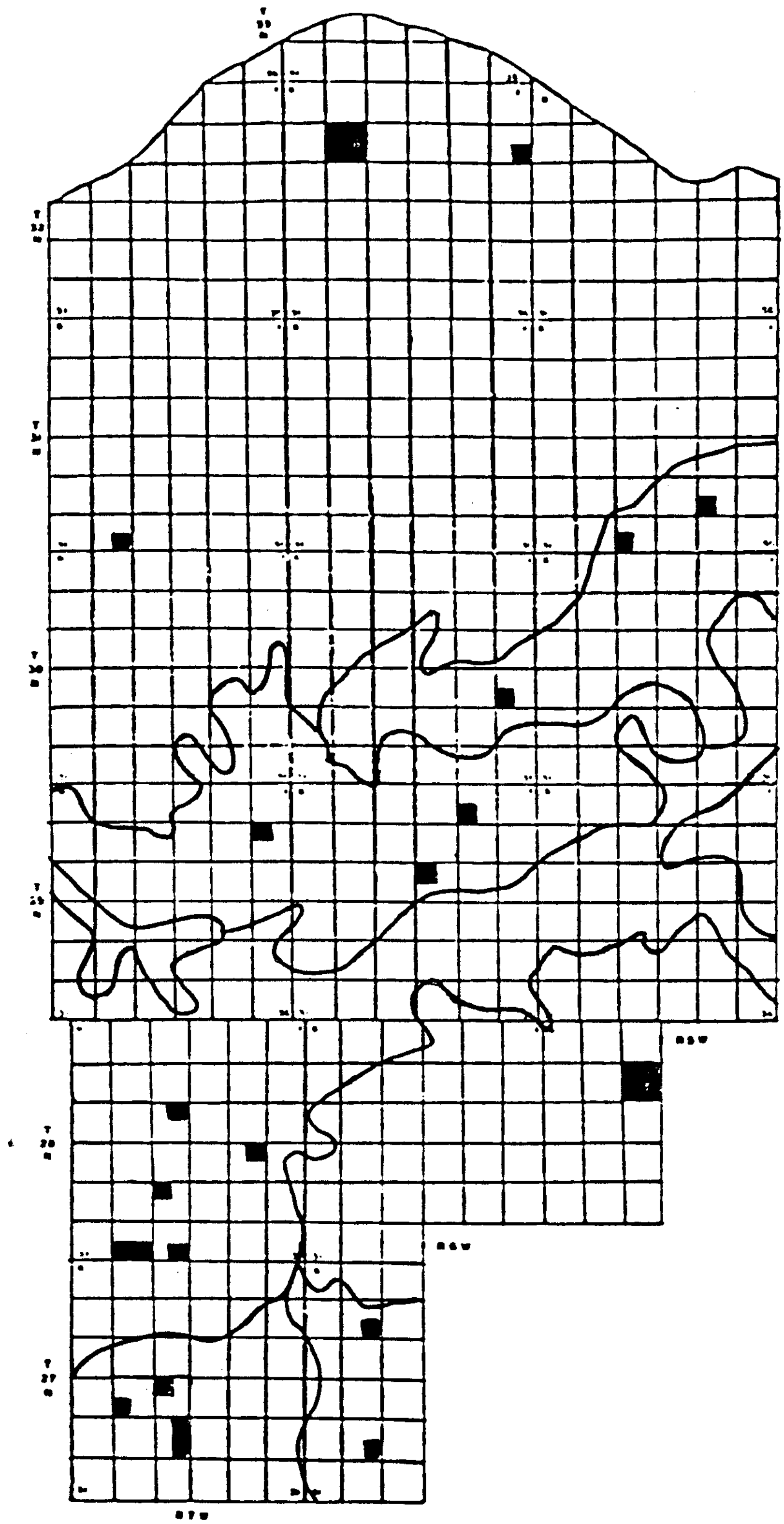


Figure 2. Location of Quarter Sections Mapped.

areas were investigated to determine the proper technique for gathering soils information and relating it to the spectral map. The first was to review the work of others in testing the accuracy of spectral classifications. The second was to explore those techniques that have been applied to checking the accuracy of soils maps.

None of the accuracy checking studies that have been done by other investigators, as reviewed earlier, were suited to this investigation. The methods employed for land use map accuracy checking were either too general, being a visual comparison only, or if quantitative, were not applicable to soils since the land use maps were dealing with relatively large areas.

In this study an initial investigation of soil map accuracy checking was made using both the line- and point-intercept transect methods. The grid survey method was rejected because it was felt that this method would not adequately represent the diversity of soils found in Jasper County.

The line-intercept method was tested on a 160 acre tract of land in the outwash area. The transects were parallel and spaced 500 feet apart, with the direction randomly determined before going into the field. This method was rejected after the initial investigation due to difficulty in noting the differences in the soils solely from the surface features.

The point-intercept transect method was also investigated. In this study the transects were again parallel (500 feet apart) and randomly oriented. The observation points were taken at 250 foot intervals along the transect lines. After field testing, it was felt that this method also was not adequate for correlation of soils to the Landsat spectral map for the following reasons: 1) the Landsat data have the characteristics of separating small differences which may be important soil characteristics but may not be noted in a transect sampling scheme, 2) due to lack of ground control points in some areas the transects could not be located accurately enough on the ground, hence leading to significant error, and 3) even if the transects could be located accurately on the ground, they could not be accurately correlated to the corresponding area of Landsat data. This is complicated by the fact that the Landsat data are only registered to within one foot in 751 feet in the east-west direction and one foot in 1088 feet in the north-south direction (a 0.1% error).

The method of free survey, or conventional mapping techniques, and area sampling were employed in this survey. The free survey consisted of walking in a random direction over each 160 acre plot, making soil borings where needed and drawing boundaries on a black and white aerial photo. In addition, the spectral map for the area of concern was used to locate areas displaying a unique spectral class. This method, while lacking the ability for quantification, allowed for sampling the largest area in the shortest amount of time. Specifically, the methodology used for gathering the soils data was:

1) Randomly choose the quarter section from those shown on Figure 2.
2) If the quarter section was one of the reselected CNI sections, a brief check was made of the previous mapping. If there were any discrepancies between those soils mapped in the CNI and what was in the field, the CNI mapping was rejected.

3) An aerial photo (from the 1976 photo block) and the corresponding spectral map were taken to the field. The mapping was done by an experienced SCS soil scientist and the author.
4) The soil series mapped were recorded on the photo and notes made of any differing situations in the field that could affect spectral response.
5) The field mapping and notes were brought back to the office, a final map inked, and an appropriate legend made.

While the majority of the mapping was conventional soils mapping, it was in much more detail than is typical for this area of Indiana where an average of 250-300 acres per day can be mapped. The average rate of mapping is, therefore, 275 acres/day/man. By comparison, the rate of mapping in this study was 160 acres/day/two men or 80 acres/day/man. This is a much slower rate than typical, but it was felt that the accuracy was much better. In addition, areas smaller than three acres are generally ignored in typical field mapping. In this study such small areas were, where practical, delineated.

Determination of Percent Soils for Each Spectral Class

Various ways were considered for quantifying the amount of soils within each spectral class. Counting picture elements, or "pixels," in a study such as was conducted here encounters a few problems. First, in some instances, the pixels will fall on a boundary line, therefore, raising the question of whether or not to count these points. Secondly, by counting pixels and relating them to a soil, the soil is defined as a group of spectral classes rather than defining a spectral class as a group of soils. Based on these problems this method was rejected.

Another method was to draw boundaries on the spectral map and compare them to the soils map on the basis of relative area. This was not done because of the difficulty of accurately computing acreages on small areas and also because of the difficulty of comparing the areas outlined on the spectral map with those areas on the soil map.

The method used was to draw a boundary around each spectral class on the map (Figure 3). These boundaries were then transferred to a clear acetate sheet as represented by Figure 4. This acetate sheet was then overlaid on the soils map that was made by the field survey. A dot grid (64 dots per square inch) was overlaid on both of these sheets (the soil map and acetate sheet). Overlaying of the grid was random in orientation. A dot count of each soil occurring within a spectral class was made. An example is presented in Table 2.

In this example, the darkest soil class, soil 7, is represented. As overlaid on the soils map it is obvious that four soils are present: Chelsea, Starks, Mahalasville, and Rensselaer. The dot grid count reveals a total of thirty-one dots occurring within this spectral class. Of these dots, five are Chelsea, four are Starks, three are Mahalasville and nineteen are Rensselaer. The breakdown of the spectral class for this quarter section is shown (Table 2). The breakdown by drainage would be: 71% poorly drained, 13% somewhat poorly, and 16% well drained. The soil map for this area is shown in Figure 5.

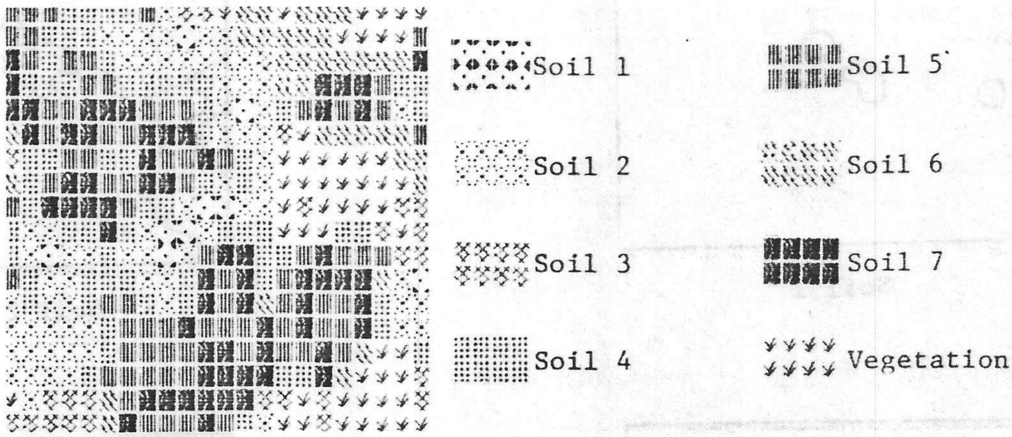
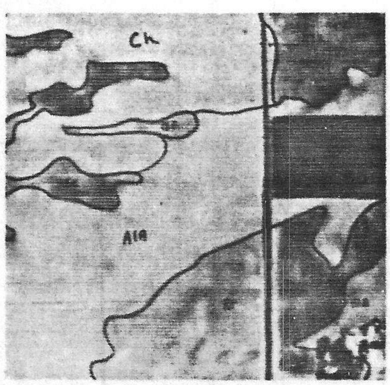


Figure 3. Spectral map of T28N, R7W, Sec. 33, SE¼.



<u>Legend</u>

AlA - Alvin, 0-2% slope
Ch - Chelsea
Gf - Gilford
Ma - Mahalasville
Rr - Rensselaer
St - Starks

Figure 5. Soil map for T28N, R7W, Sec. 33, SE¼.

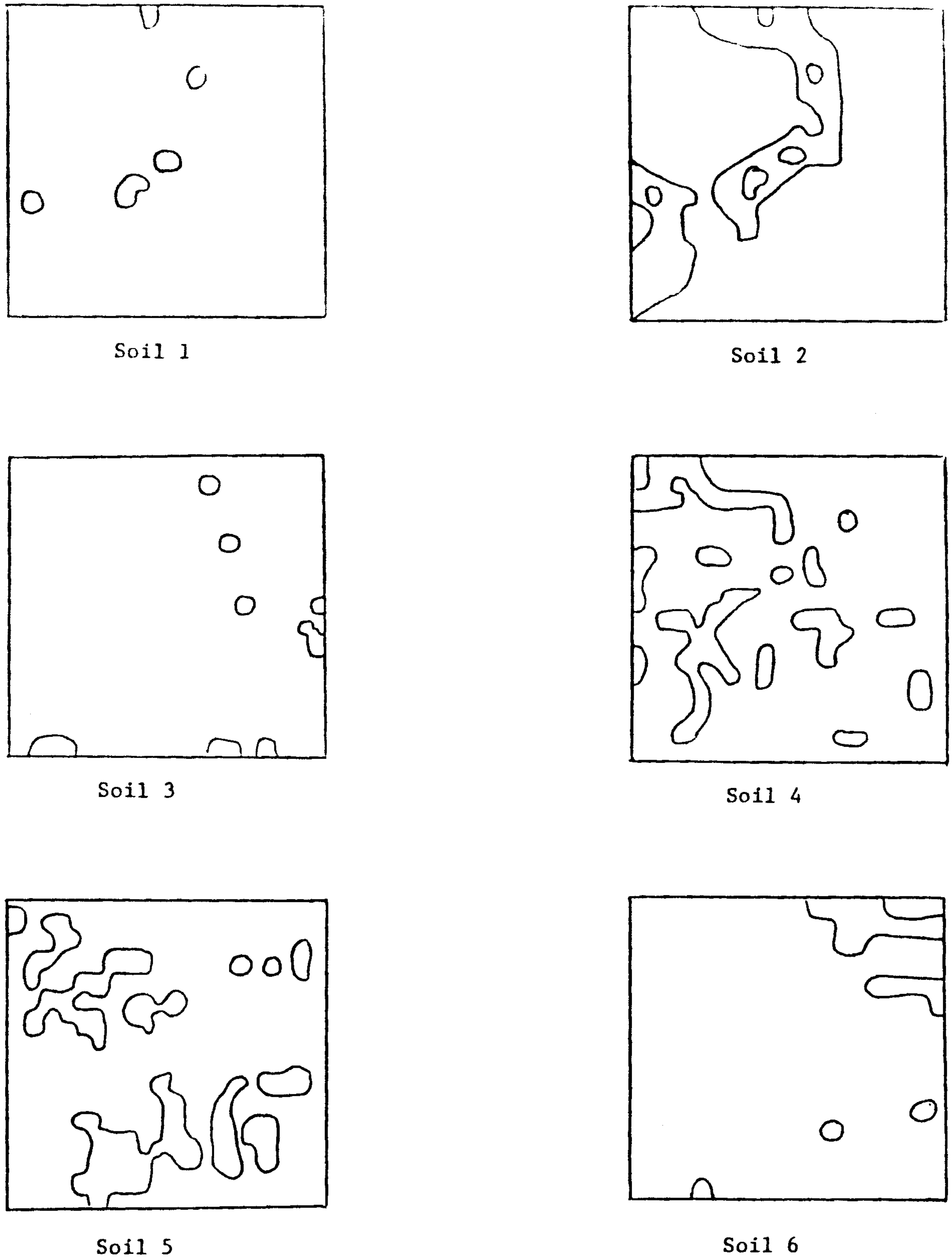
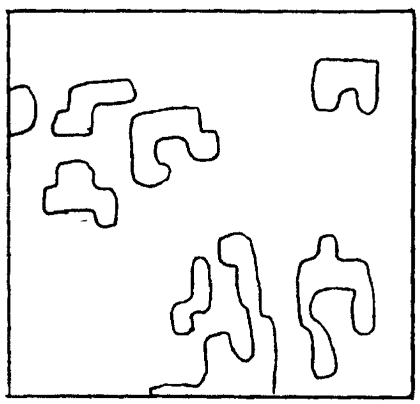
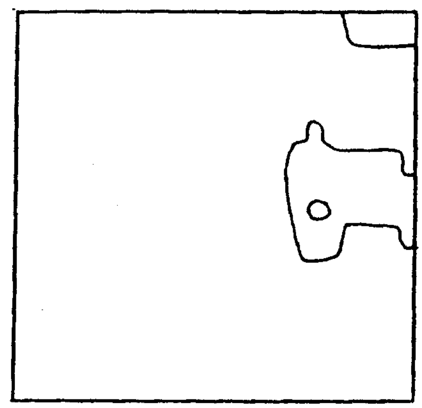


Figure 4. Soil Spectral Classes As Delineated by Boundaries.



Soil 7



Vegetation

Figure 4. (Continued).

Table 2. Example Dot Grid Count.

Soil Class	Well Drained		Moderately Well Drained		Somewhat Poorly Drained		Poorly Drained		Total
Soil 7	Chelsea:5				Starks:4		Rens:19 Mahal:3		
	Dots	%	Dots	%	Dots	%	Dots	%	Dots
	5	16	-	-	4	13	22	71	31

This technique was employed for every quarter section in every parent material area. The dot counts were grouped for those quarter sections in each parent material area and relative percentages calculated. Other comparisons and calculations were made on the basis of these dot counts.

The results of the grouped dot counts are presented in tables in the discussion of each parent material area. Comparisons of all soil spectral classes are made within each parent material area. Due to the subjective nature of the soil sampling technique as well as the inherent variability of soils, statistical analysis procedures were not employed in the study.

RESULTS AND DISCUSSION

A total of twenty-eight quarter sections were mapped in detail by the methods described previously. These areas represented a total of 4480 acres, approximately 1.25% of the county. The results of this mapping are shown on representative quarter sections for each parent material area.

In the discussion of each parent material area, a table showing the summed results of the grid count is presented as is a legend for each spectral class. Possible combinations of soil spectral classes representing similar soils are presented. These combinations are made by displaying the distinct soil spectral classes with the same pattern.

The soils were grouped by their internal drainage classes as defined in Table 3. In all spectral classes soils of differing drainage classes were found although one drainage class predominates. This should be expected since even in the conventional field mapping of soils, inclusions of differing drainage classes are typically found within the named mapping unit.

It does not appear from this study that soil series can be consistently separated using spectral data on a county-wide basis. However, if the internal drainage of the soils of an area can be ascertained and the parent material of this area known, a group of soil series can be predicted. This does, in fact, seem to be a possibility.

The general trend for all soils spectral classes was for the poorly drained soils to have a lower magnitude of reflectance. This can best be seen by comparing the graphs of percent composition versus soil spectral class that accompany the discussion of each parent material section.

Table 3. Guide for determining natural soil drainage class.

Overall Appearance of the Diagnostic Zone When Moist (Ped Coatings)	Closer Examination of Diagnostic Zone (Ped Interiors)	Drainage Class
A. Soils with ten inches or more of dark-colored surface.		
Gray colors	Gray colors predominate in the 6-inch layer below dark-colored soil material.	Poorly Drained
Gray or brownish colors	Brownish colors predominate in the 6-inch layer below dark-colored soil material, but gray mottles are present.	Somewhat Poorly Drained
Brownish colors	Brownish colors with few or no gray mottles in the 6-inch layer below dark-colored soil material, but with gray mottles above 30 inches.	Moderately Well Drained
	Brownish colors below dark soil material with few or no gray mottles above 30 inches.	Well Drained
B. Other soils.		
Gray colors	Gray colors predominate in the 10 to 18 inch layer.	Poorly Drained
Gray or brownish colors	Brownish colors predominate to 10 to 18 inch layer, but gray mottles are present.	Somewhat Poorly Drained
Brownish colors	Brownish colors with few or no gray mottles in the 10 to 18 inch layer, but with gray mottles between 18 and 30 inches.	Moderately Well Drained
	Brownish colors with few or no gray mottles between 10 and 30 inches.	Well Drained

Note: The term "gray mottles" means that more than 2% of the soil material is gray. (From: Understanding and Judging Indiana Soils. ID-72 Pilot, Agronomy Dept., Purdue University. March 1978.)

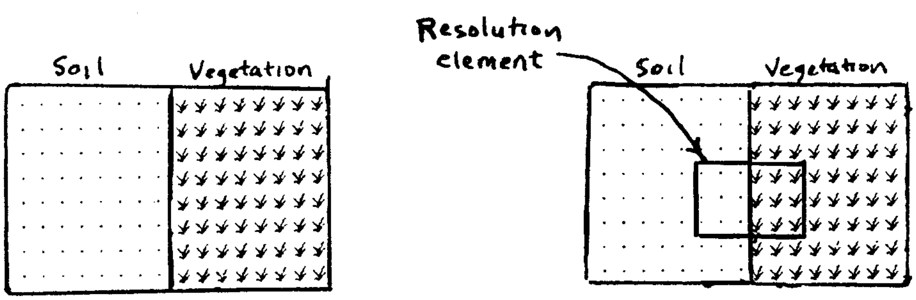
Various confusion factors were also noted in this study. At least one soil-vegetation confusion class was noticed for each parent material area. A soil-vegetation confusion class can be defined as a spectral grouping where the reflectance characteristics of vegetation have been mixed with the reflectance characteristics of soils. These confusion classes are likely to occur in one or both of two ways.

The first way is that the area used as a training area for the spectral statistics may have been planted and the crops were just beginning to emerge. An example using corn is presented in Figure 6a where the corn is four to six inches high. If it was this way during the Landsat overpass, the vegetative cover of these corn plants would not mask the soil spectral response but would influence the spectral response of the area. An example of this can be seen by comparing the graph of two spectral soils classes of the outwash over till area (Figure 7). The statistics for the four Landsat bands are presented in Table 4 for comparison. Notice that the total magnitude of the two soils is almost identical. When graphed, however, the curves appear very different. Soil 3 has the depression in channel 2 (0.60-0.7μm) and elevation in channel 3 (0.7-0.8μm) which is characteristic of the spectral response of vegetation. Figure 7 presents the curve for the two soils and a vegetation response curve.

Table 4. Relative spectral magnitudes.

	Band (μm)				
Spectral Class	0.5-0.6	0.6-0.7	0.7-0.8	0.8-1.1	Total
Soil 3	39.33	34.50	46.85	22.71	143.39
Soil 4	41.87	40.19	41.80	19.16	143.01
Vegetation	40.49	35.93	53.12	27.10	156.64

The second way that a soil-vegetation confusion class could occur is because of "mixed pixels." This term can best be defined as a pixel resulting from a situation where the resolution element of the satellite falls on a boundary of a vegetation class and a soils class. The illustration below represents a hypothetical situation.



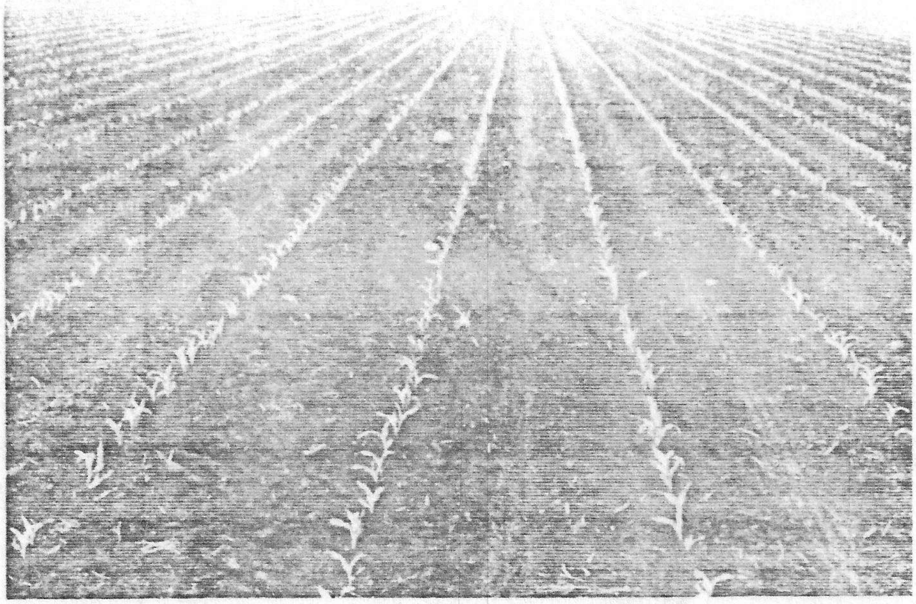


Figure 6a. Emerging corn.

Figure 6b. Edge vegetation.

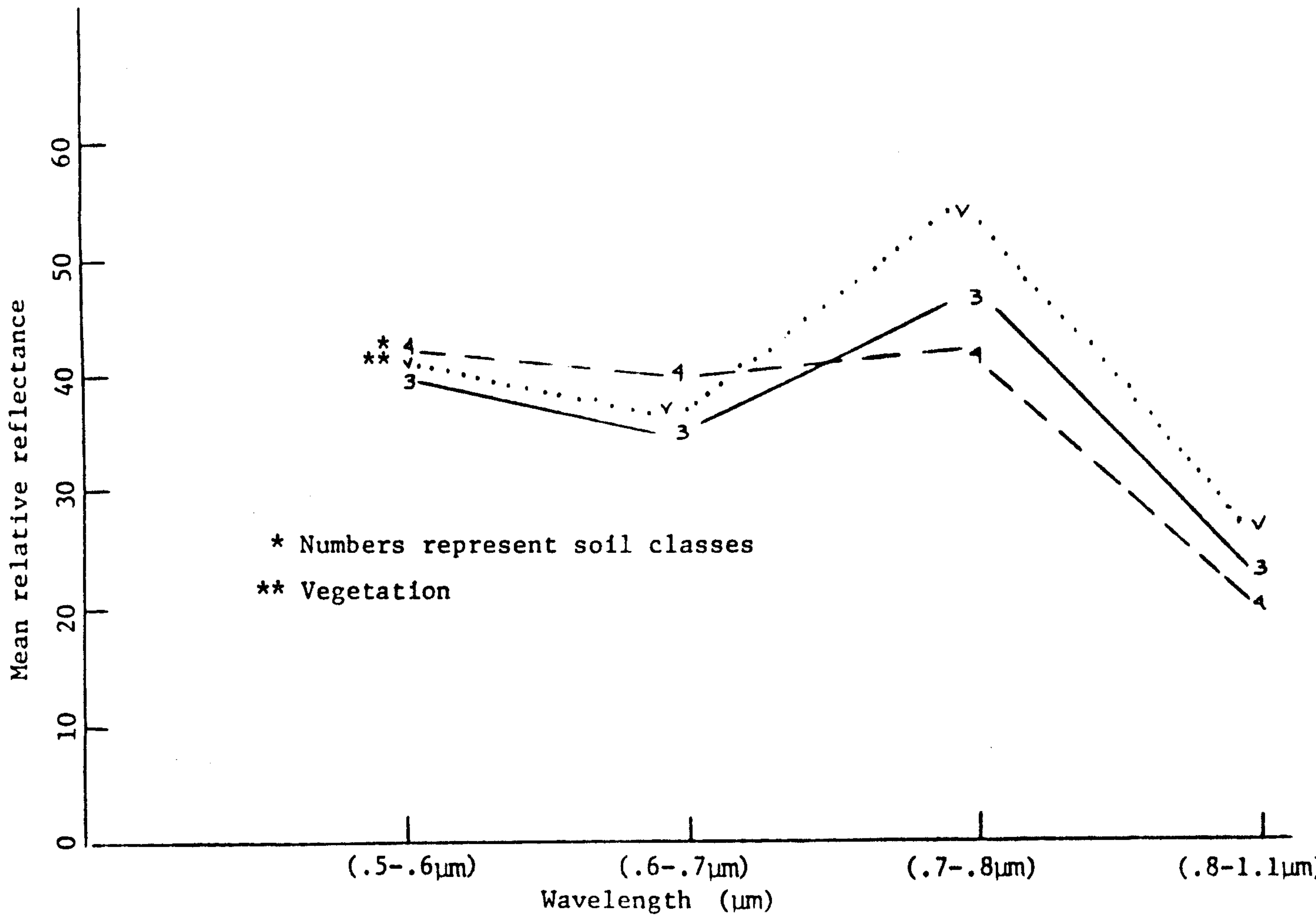


Figure 7. Soil-vegetation confusion class analysis--outwash over till.

It can be seen that the resulting resolution element (or pixel) would actually be an average of a vegetation and a soil spectral response. The resulting spectral curve would be similar to that described before. An illustration noted in the field is shown in Figure 6b. It is believed that both of these situations contributed to the soil-vegetation confusion classes found.

In all parent material areas the soil-vegetation confusion classes are described. A reclassification of specific areas was made using statistics where these soil-vegetation confusion classes were eliminated. An analysis of the percent of change of these classes is made. Over the entire classification, however, it is recommended that these confusion classes be maintained because it is felt that they may offer some useful soil information when used in the field, particularly when interpreting boundaries. Strict interpretation of these soil-vegetation confusion classes should, however, be avoided. It also seems from the analyses made that the soil-vegetation classes are not consistently reclassified into only one of the remaining soil classes but reclassified into several of the remaining classes.

Surface conditions were also found to influence the spectral response of the soils. Such conditions as a sandy surface, recent disking versus a crusted soil, extreme moisture, and an exposed subsurface were all noted in the field investigation and are likely influences in the soil spectral response. Detailed discussion of specific examples is presented later.

There is one combined vegetation class for the entire classification. Soils are associated with this vegetation class, but no consistent association occurs. Those areas covered by vegetation must, therefore, be field checked for accurate interpretation of the soils. It would appear possible, however, that if an association of soil and vegetation could be arrived at, soils could be mapped by mapping vegetative classes.

Outwash

Table 5 indicates the percentage make-up of the soils spectral classes for the outwash area. Outwash soils include approximately 202,040 acres representing 56.3% of the entire county. The graph of the soil spectral curves is shown in Figure 8.

In this area the equivalent of ten quarter sections was mapped. Eight of these quarter sections were contiguous and mapped as entire sections. The area sampled was 1600 acres in extent and represented 0.79% of the total area of outwash soils. The following legend is presented for the eight spectrally separable soil classes and the one combined vegetation class. No separate class was developed for water; therefore, water bodies are classified as Soil 9.

Soil 1 - This spectral class indicates predominantly excessively drained and well drained soils. Those soils sampled were Plainfield, Chelsea, and Oshtemo. Significant inclusions of somewhat poorly drained soils (Morocco, Brady, Tedrow) and very minor inclusions of very poorly drained soils (Maumee) are found.

Table 5. Dot grid count for outwash area.

Class	ED - WD		MWD		SPD		VPD		T
Soil 1	Ch: 2 Os: 3 Pn:31				Bb:15 Mr: 8 Td: 4		Md: 3		66
	D	%	D	%	D	%	D	%	
	36	55			27	41	3	4	
Soil 2	Pn:20				Bb: 4 Db:21 Mr: 1 Td: 7 Wk: 5		Gf:24 Md: 3 Rr: 4 Sb: 2		91
	D	%	D	%	D	%	D	%	
	20	22			38	42	33	36	
Soil 3	Pn: 6		Be: 8				Gf: 8 Md: 2		24
	D	%	D	%	D	%	D	%	
	6	25	8	33			10	42	
Soil 5	Pn: 5				Db: 6 Mr: 4		Gf:140 Md: 13		168
	D	%	D	%	D	%	D	%	
	5	3			10	6	153	91	
Soil 6	Mb: 3 Pn: 8				Mr: 8 Sa:12		Gf:190 Ho: 6 Md: 24 Rr: 7 Sa: 2		259
	D	%	D	%	D	%	D	%	
	11	4			20	8	228	88	

Table 5. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 7	Mb: 4 Pn: 2				Bb:10 Db:10 Mr: 2		Gf:134 Md: 16 Mu: 24 Rr: 14		221
	D	%	D	%	D	%	D	%	
	6	3			22	12	188	85	
Soil 8					Mr:10		Ad: 9 Rr:21 Gf:142 Sb:23 Ho: 7 Md: 26 Mu: 16		254
	D	%	D	%	D	%	D	%	
					10	4	244	96	
Soil 9					Db:11		Ad: 5 Gf:576 Md: 21 Mu:125 Rr: 66 Sb: 22		846
	D	%	D	%	D	%	D	%	
					11	1	835	99	
Veg	Pn:53		Be:14		Bb: 2 Mr:38		Gf:271 Mu: 7 Sb: 3		388
	D	%	D	%	D	%	D	%	
	53	14	14	4	40	10	281	72	
Total	137		22		183		1975		2317

Table 5. (Continued).

Soil Key

Ad - Adrian
Bb - Brady
Be - Brems
Ch - Chelsea
Db - Darroch
Gf - Gilford
Ho - Houghton
Mb - Martinsville
Md - Maumee
Mr - Morocco
Mu - Mussey
Os - Oshtema
Pn - Plainfield
Rr - Rensselaer
Sa - Seafield
Sb - Sebewa
Td - Tedrow
Wk - Whitaker

Table Key

ED - excessively drained
WD - well drained
MWD - moderately well drained
SPD - somewhat poorly drained
VPD - very poorly drained
T - Total
D - Dots

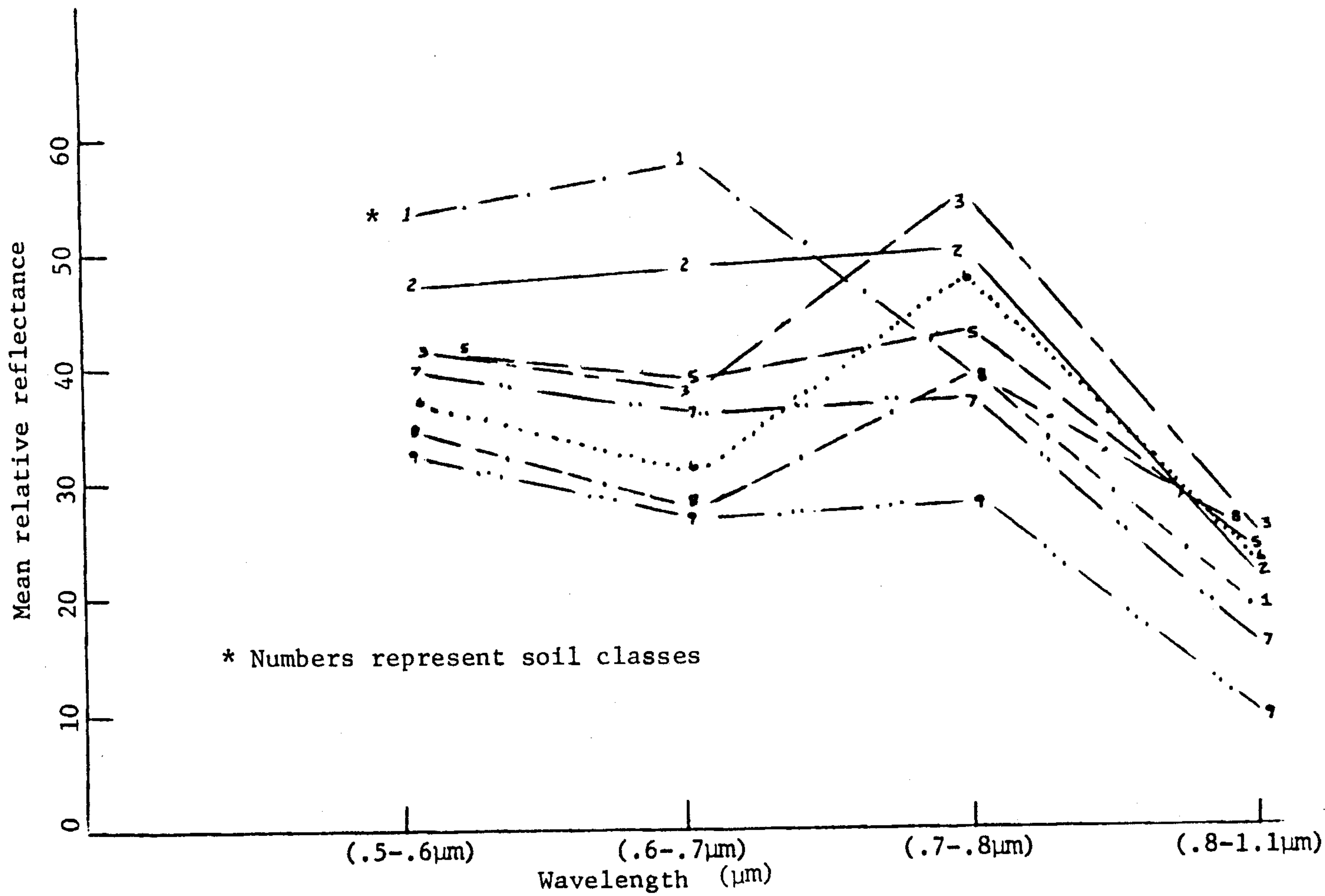


Figure 8. Soil spectral classes--outwash.

Soil 2 - This spectral class is dominated by somewhat poorly drained soils including Whitaker, Morocco, Darroch, Brady, and Tedrow. The poorly drained soils are also present as significant inclusions (Gilford, Rensselaer, Maumee, Sebewa). The excessively drained soils are also (Plainfield) significant inclusions.

Soil 3 - This spectral class is dominated by the very poorly drained soils including Gilford and Maumee. Significant inclusions of moderately well drained Brems and excessively drained Plainfield are apparent. This class is a soil-vegetation confusion class.

Soil 5 - This spectral class is dominated by the very poorly drained soils. Those soils sampled were Gilford and Maumee. Minor inclusions of somewhat poorly drained soils (Darroch, Morocco) and excessively drained soils (Plainfield) are also found.

Soil 6 - This spectral class is dominated by the very poorly drained soils including Maumee, Gilford, Sebewa, Houghton, and Rensselaer. Minor inclusions of somewhat poorly drained Morocco and Seafield and well drained Martinsville and excessively drained Plainfield occur. This class is a soil-vegetation confusion class.

Soil 7 - This spectral class is predominantly very poorly drained soils including Gilford, Maumee, Mussey and Rensselaer. Minor inclusions of somewhat poorly drained soils (Morocco, Darroch, Whitaker and Brady) are found. An extremely small percentage of well drained and excessively drained soils (Plainfield, Martinsville) were found as inclusions.

Soil 8 - This spectral class is predominantly very poorly drained soils including Mussey, Gilford, Maumee, Houghton, Rensselaer, Sebewa and Adrian. Very minor inclusions of the somewhat poorly drained Morocco were sampled. This class is a minor soil-vegetation confusion class.

Soil 9 - This spectral class is predominantly very poorly drained soils. Soils sampled included Gilford, Mussey, Rensselaer, Maumee, Sebewa and Adrian. Very minor inclusions of the somewhat poorly drained Darroch were also found. Water is most likely to fall into this spectral class.

Vegetation - The vegetation class is predominantly poorly drained soils including Gilford, Sebewa and Maumee. Inclusions of excessively drained (Plainfield), moderately well drained (Brems) and somewhat poorly drained (Morocco, Brady) were sampled.

Discussion

Soils 1 and 2 appear to be the only distinct soil groups when grouped by drainage classes. Soil 1 is predominantly well or excessively drained while Soil 2 is predominantly somewhat poorly drained. Soils 3 through 9 are all predominantly very poorly drained soils. Of these classes Soil 3 and Soil 6 are soil-vegetation confusion classes. This was noted here and in all other parent material sections in two ways: (1) by the spectral curve as described earlier and (2) by the spatial association with known vegetative classes. Soil 8 is also somewhat of a soil-vegetation confusion class but is of only minor importance. It has been noted that this spectral class has been confused with coniferous vegetation. This is not a serious problem because of the lack of coniferous vegetation in Jasper County. It is recommended that where known coniferous vegetation occurs (i.e., from aerial photography), investigation should be made into that area to determine what soil actually occurs there.

Soil 5 is predominantly very poorly drained soils but contains a large percentage of borderline somewhat poorly drained soils. Soils 6,7,8 and 9 are all predominantly poorly drained soils.

Figure 9 indicated the trend of drainage class versus relative magnitude. As the magnitude of spectral response decreases, the percent of well drained soils decreases and the percent of very poorly drained soils increases.

Soil 3, a soil-vegetation confusion class shows a broad range of percentages for soils of different drainage classes (Figure 10).

The vegetation class shows soils represented in all drainage classes with those soils in the very poorly drained class being represented in the greater percentage.

On the basis of the analysis presented it appears that certain spectral classes can be combined because of similarity in soils composition. Figure 12 displays the three suggested combinations for T32N, R6W, Sec. 12, SE¼. Combination one is actually no combination. Combination two displays soils 6 and 7 similarly and soils 8 and 9 similarly. Combination three displays 5,6 and 7 and 8,9. Figure 11a shows the soil map.

It appears that combination two best represents the actual soil conditions for this area. There is not much difference, however, between combination one and combination two. Combination three results in too great of a loss of soil information. It may be best in this parent material area, as well as the other areas, to suggest which spectral classes are to be combined but to leave them distinct on the map. These suggested combinations can then be made at the discretion of the soil surveyor.

Figure 13 of T28N, R6W, Sec. 33, NE¼, a quarter section not mapped in this study, indicates that combination two is again the best for an interpretive map (assuming the field mapping is correct). The soil-vegetation confusion classes 3 and 6 appear to be a problem on this area. The Whitaker soil (Wk) is represented as soil 6, a predominantly poorly drained soil in the southwest corner of the quarter section. The relatively large area of soils 1 and 2 in the northeast part of the quarter section does not seem to represent what is mapped in the field. The soil pattern on the photo (Figure 11b) does seem to fit better to the spectral map. In this case, an error in mapping is possible.

Figure 14 is a reclassification of T32N, R6W, Sec. 12, SE¼ eliminating soil-vegetation confusion classes 3 and 6. Likewise Figure 15 is a reclassification of this quarter section eliminating soils 3,6 and 8. The results are presented below (Table 6).

This analysis presents situations that may occur when eliminating soil-vegetation confusion classes. They may, if strongly influenced by vegetation, be dominantly reclassified as vegetation. This appears to be the situation

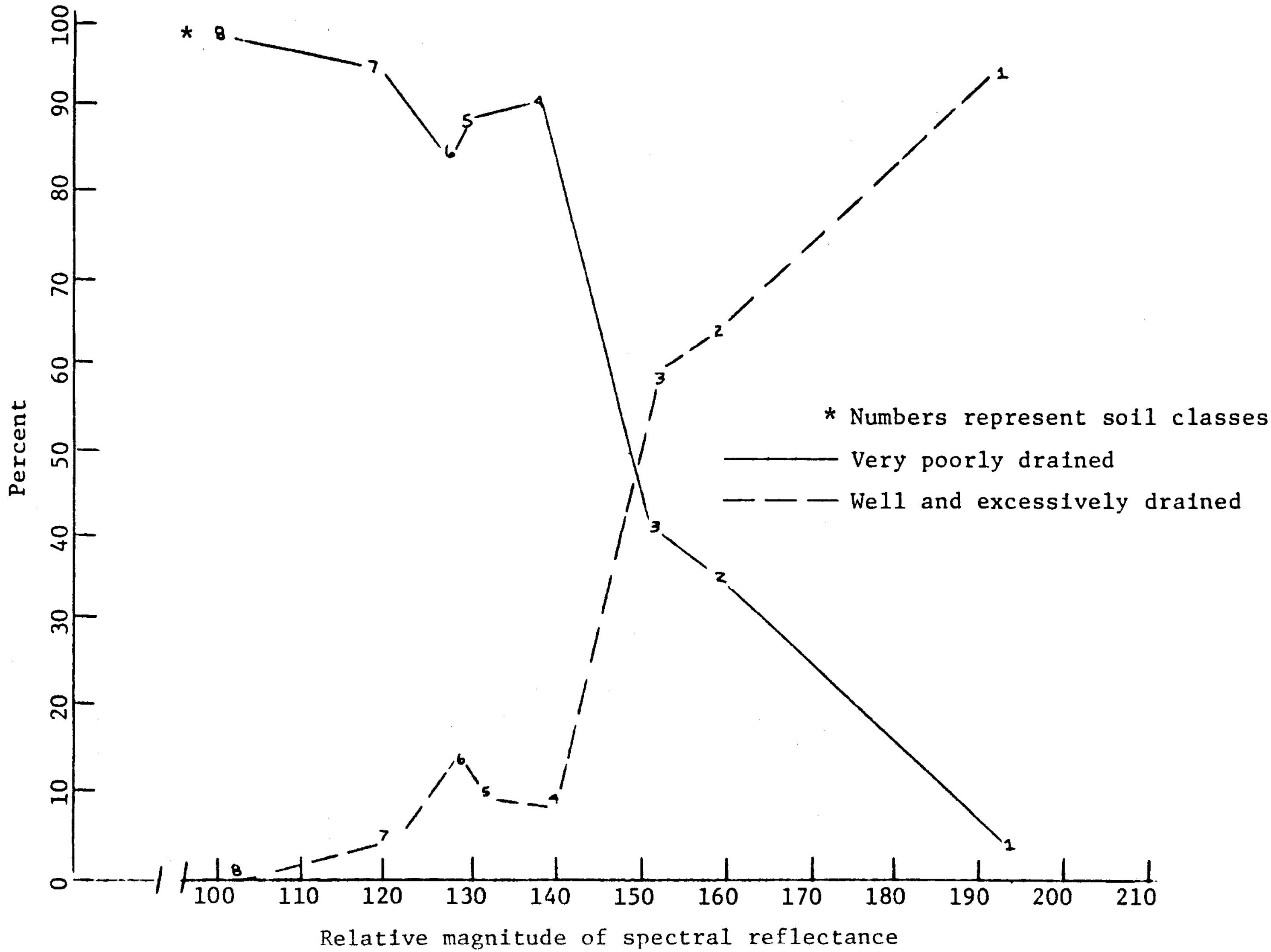


Figure 9. Relative drainage composition of spectral soil classes vs. magnitude (outwash).

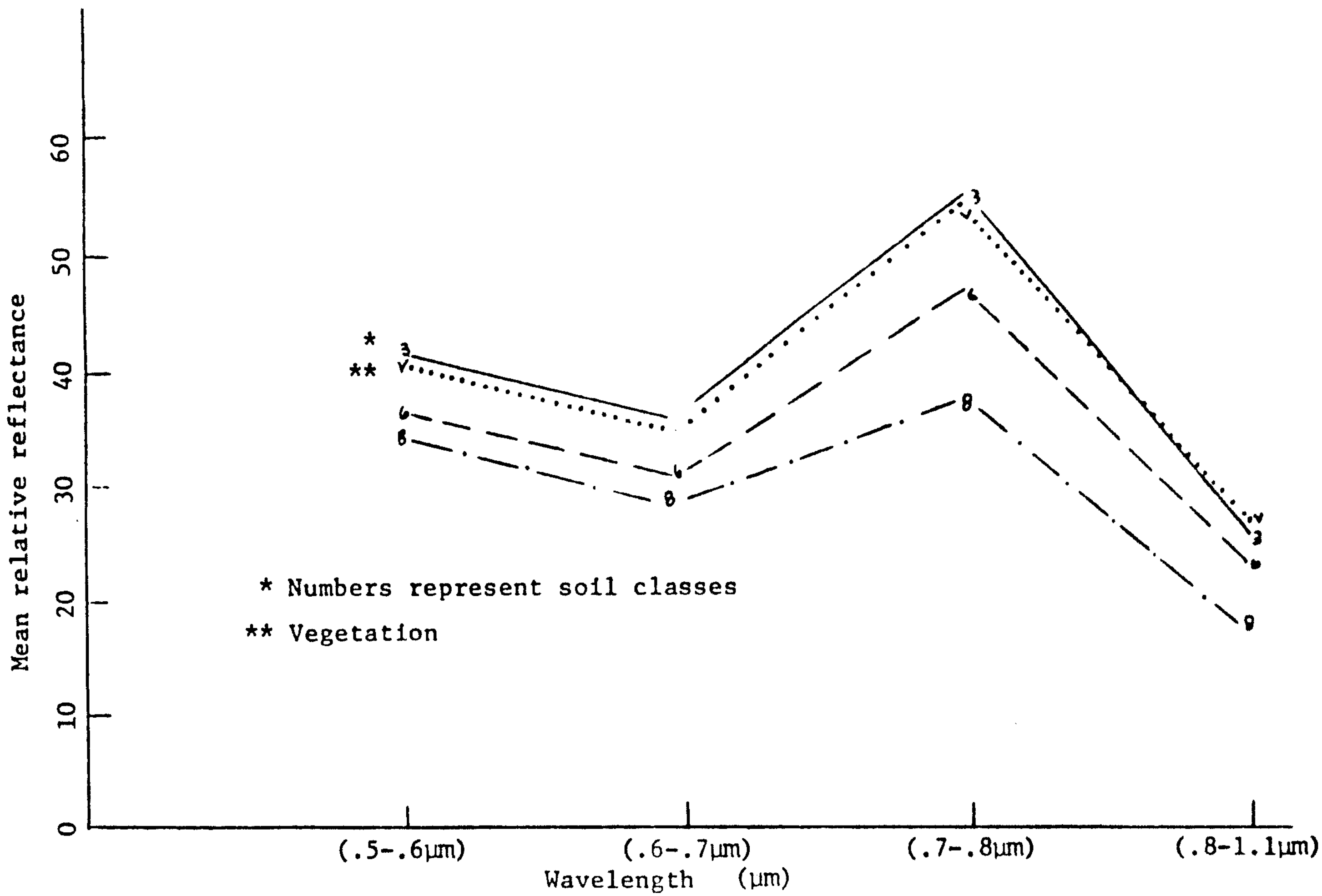
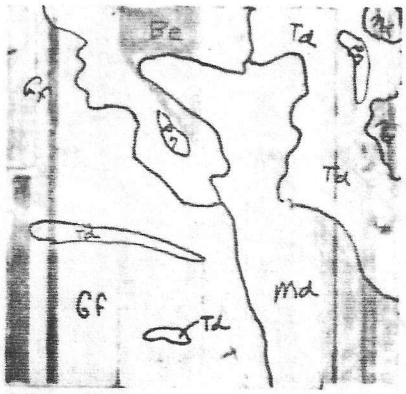


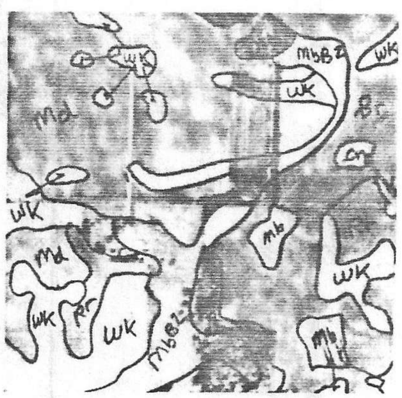
Figure 10. Soil-vegetation confusion classes--outwash.



Legend 1

Be - Brems
Gf - Gilford
Md - Maumee
Pn - Plainfield
Td - Tedrow

Figure 11a. Soil map of T32N, R6W, Sec. 12, SE¼.



Legend 2

Br - Brookston
Mb - Martinsville
Mb B2 - Martinsville,
2-6%, moderately eroded
Md- Maumee
Pn - Plainfield
Rr - Rensselaer
Wk - Whitaker

Figure 11b. Soil map of T28N, R6W, Sec. 33, NE¼.

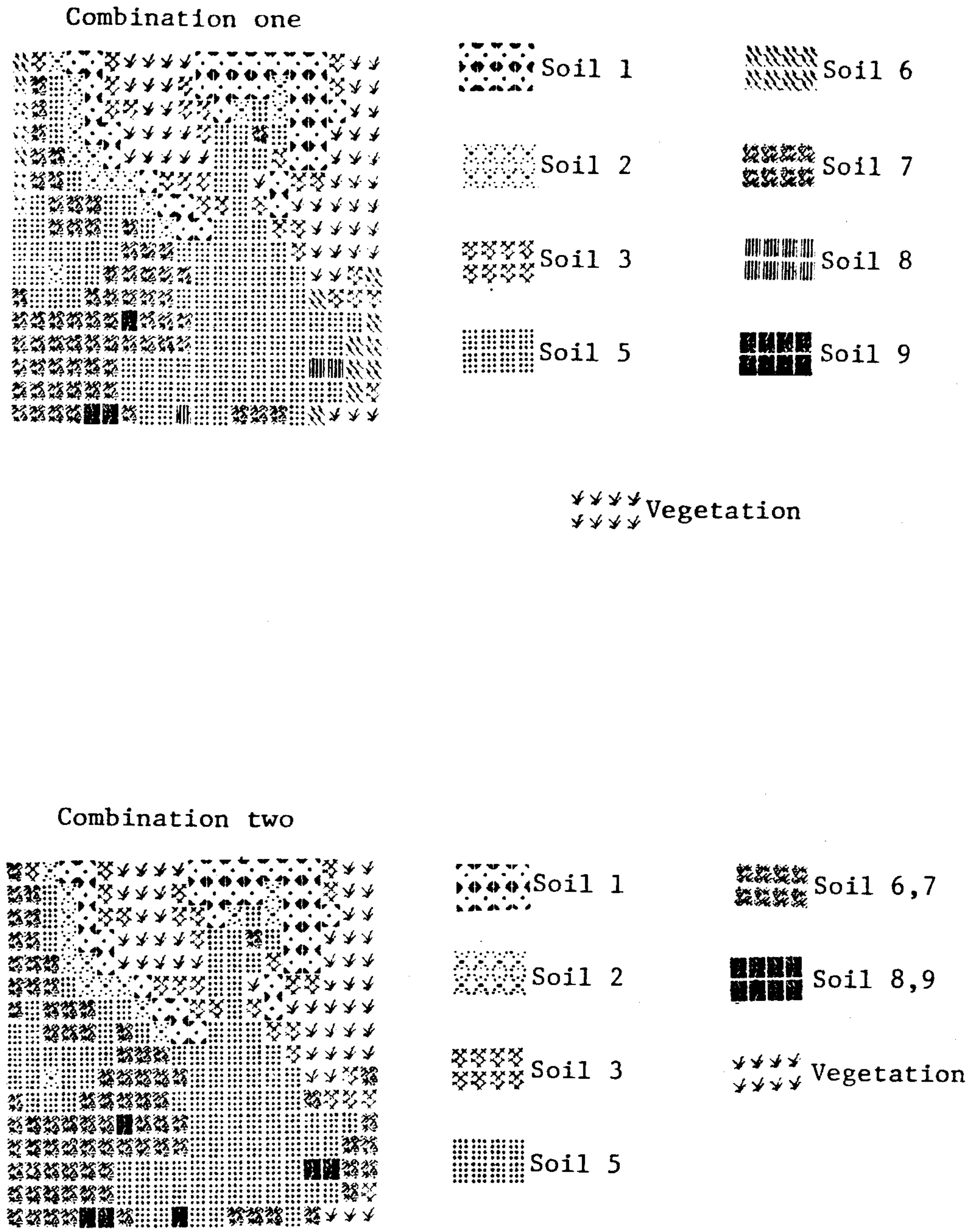


Figure 12. Combinations for T32N, R6W, Sec. 12, SE¼.

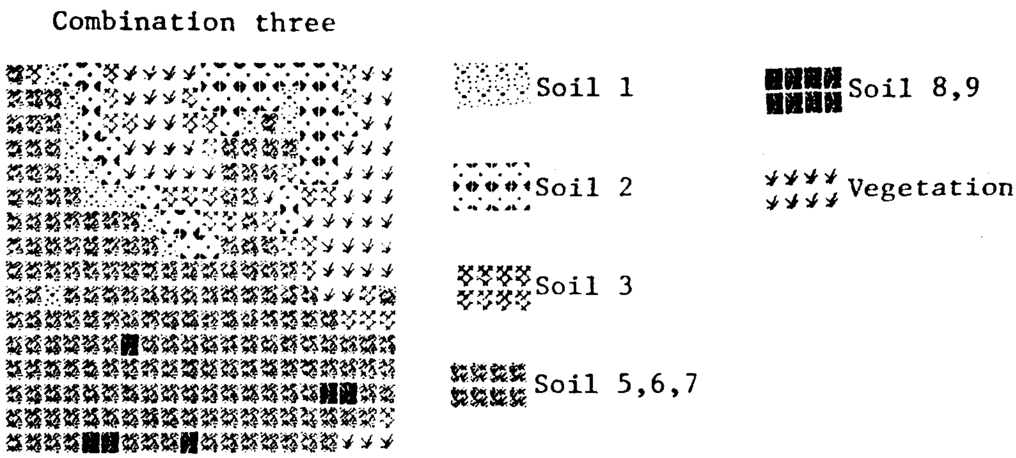
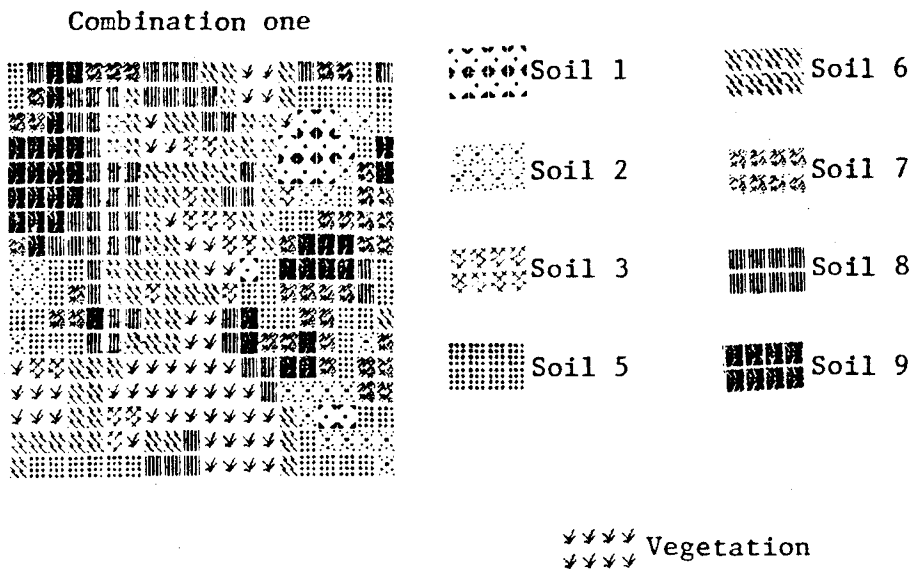


Figure 12. (Continued).



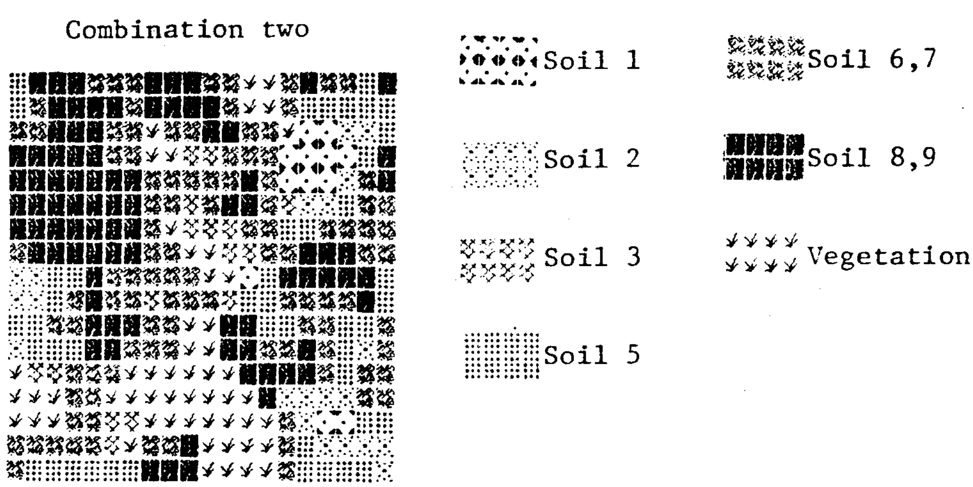


Figure 13. Combinations for T28N, R6W, Sec. 33, NE¼.

Combination three

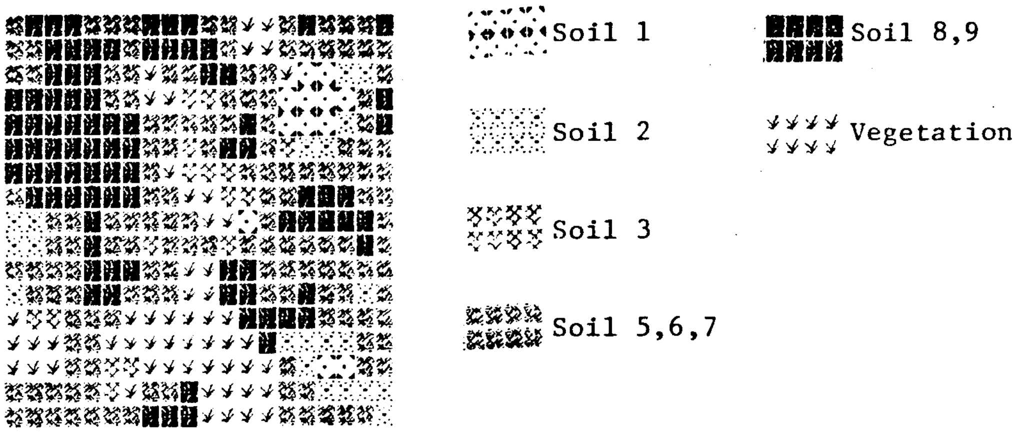


Figure 13. (Continued).

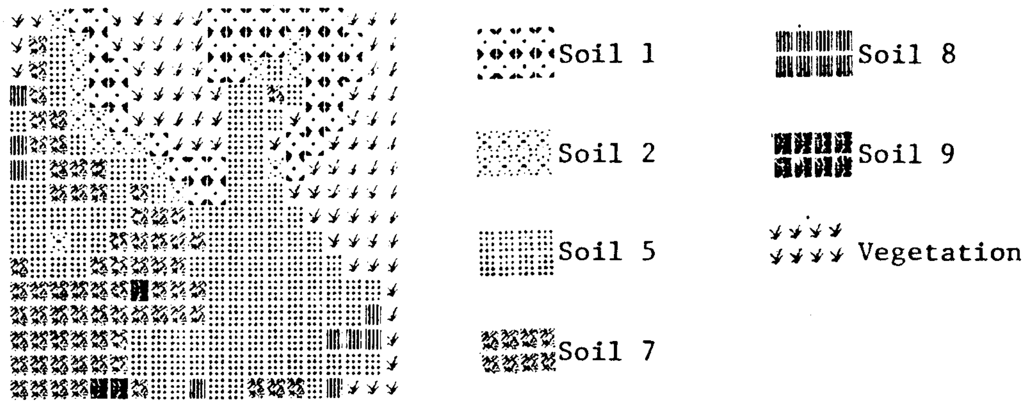


Figure 14. T32N, R6W, Sec. 12, SE¼ eliminating soil-vegetation classes 3 and 6.

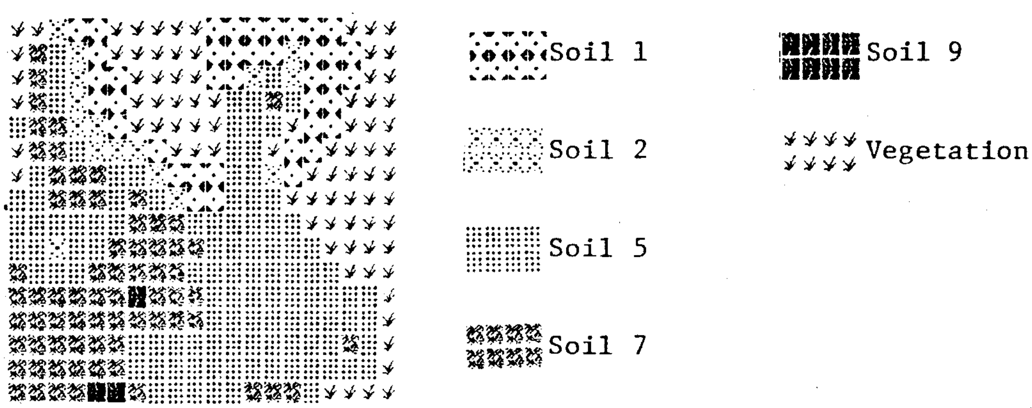


Figure 15. T32N, R6W, Sec. 12, SE¼ eliminating soil-vegetation classes 3,6 and 8.

Table 6. Soil-vegetation analysis, outwash.

Soil-vegetation Confusion Class	Total Points in ¼ Section	Points after Reclassification	% Change
3	29	24 to vegetation	83%
		5 to soil 1	17
6	16	11 to vegetation	69
		5 to soil 5	31
8	10	4 to vegetation	40
		2 to soil 2	20
		1 to soil 5	10
		1 to soil 7	10
		2 to soil 9	20

with soils 3 and 6. However, if the soil-vegetation confusion class is predominantly soil, it will be reclassified as such. Soil 8 is an example of such a situation. A problem arises with soil 8, however, in that those pixels reclassified as soil are separated broadly into four soil classes. An analysis of all the soil-vegetation confusion classes for all six parent material areas and suggested reasons and solutions will be presented later.

It appears that soils 3 and 6 are predominantly vegetation and soil 8, while influenced by vegetation, also represented a wide range of soil classes.

Outwash Over Till

Table 7 indicates the relative percentage of soils for each spectral class for the outwash over till area. This area includes 26,880 acres representing 7.5% of the entire county. The graph of the spectral responses for the soil classes is shown in Figure 16.

In this parent material area three quarter section (480 acres) were mapped, representing 1.79% of the outwash over till area. The composition of the eight spectrally separable soil classes and the one all-inclusive vegetation class follows. Water is classified as soil 7.

Soil 1 - This spectral class predominantly represents the somewhat poorly drained soils (Whitaker, Morocco). Inclusions of excessively drained soils (Chelsea) and moderately well drained soils (Brems) are present.

Soil 2 - This spectral class is dominated by the somewhat poorly drained soils (Whitaker, Tedrow, Seafield, Morocco, Brady). Inclusions of excessively drained (Plainfield, Chelsea) and moderately well drained soils (Brems) are significant. The very poorly drained soils (Rensselaer, Gilford, Maumee) are relatively minor inclusions.

Soil 3 - This spectral class is dominantly very poorly drained soils (Rensselaer, Maumee, Muskego, Houghton) with an almost equal representation of somewhat poorly drained soils (Tedrow, Whitaker, Seafield, Morocco). Moderately well drained soils (Brems) represent only minor inclusions. This spectral class is a soil-vegetation confusion class.

Table 7. Dot grid count for outwash over till.

Class	ED - WD		MWD		SPD		VPD		T
Soil 1	Ch: 4		Be: 3		Mr: 2 Wk:13				22
	D	%	D	%	D	%	D	%	
	4	18	3	14	15	68			
Soil 2	Ch: 5 Pn: 8		Be: 11		Bb: 1 Mr: 4 Sa: 1 Td: 9 Wk:28		Gf: 1 Mu: 1 Rr: 3		72
	D	%	D	%	D	%	D	%	
	13	18	11	15	43	60	5	7	
Soil 3			Be: 3		Mr: 9 Sa: 1 Td: 3 Wk: 3		Ho: 4 Md: 7 Mu: 3 Rr: 7		43
	D	%	D	%	D	%	D	%	
			3	5	19	45	21	50	
Soil 4	Ch: 4		Be: 3		Mr: 7 Sa: 1 Td: 2 Wk:33		Ho: 4 Mu: 5		59
	D	%	D	%	D	%	D	%	
	4	7	3	5	43	73	9	15	
Soil 5	Ch: 1		Be: 2		Mr: 2 Sa: 2 Wk: 8		Gf: 1 Md:10 Pb: 7 Rr:79 Mu:12		124
	D	%	D	%	D	%	D	%	
	1	1	2	1	12	10	109	88	

Table 7. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 6					Mr: 1		Gf: 1 Md: 13 Pb: 26 Pk: 2 Rr: 133		176
	D	%	D	%	D	%	D	%	
					1	1	175	99	
Soil 8					Mr: 2		Ad: 9 Rr: 21 Ho: 16 Md: 3 Mu: 41 Pk: 3		93
	D	%	D	%	D	%	D	%	
							93	98	
Soil 7							Gf: 3 Ho: 28 Mu: 10 Pk: 9 Rr: 27		77
	D	%	D	%	D	%	D	%	
							77	100	
Veg	Ch: 2 Ph: 6		Be: 19		Mr: 35 Sa: 1		Ad: 5 Gf: 10 Ho: 3 Md: 54		136
	D	%	D	%	D	%	D	%	
	8	6	19	14	36	26	73	54	
Total	30		41		169		562		802

Table 7. (Continued).

Soil Key		Table Key	
Ad	Adrian	ED	excessively drained
Bb	Brady	WD	well drained
Be	Brems	MWD	moderately well drained
Ch	Chelsea	SPD	somewhat poorly drained
Gf	Gilford	VPD	very poorly drained
Ho	Houghton	T	Total
Md	Maumee	D	Dots
Mr	Morocco		
Mu	Muskego		
Pb	Palms		
Pk	Patton		
Pn	Plainfield		
Sa	Seafield		
Td	Tedrow		
Wk	Whitaker		

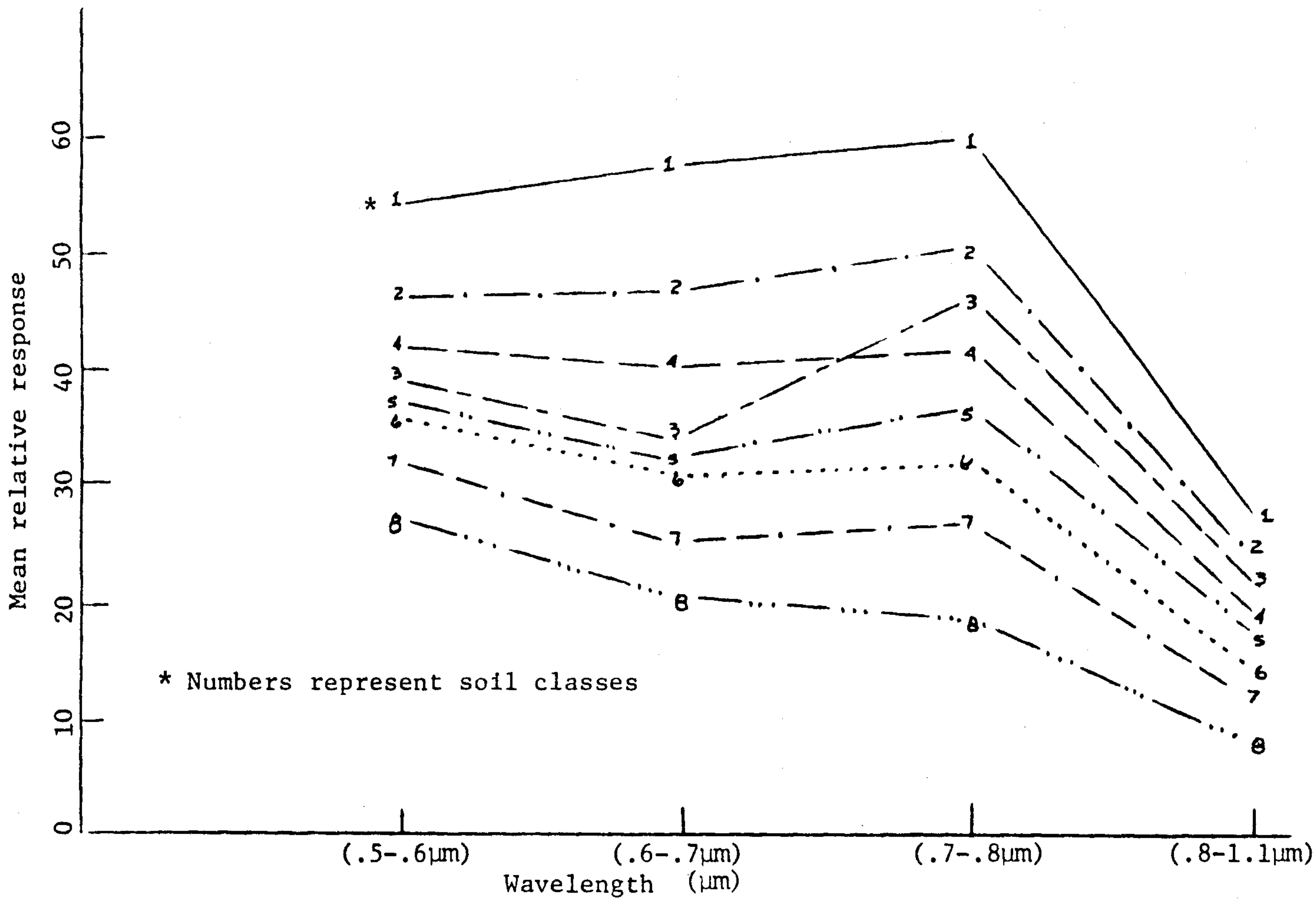


Figure 16. Soil spectral classes--outwash over till.

Soil 4 - This spectral class represents somewhat poorly drained soils (Morocco, Whitaker, Seafield, Tedrow). Very poorly drained soils make up relatively significant inclusions (Houghton, Maumee). Excessively drained soils (Chelsea) and moderately well drained soils (Brems) make up minor inclusions.

Soil 5 - This spectral class is dominantly very poorly drained soils (Muskego, Rensselaer, Palms, Maumee, Gilford). Some inclusions of somewhat poorly drained soils (Seafield, Morocco, Whitaker) are apparent. Other inclusions of well drained and moderately well drained soils are minor.

Soil 6 - This spectral class is dominantly very poorly drained soils including Palms, Maumee, Gilford, Rensselaer, and Patton. Inclusions of somewhat poorly drained soils (Morocco) are minor.

Soil 8 - This spectral class is dominantly very poorly drained soils (Rensselaer, Patton, Maumee, Muskego, Houghton, and Adrian). Very minor inclusions of somewhat poorly drained soils (Morocco) are apparent.

Soil 7 - This spectral class is entirely very poorly drained soils (Gilford, Maumee, Houghton, Adrian).

Vegetation - The vegetation spectral class is dominantly very poorly drained soils but represent significant inclusions of soils of other drainage classes.

Discussion

This area has an extremely complex mottled surface pattern caused by the interspersed knobs of till as described before. This pattern made detailed field mapping difficult since very small inclusions could not be separated. Similarly, the mottled pattern may have influenced the spectral map because of an averaging effect (described later).

The general trend of the increasing percentage of very poorly drained soils with decreasing magnitude is apparent here as is the trend of decreasing percentage of well and excessively drained soils with decreasing magnitude (Figure 17).

None of the spectral classes in this classification were dominated by a well drained class. Soil 1 and 2 have significant inclusions of excessively and moderately well drained soils but are dominated by somewhat poorly drained soils. This may be due to an averaging effect as described below.

As can be seen from viewing the picture of the sample quarter sections (Figure 18a) the soil pattern is mottled, interspersed with light and dark soils. Due to the size of the resolution element of the Landsat satellite an averaging effect of the light (well drained) and dark (poorly drained) soils is likely. The result would be a soil curve with an intermediate value that would appear similar to the magnitude of a somewhat poorly drained

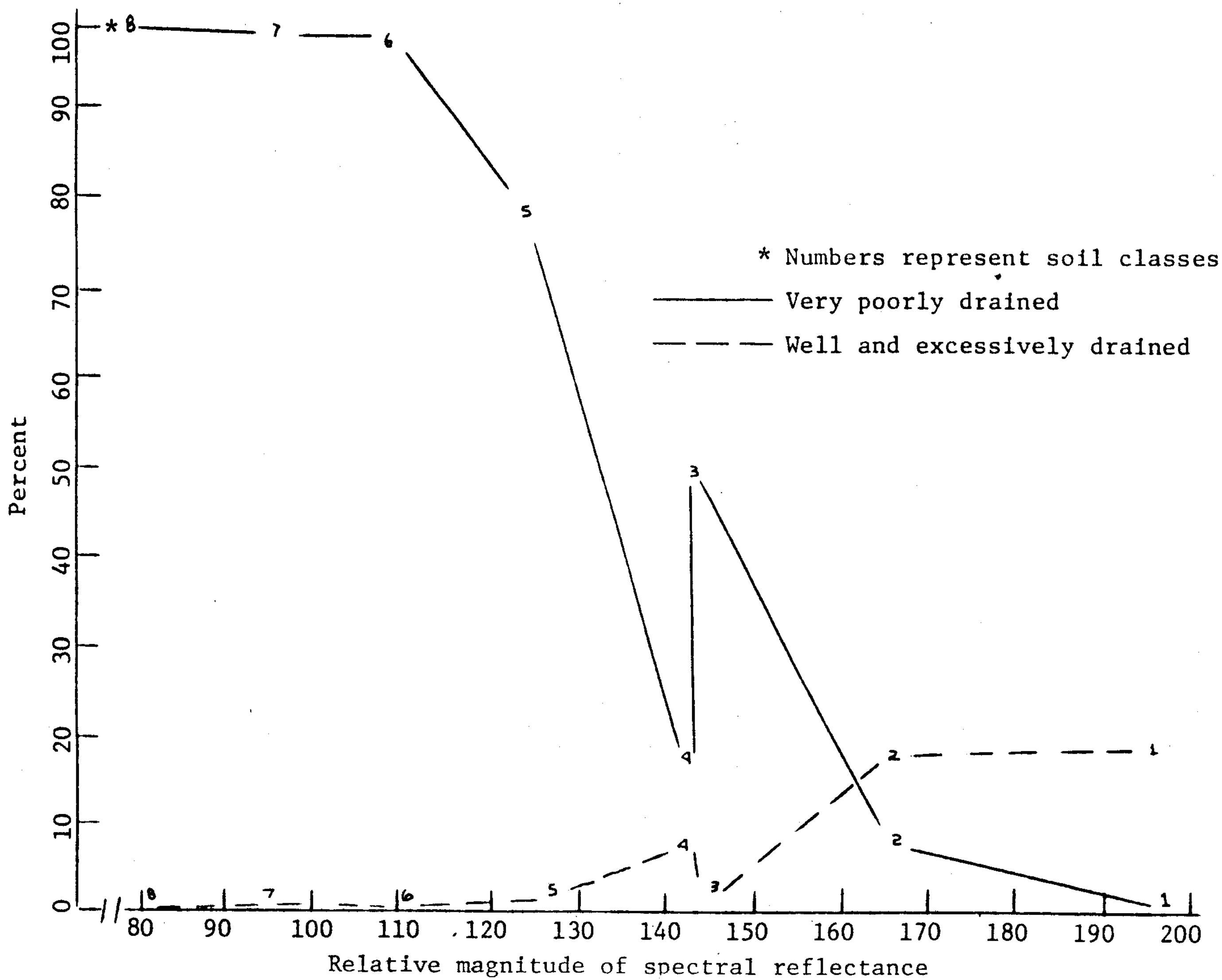


Figure 17. Relative drainage composition of spectral soil classes vs. magnitude (outwash over till).

Figure 18a. Mottled soil pattern.

Figure 18b. Averaging effect.

soil. This seems to be the case for soils 1,2 and 4. Figure 18b shows the field view of an area where such an averaging effect may occur.

Soil 3 is a soil-vegetation confusion class. The graph of the spectral curve is shown in Figure 19. This soil should not be taken as a strict soil information class.

Soils 5,6,7 and 8 are all dominantly very poorly drained soils. Soil 5 has significant inclusions of soils represented by other drainage classes.

The vegetation class is predominantly very poorly drained soils as it was in the outwash area described previously. Soils of all drainage classes are represented however.

On the basis of the analysis presented, certain of the soil spectral classes can be combined. Combination one represents no combination. Combination two represents a combination of soils 1 and 2 together and soils 6, 7 and 8 together. The results of these combinations are presented in Figure 20. Mapped photos are Figures 21a and 21b.

When compared to the field mapping, it appears that for T30N, R6W, Sec. 24, SW¼ (mapped in this study) combination two results in no loss of information and, in fact, makes the spectral map easier to interpret. When a comparison of the spectral map and the CNI mapped quarter section (Figure 22)(not mapped in this study) is made, combination two also appears to be the best of those combinations considered.

Soil 3, the soil-vegetation confusion class, was eliminated and T30N, R6W, Sec. 24, SW¼ was reclassified. The resulting spectral map is shown in Figure 23. The results are below (Table 8).

It appears that soil 3 is predominantly vegetation. Combination of the soils classes as described before can also be used if the soil-vegetation confusion class is eliminated.

Table 8. Soil-vegetation analysis, outwash over till.

Soil-vegetation Confusion Class	Total Points in ¼ Section	Points after Reclassification	% Change
3	27	16 to vegetation	59
		6 to soil 4	22
		5 to soil 5	

Rolling Moraine

Table 9 indicates the relative percentage of the soil spectral classes for the rolling moraine area. These soils include approximately 35,840 acres, representing 10.0% of the entire county. The graph of the relative spectral responses is shown in Figure 24.

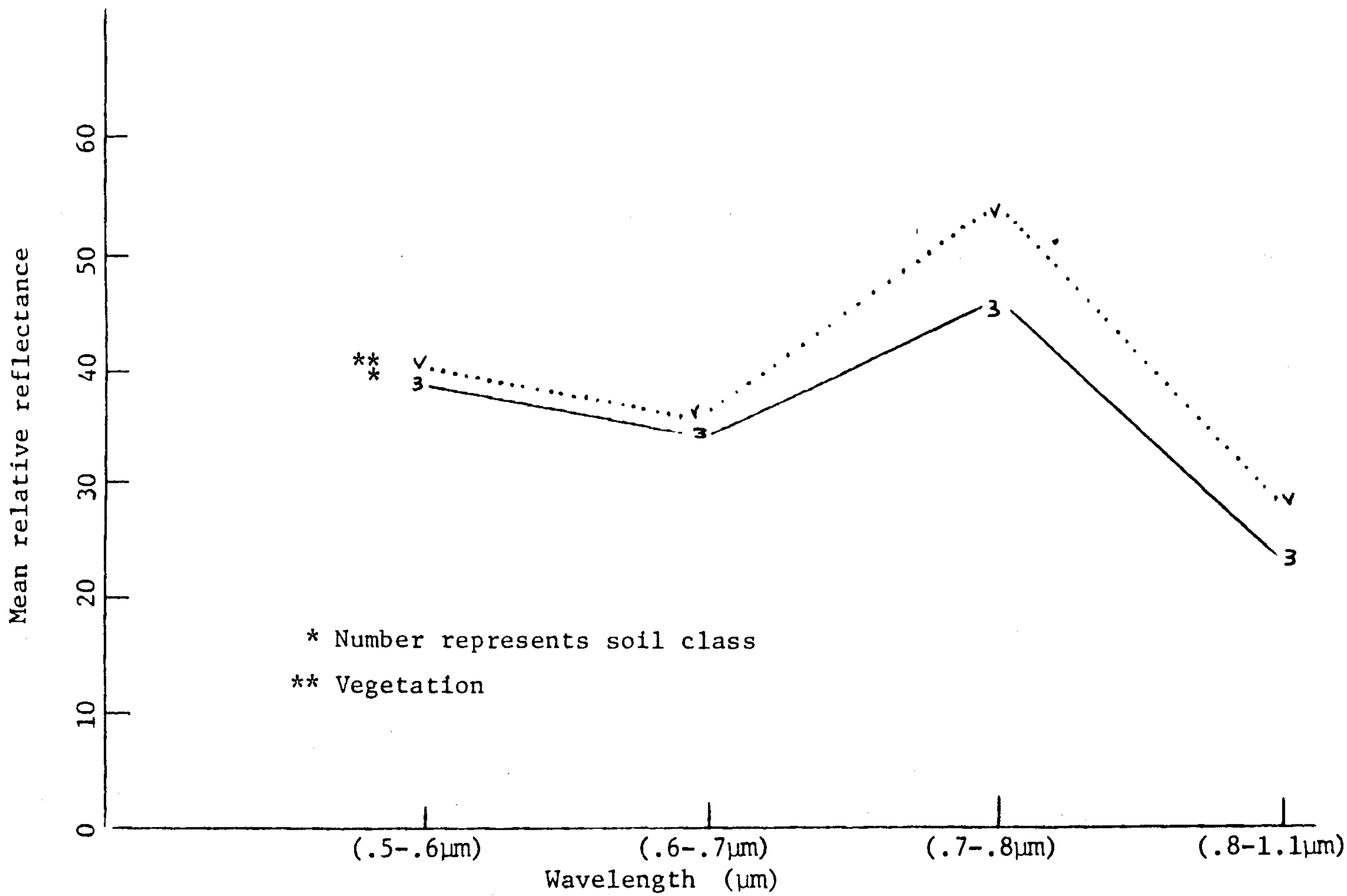


Figure 19. Soil-vegetation confusion class--outwash over till.

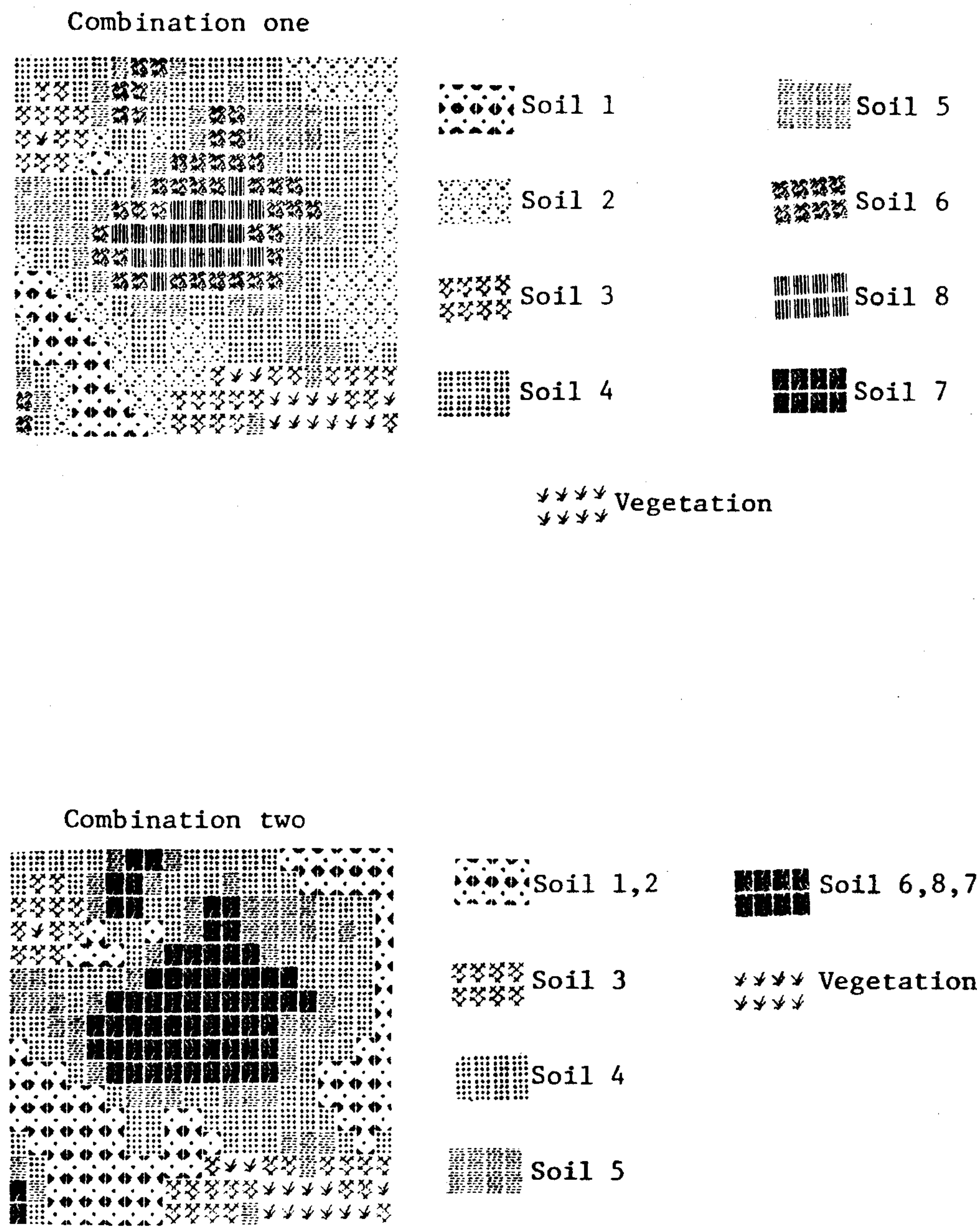
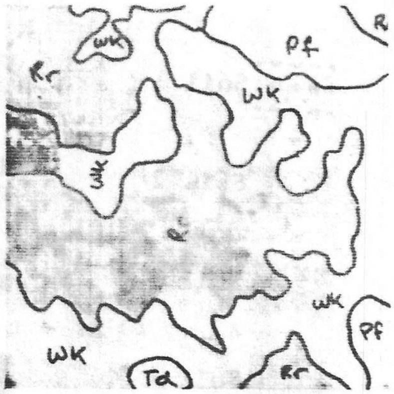


Figure 20. Combinations for T30N, R6W, Sec. 24, SW¼.



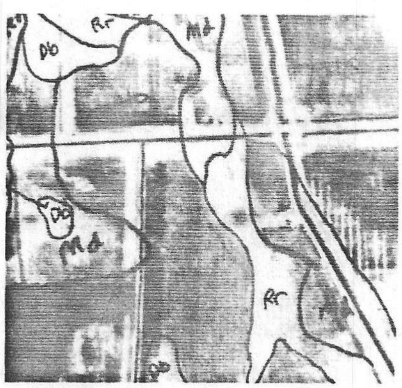
Legend 1

Pn - Plainfield

Rr - Rensselaer

Wk - Whitaker

Figure 21a. Soil map of T30N, R6W, Sec. 24, SW¼.



Legend 2

Db - Darroch

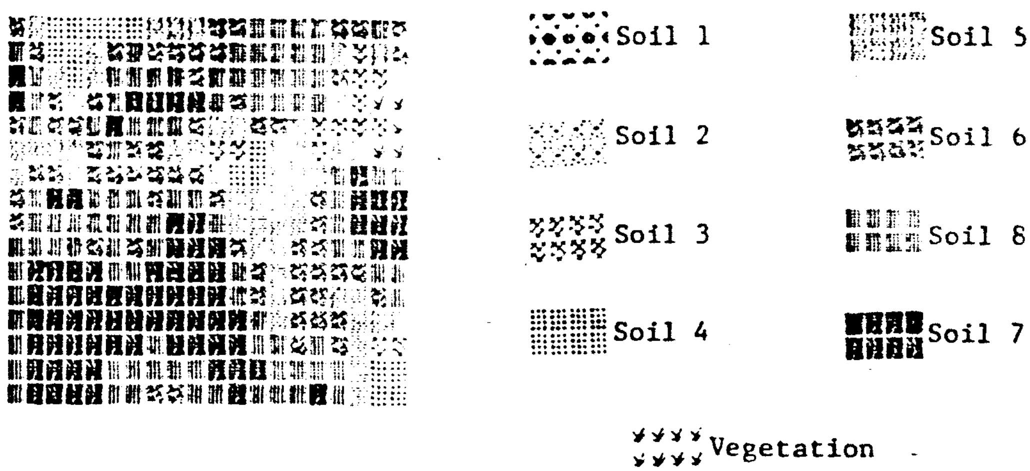
Ho - Houghton

Md - Maumee

Rr - Rensselaer

Figure 21b. Soil map of T30N, R5W, Sec. 7, SE¼.

Combination one



Combination two

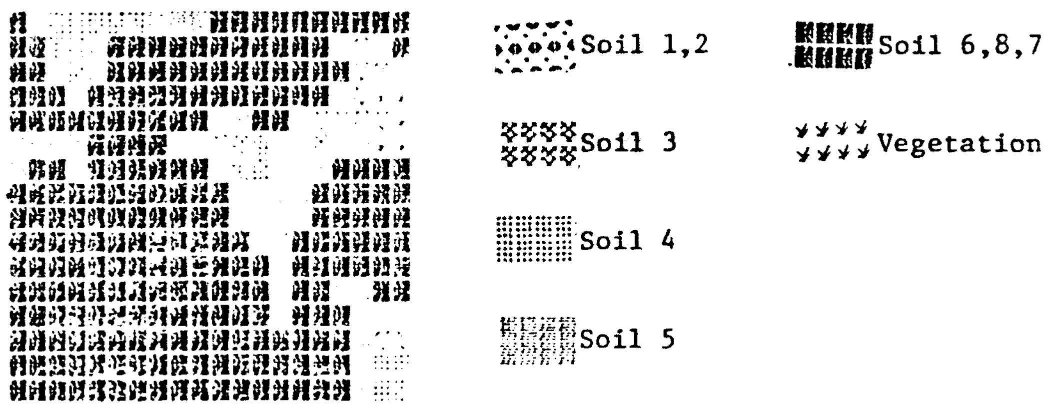


Figure 22. Combinations for T30N, R5W, Sec. 7, SE¼.

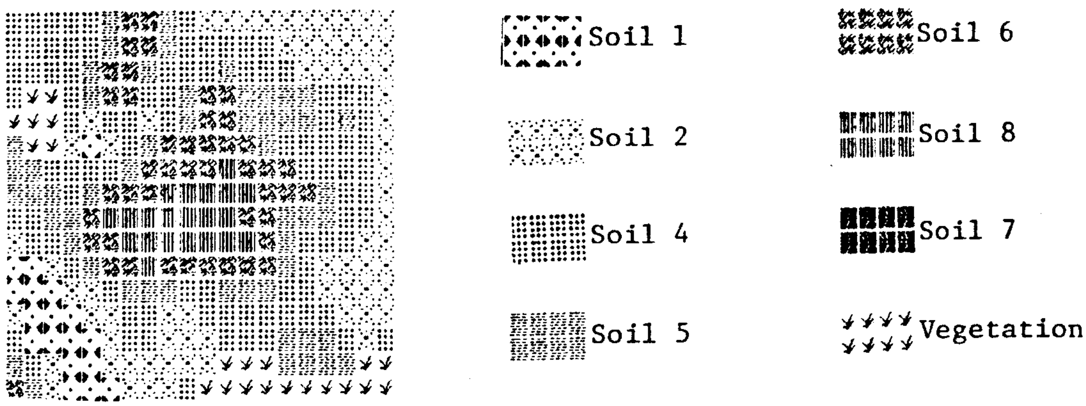


Figure 23. T30N, R6W, Sec. 24, SW¼, eliminating soil-vegetation confusion class 3.

Table 9. Dot grid count for rolling moraine.

Class	ED - WD		MWD		SPD		VPD		T
Soil 1	Mb:23 Mn: 2 Pn: 2				Wk:15				42
	D	%	D	%	D	%	D	%	
	27	64			15	46			
Soil 2	Mb:15 Mg: 4 Mn: 4 Pc: 1		Cc:3		Wk:23		Rr:2		52
	D	%	D	%	D	%	D	%	
	24	46	3	6	23	44	2	4	
Soil 3	Mb: 5 Mn: 3 Pc: 2				Od: 1 Wk: 1				12
	D	%	D	%	D	%	D	%	
	10	83			2	17			
Soil 4	Jc: 2 Mn: 4 Pc:15 Sp: 1		Cc:5 Co:1		Au: 2 Db: 1 Od: 2 Wk: 6		Pk:3 Rr:9		51
	D	%	D	%	D	%	D	%	
	22	43	6	12	11	22	12	23	
Soil 5	Mb: 2 Pc: 4		Fr:2		Od:11 Wk: 1		Rr:2 Wo:5		27
	D	%	D	%	D	%	D	%	
	6	22	2	8	12	44	7	26	

Table 9. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 6	Mb: 2 Mn: 1 Pc:20		Cc:4 Fr:3		Od: 8		Pk:21 Rr:13 Wo: 6		78
	D	%	D	%	D	%	D	%	
	23	29	7	10	8	10	40	51	
Soil 7	Ay: 3 Mb: 1 Pc:13		Cc:2 Fr:2		Od:16		Br:14 Pk:14 Rr:13		78
	D	%	D	%	D	%	D	%	
	17	22	4	4	16	21	41	53	
Soil 8	Pc: 1		Fr:2		Od: 6		Br:14 Pk: 1 Rr:10		34
	D	%	D	%	D	%	D	%	
	1	2	2	6	6	18	25	74	
Soil 9	Ay: 1		Fr:6		Db: 2 Od:16		Br:37 Ho: 2 Pk:32 Rr:17		111
	D	%	D	%	D	%	D	%	
	1	4	6	7	18	16	86	77	
Soil 10							Br:16 Pk: 2 Rr: 5		28
	D	%	D	%	D	%	D	%	
							28	100	

Table 9. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Veg	Mb: 2 Mg: 2 Mn:20				Od:9		Br:16 Pk: 2 Rr: 5		66
	D	%	D	%	D	%	D	%	
	34	52			9	13	23	35	
Total	165		30		120		264		579

Soil Key

Au - Aubbeenaubbee
Ay - Ayr
Br - Brookston
Cc - Celina
Co - Corwin
Db - Darroch
Fr - Foresman
Jc - Jasper
Mb - Martinsville
Mg - Metea
Mn - Miami
Od - Odell
Pc - Parr
Pk - Patton
Pn - Plainfield
Rr - Rensselaer
Wk - Whitaker
Wo - Wolcott

Table Key

ED - excessively drained
WD - well drained
MWD - moderately well drained
SPD - somewhat poorly drained
VPD - very poorly drained
T - Total
D - Dots

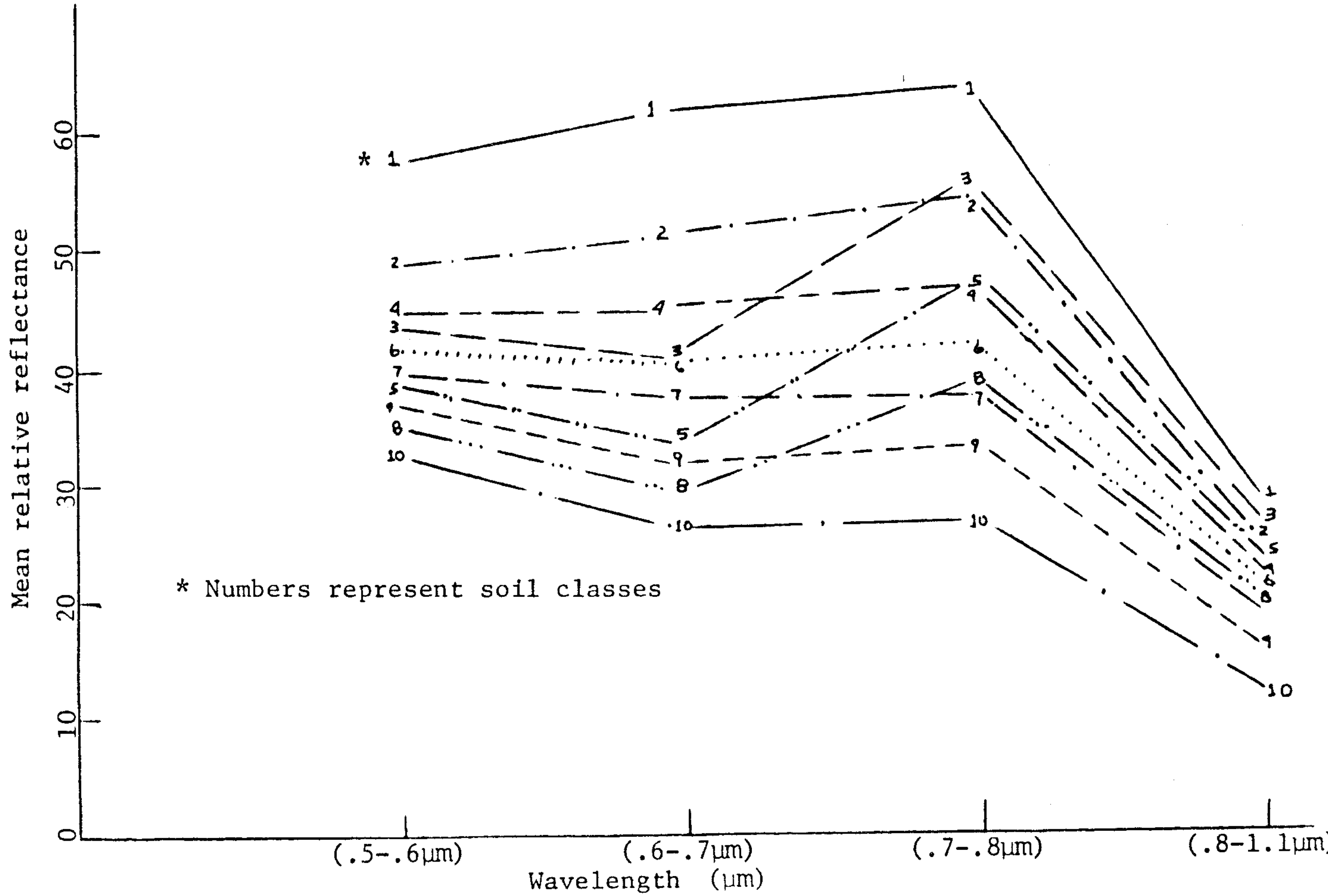


Figure 24. Soil spectral classes--rolling moraine.

In this parent material area, four quarter sections were mapped. This corresponds to 640 acres and represents 1.34% of the total area. The composition of the ten spectrally separable classes and the combined vegetation class is shown below. Water is classified as soil 10.

Soil 1 - This spectral class represents predominantly well or excessively drained soils. Those soils sampled included Miami, Plainfield, and Martinsville. Significant inclusions of somewhat poorly drained soils (Whitarer) are also found.

Soil 2 - This spectral class is dominantly well or excessively drained soils (Miami, Parr, Martinsville) but represent almost an equal percentage of somewhat poorly drained soils (Whitaker). Minor inclusions of the moderately well drained soils (Celina) and very poorly drained soils (Rensselaer) are found.

Soil 3 - This spectral class represents the well drained soils (Miami, Martinsville, Parr). Some inclusions of somewhat poorly drained soils (Odell, Whitaker) are apparent. This class is a soil-vegetation confusion class.

Soil 4 - The spectral class predominantly represents well drained soils (Miami, Parr Sparta, Jasper). Significant inclusions of somewhat poorly (Aubbeenaubee, Odell, Darroch, Whitaker) and very poorly drained soils (Patton, Rensselaer) are found. Minor inclusions of moderately well drained soils (Celina, Crosby) are also present.

Soil 5 - This spectral class represents the somewhat poorly drained soils (Odell, Whitaker). Signficant inclusions of very poorly drained (Wolcott, Rensselaer) and well drained (Parr, Martinsville) are also represented. Minor inclusions of moderately well drained soils occur (Foresman). This class is a soil-vegetation confusion class.

Soil 6 - This spectral class represents very poorly drained soils (Wolcott, Rensselaer, Patton). Significant inclusions of well drained soils (Parr, Martinsville, Miami) are present. Minor inclusions of moderately well drained soils (Celina, Foresman) and somewhat poorly drained soils (Odell) also occur.

Soil 7 - This spectral soil class is predominantly very poorly drained soils (Brookston, Rensselaer, Patton) with a high percentage of well drained inclusions (Parr, Ayr, Martinsville). The somewhat poorly drained soils (Odell) also represent significant inclusions. The moderately well drained soils (Celina, Foresman) represent only minor inclusions.

Soil 8 - This spectral class is predominantly very poorly drained soils (Brookston, Rensselaer, Patton). A significant portion of somewhat poorly drained soils (Odell) occur. Minor inclusions of well drained soils (Parr) and moderately well drained soils (Foresman) are represented. This is a soil-vegetation confusion class.

Soil 9 - This spectral class is dominantly very poorly drained soils (Patton, Houghton, Rensselaer, Brookston). Some inclusions of somewhat poorly drained soils (Odell, Darroch) are significant. Minor inclusions of well drained (Ayr) and moderately well drained (Foresman) also occur.

Soil 10 - This spectral class represents only very poorly drained soils (Patton, Houghton, Rensselaer, Brookston).

Vegetation - The vegetation class in this parent material area represents well drained soils (Miami, Metea, Parr, Martinsville). Significant inclusions of very poorly drained soils (Rensselaer, Patton, Brookston) occur. Minor inclusions of somewhat poorly drained soils (Odell) are also represented.

Discussion

The general trend of soil spectral class versus percent well drained and very poorly drained is apparent in this parent material area (Figure 25).

Soils 1,2,3, and 4 are predominantly well drained soils with soils of all drainage classes represented. In fact, this parent material area has a broad range of percentages of soils of all drainage classes as compared to other parent material areas. The reason for this may be in the nature of the soils that are developed in this parent material. Till has a characteristic mottled pattern with many light and dark soils delineations. The averaging effect as described before may be at work here.

Soil 5 is predominantly somewhat poorly drained soils but also includes significant percentages of well drained and very poorly drained soils. Soils 6,7,8,9 and 10 are all predominantly very poorly drained soils. With the exception of soil 10, however, all of these spectral classes have significant inclusions of soils of better drainage classes.

Soils 3,5 and 8 are soil-vegetation classes. Figure 26 presents a graph of these three spectral classes as compared to a vegetation class. Interpretation of these spectral classes as soils should be avoided. They should only be interpreted in conjunction with surrounding soils classes.

The vegetation class is predominantly well drained soils. This is in contrast to the previous parent material areas where vegetation is predominantly very poorly drained soils.

Based on the grid count, some combinations of spectral classes can be made. Combination one is no combination. Combination two combines 4 and 5 together, 6 and 7 together, and 8 and 9 together.

The results of these combination of classes can be seen in Figures 27 and 28. Analysis of T29N, R7W, Sec. 12, NW¼ which was mapped for this study indicates that the best spectral class combination is combination two. Combination three eliminates too much soil information. Combination one (no combination) also appears to be adequate for this area. Figure 29a is the soil map for this quarter section.

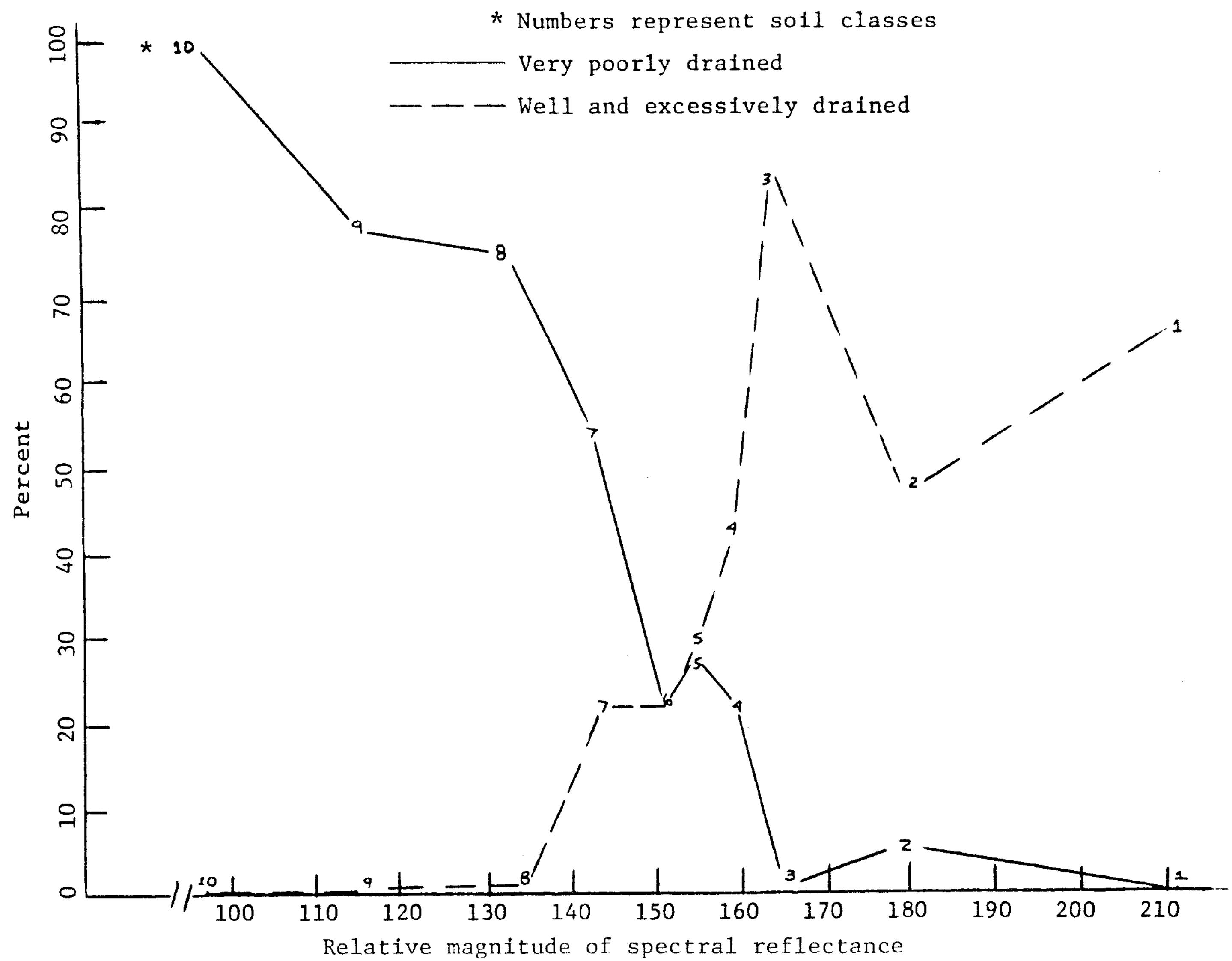


Figure 25. Relative drainage composition of spectral soil classes vs. magnitude (rolling moraine).

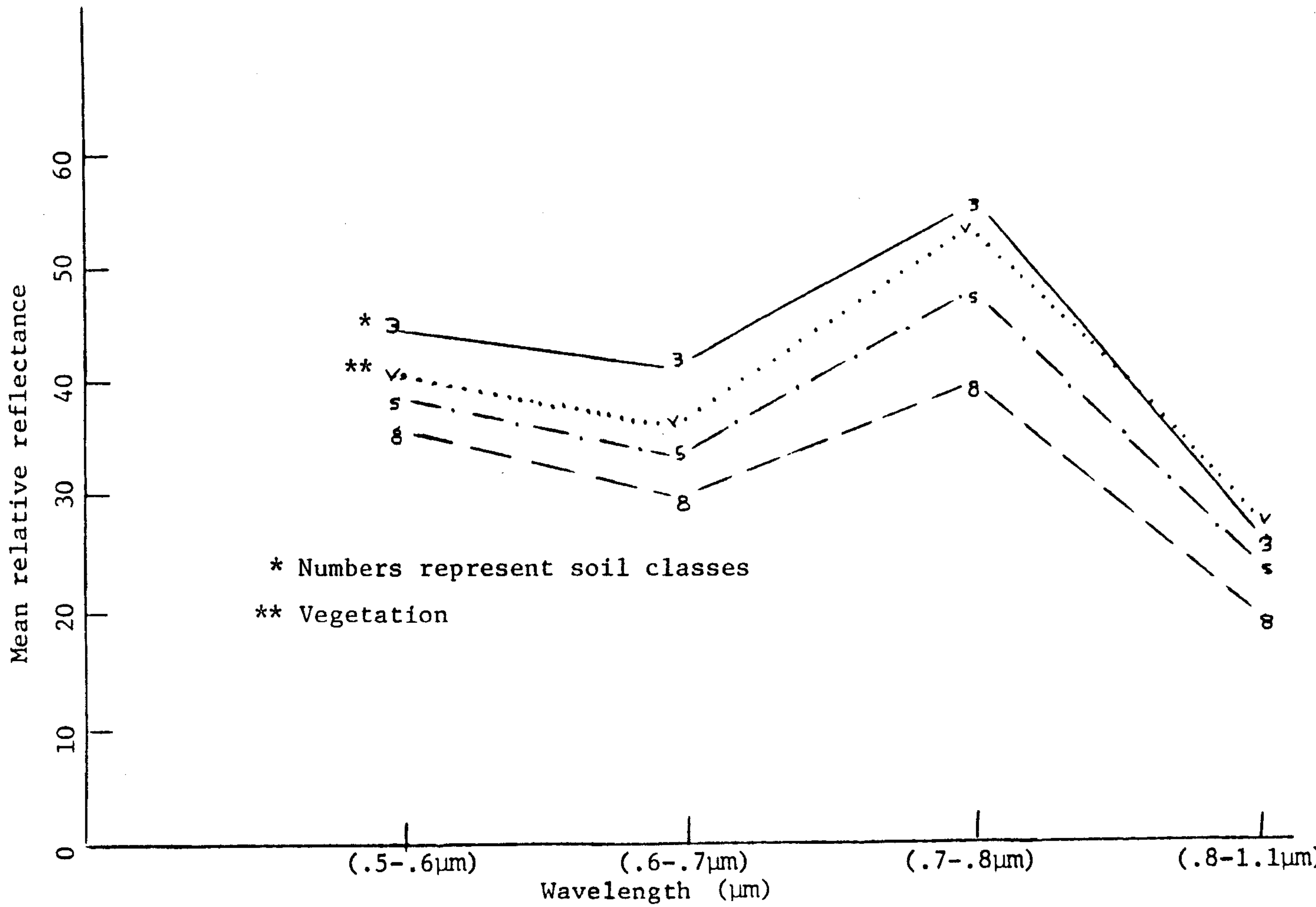


Figure 26. Soil-vegetation confusion classes--rolling moraine.

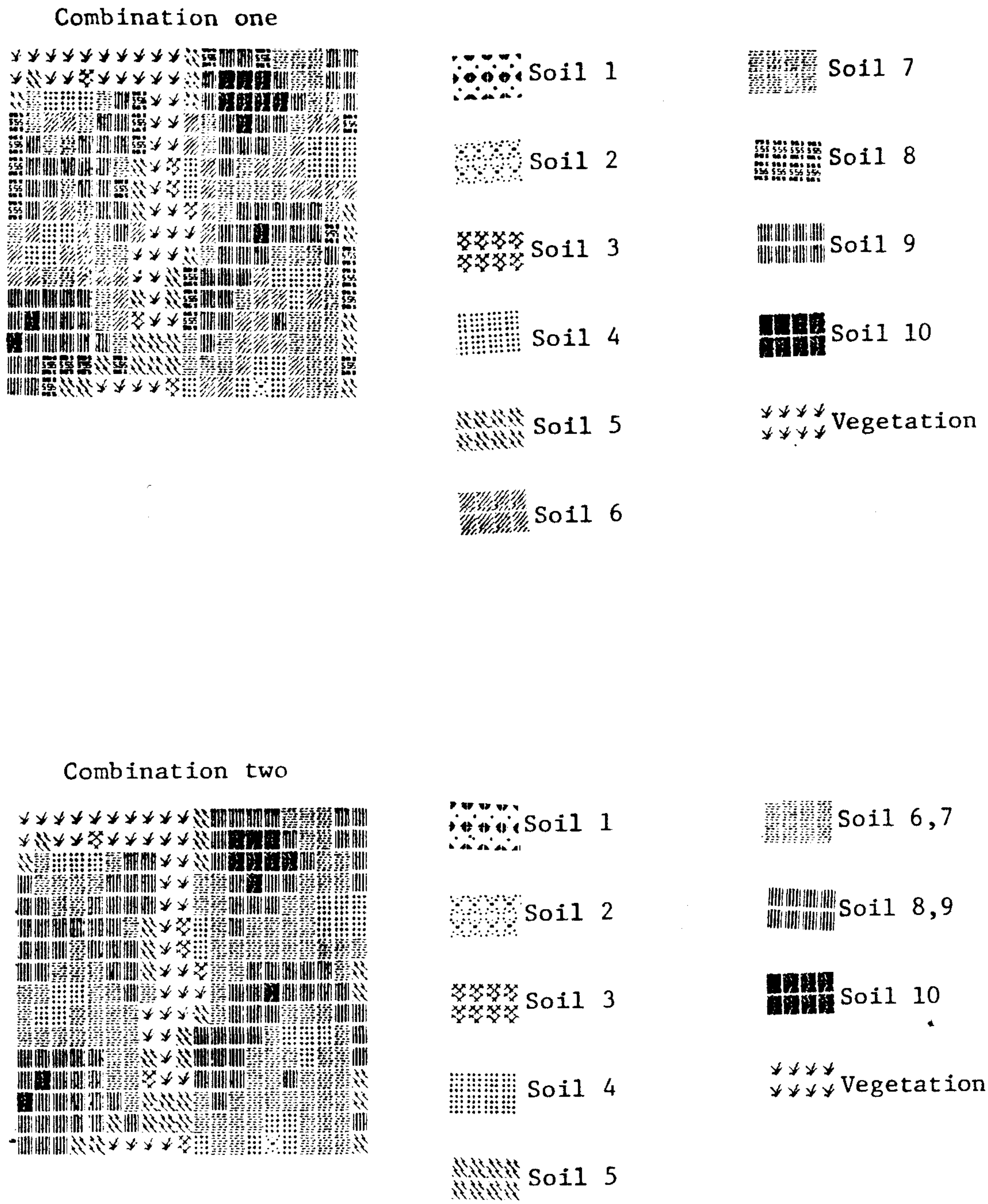


Figure 27. Combinations for T29N, R7W, Sec. 12, NW¼.

Combination three

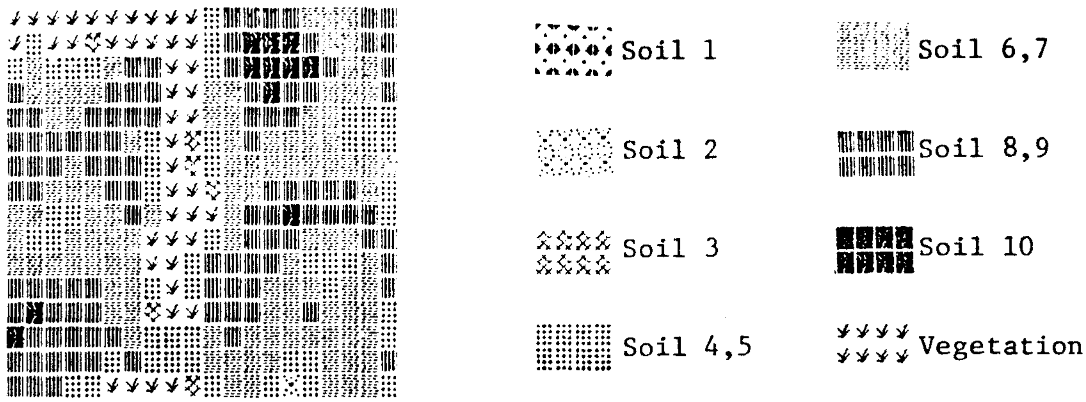
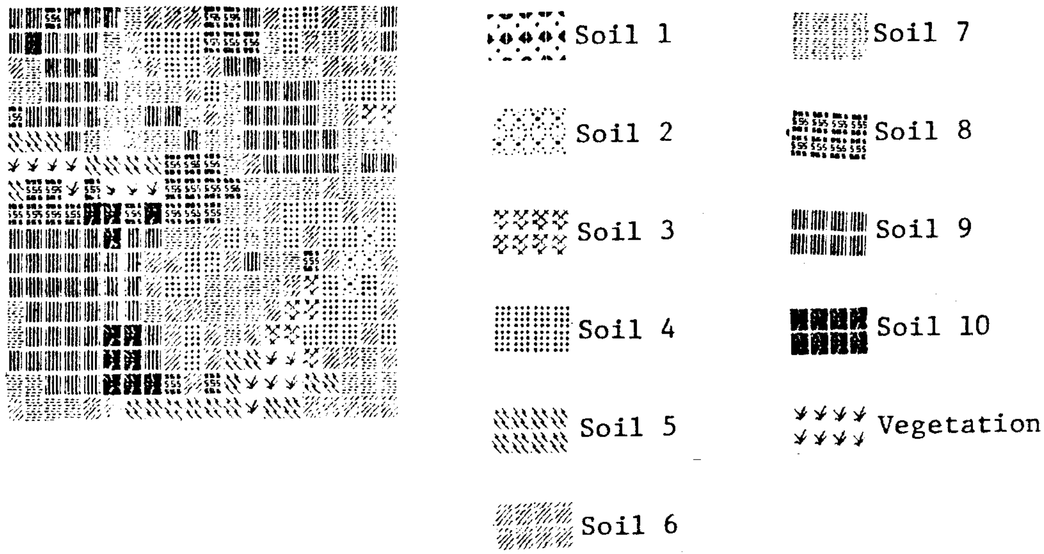


Figure 27. (Continued).

Combination one



Combination two

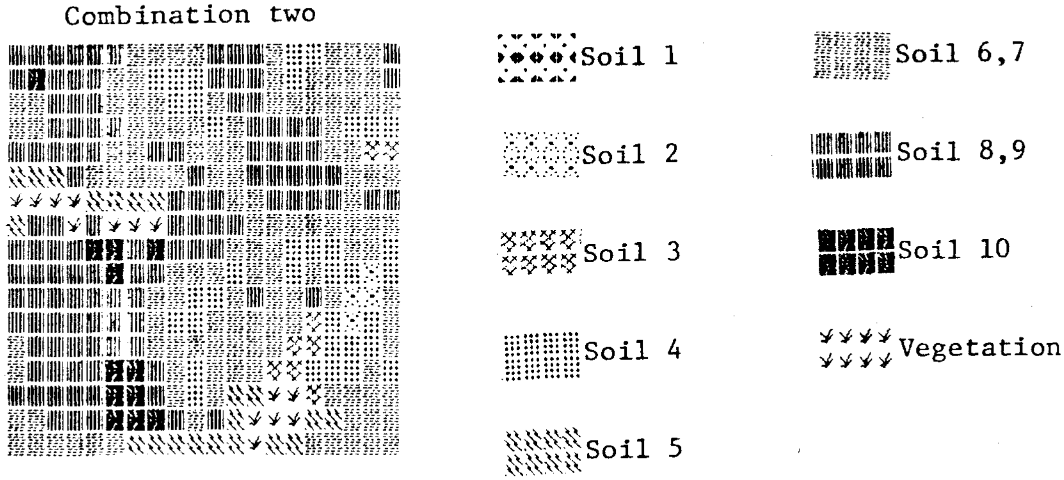


Figure 28. Combinations for T29N, R7W, Sec. 15, SW¼.

Combination three

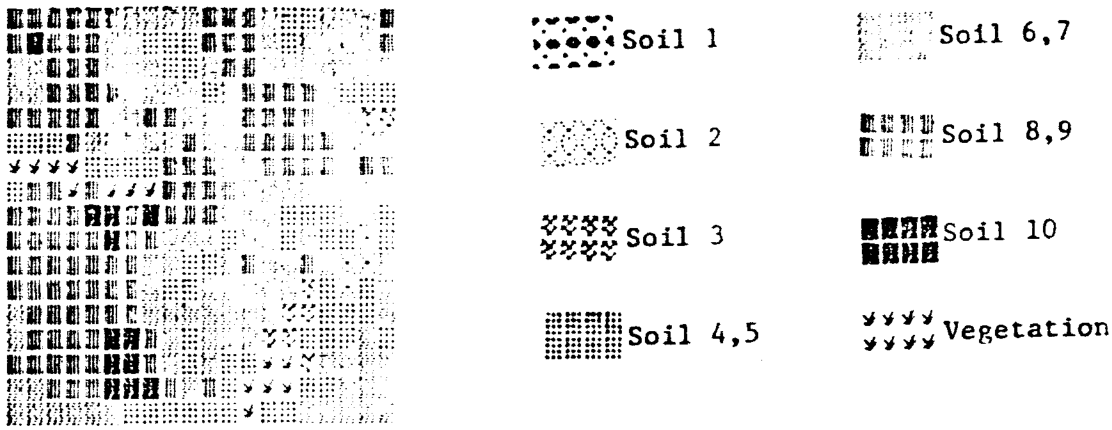
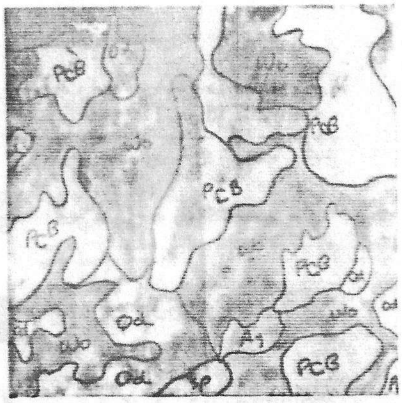


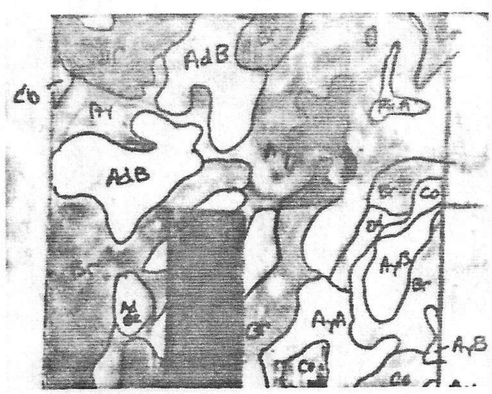
Figure 28. (Continued).



Legend 1

Ay - Ayr
Od - Odell
PcB - Parr, 2-6% slope
Sp - Sparta
Wo - Wolcott

Figure 29a. Soil map of T29N, R7W, Sec. 12, NW¼.



Legend 2

AdB - Ade, 0-2% slope
Ay - Ayr
AyB - Ayr, 0-2% slope
Br - Brookston
Co - Corwin
PnA - Plainfield, 0-2% slope

Figure 29b. Soil map of T29N, R7W, Sec. 15, SW¼.

Analysis of the CNI plot (not mapped in this study) supports the conclusion that combination two is ideal and combination one is adequate. The soil spectral classes generally agree with the CNI mapping, but the spectral map seems to indicate a greater percentage of poorly drained soils. While this quarter section was not mapped, the results of field checking indicated that there was, in fact, a greater percentage of poorly drained soils than is represented in the CNI map (Figure 29b).

Figure 30 is a reclassification of T29N, R7W, Sec. 12, NW¼ elimination the soil-vegetation confusion classes (soils 3,5 and 8). The changes are indicated below (Table 10).

This indicates that soils 3 and 5 are dominantly vegetation, but soil 8 is predominantly soils. These spectral classes should be interpreted with this in mind.

Table 10. Soil-vegetation analysis, rolling moraine.

Soil-vegetation Confusion Class	Total Points in ¼ Section	Points after Reclassification	% Change
3	6	6 to vegetation	100%
		20 to vegetation	77%
5	26	4 to soil 6	15%
		2 to soil 7	8%
		6 to vegetation	24%
8	25	8 to soil 7	32%
		11 to soil 9	44%

Lacustrine

Table 11 indicates the relative percentage composition of soil for the spectral classes found in the lacustrine area. Lacustrine soils include 43,360 acres, representing 17,7% of the entire county. The graph of the spectral responses is shown in Figure 31.

In this parent material area six quarter section (960 acres) were mapped, representing 1.52% of the lacustrine area. The composition of the seven spectrally saparate soil classes and the combined vegetation class is described below. No separate class was developed for water; therefore, it will be classified as soil 7.

Soil 1 - This spectral class is predominantly well and excessively drained soils (Chelsea, Dickinson) with significant inclusions of the moderately well drained Alvin.

Soil 2 - This spectral class is dominated by well and excessively drained soils (Jasper, Sparta, Plainfield, Chelsea, Dickinson) with significant inclusions of the moderately well drained Alvin soil. Minor inclusions of somewhat poorly drained Darroch and Tedrow are found as are very poorly drained soils (Rensselaer).

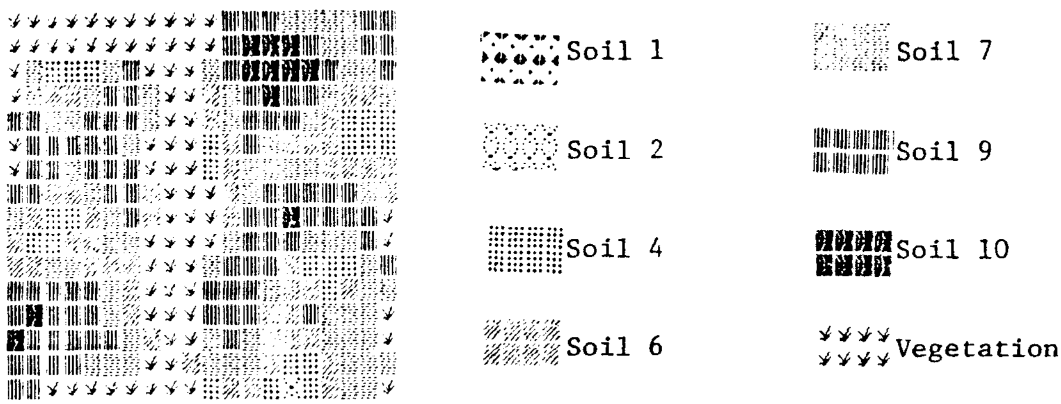


Figure 30. T29N, R7W, Sec. 12, NW¼, eliminating soil-vegetation classes 3, 5 and 8.

Table 11. Dot grid count for lacustrine area.

Class	ED - WD		MWD		SPD		VPD		T
Soil 1	Ch: 3 Dk: 3		Al: 3						8
	D	%	D	%	D	%	D	%	
	6	63	3	37					
Soil 2	Ch:15 Dk:32 Jc: 3 Pn: 3		Al:38		Db:18 Td: 1		Rr: 15		133
	D	%	D	%	D	%	D	%	
	61	46	38	29	19	14	15	11	
Soil 3	Ch: 1 Dk: 7 Jc: 2 Pn: 3		Al :12		Rt: 1		Rr: 4		30
	D	%	D	%	D	%	D	%	
	13	43	12	40	1	4	4	13	
Soil 4	Ch: 8 Dk:33 Jc: 7 Sp: 3		Al:29		Db:37 Rt: 5 Td: 1		Ma: 2 Rr:103		233
	D	%	D	%	D	%	D	%	
	51	22	29	13	43	18	110	47	
Soil 5	Ch:13 Jc: 3 Sp: 1		Al:23		Db:76 Od: 1 St: 1 Td: 1		Ma: 14 Rr:156		293
	D	%	D	%	D	%	D	%	
	17	6	23	8	79	27	174	59	

Table 11. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 6	Ch:2 Dk:3		Al: 6				Ma: 5 Rr: 4		20
	D	%	D	%	D	%	D	%	
	5	25	6	30			9	45	
Soil 7	Ch:5 Dk:6		Al: 4		Db:12 Rt: 3 St: 4		Ma: 39 Rr:156		228
	D	%	D	%	D	%	D	%	
	11	5	4	2	19	8	194	85	
Veg	Dk:6 Jc:2 Pn:9		Al:27		Db: 1 Rt: 1		Ma: 2 Rr: 15		63
	D	%	D	%	D	%	D	%	
	17	27	27	43	2	3	17	27	
Total	180		142		163		523		1008

Soil Key

Al - Alvin
Ch - Chelsea
Db - Darroch
Dk - Dickinson
Jc - Jasper
Ma - Mahalasville
Od - Odell
Pn - Plainfield
Rt - Roby
Sp - Sparta
St - Starks
Td - Tedrow
Rr - Rensselaer

Table Key

ED - excessively drained
WD - well drained
MWD - moderately well drained
SPD - somewhat poorly drained
VPD - very poorly drained
T - Total
D - Dots

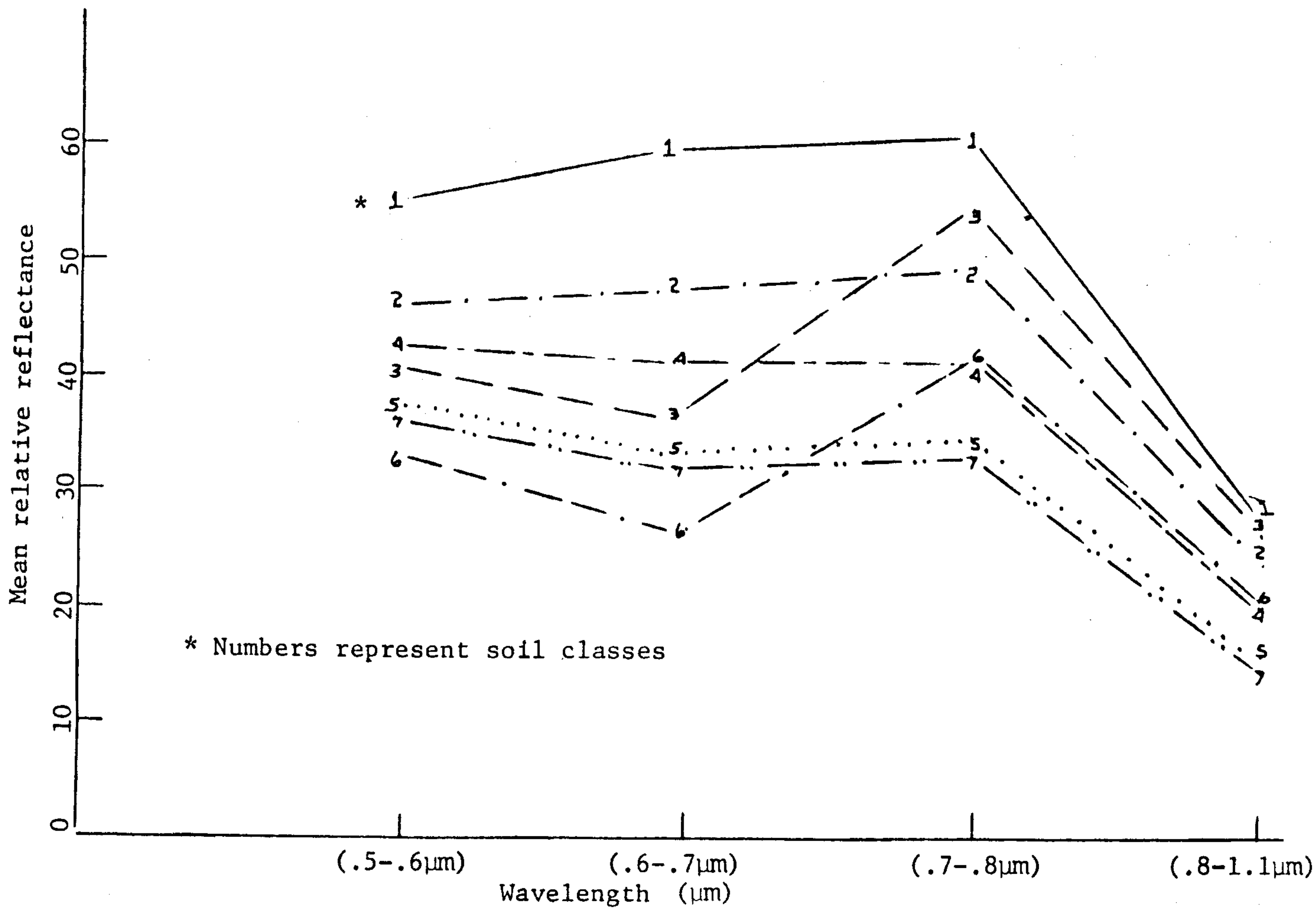


Figure 31. Soil spectral classes--lacustrine.

Soil 3 - This soil spectral class predominantly represents well and excessively drained soils (Jasper, Plainfield, Dickenson, Chelsea). The moderately well drained soils represent an almost equal percentage (Alvin). Minor inclusions of the somewhat poorly drained soils (Roby) and very poorly drained soils (Rensselaer) are also apparent. This class is a soil-vegetation confusion class.

Soil 4 - This spectral class is predominantly very poorly drained soils (Rensselaer, Mahalasville). Inclusions of somewhat poorly drained (Darroch, Roby, Tedrow) and moderately well drained (Alvin) and well and excessively drained soils (Dickenson, Chelsea, Sparta, Jasper) also occur.

Soil 5 - This spectral class is dominated by the very poorly drained soils (Rensselaer, Mahalasville). The somewhat poorly drained soils (Darroch, Starks, Tedrow, Odell) are significant inclusions. Minor inclusions of moderately well (Alvin) and well and excessively drained soils (Chelsea, Jasper, Sparta) also occur.

Soil 6 - This spectral class has a wide spread of soils but predominantly represents the very poorly drained soils including Rensselaer and Mahalasville. The well and excessively drained (Dickenson, Chelsea) and moderately well drained (Alvin) are significant inclusions. This class is a soil-vegetation confusion class.

Soil 7 - This spectral class is dominantly very poorly drained soils (Rensselaer, Mahalasville). The somewhat poorly drained soils (Darroch, Roby, Starks), moderately well drained soils (Alvin), and well and excessively drained soils (Chelsea, Dickenson) all make up minor inclusions.

Vegetation - The vegetation class is dominated by the moderately well drained soils (Alvin). The well and excessively drained soils (Plainfield, Jasper, Dickenson) and the very poorly drained soils (Rensselaer, Mahalasville) are equally represented. The somewhat poorly drained soils (Roby, Darroch) represent minor inclusions.

Discussion

The trend of increasing percent of very poorly drained soils with decreasing magnitude of spectral reflectance is indicated in Figure 32.

Soils spectral classes 1,2 and 3 are dominated by well and excessively drained soils while 4,5,6 and 7 are predominantly very poorly drained soils. Soils 2 and 3 have significant inclusions of somewhat poorly and very poorly drained soils. Soil 4, while predominantly very poorly drained, has significant inclusions of other drainage classes, as do soils 5 and 6.

Soils 3 and 6 are soil-vegetation confusion classes as illustrated in Figure 33. This explains the significant percentages of unlike soil drainage classes for these two soil spectral classes. Soil 4 also has a broad range and may represent a transitional soil. Comparing the spectral map to the conventional soils map (Figures 34a and 35), this seems likely.

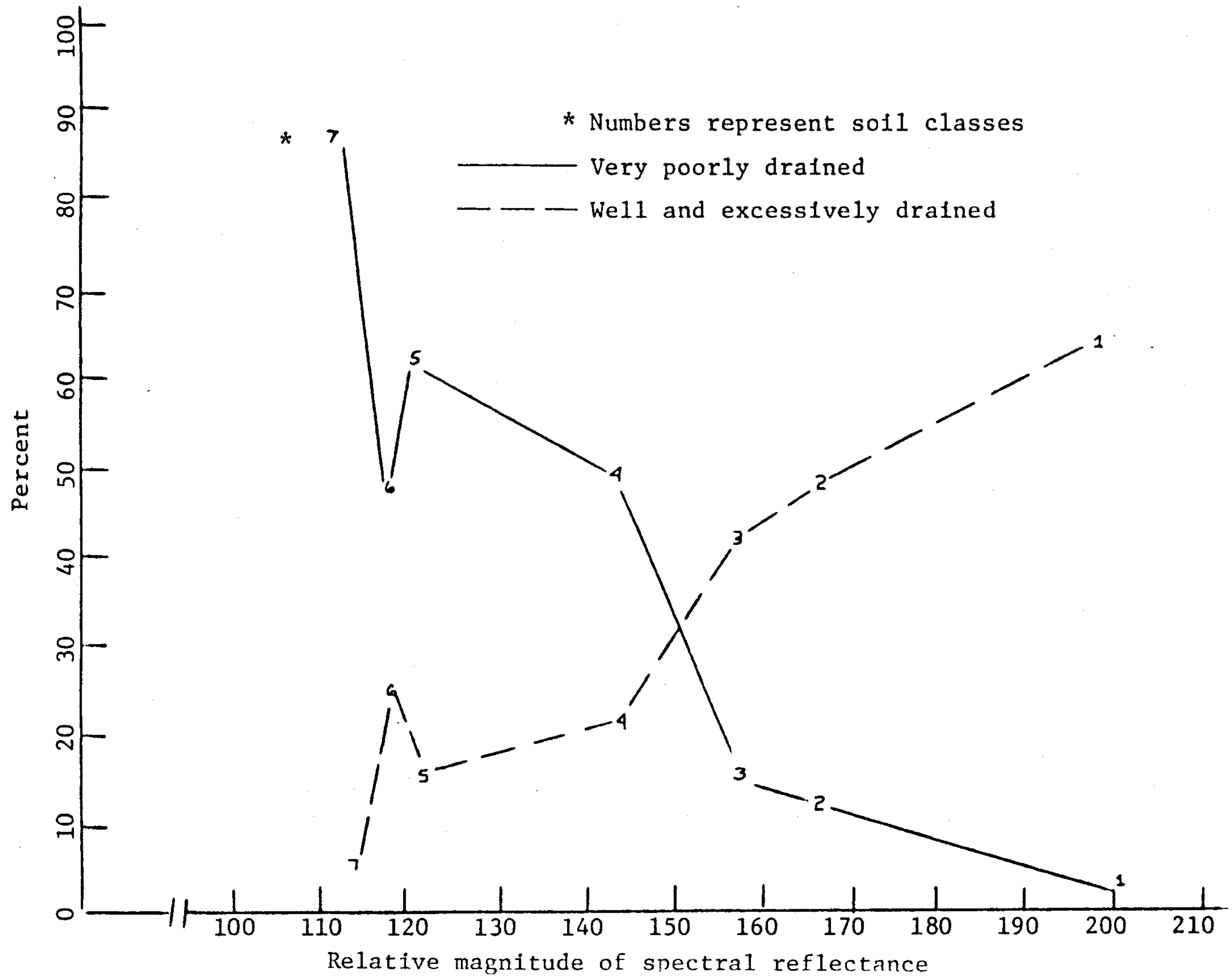


Figure 32. Relative drainage composition of spectral soil classes vs. magnitude (lacustrine).

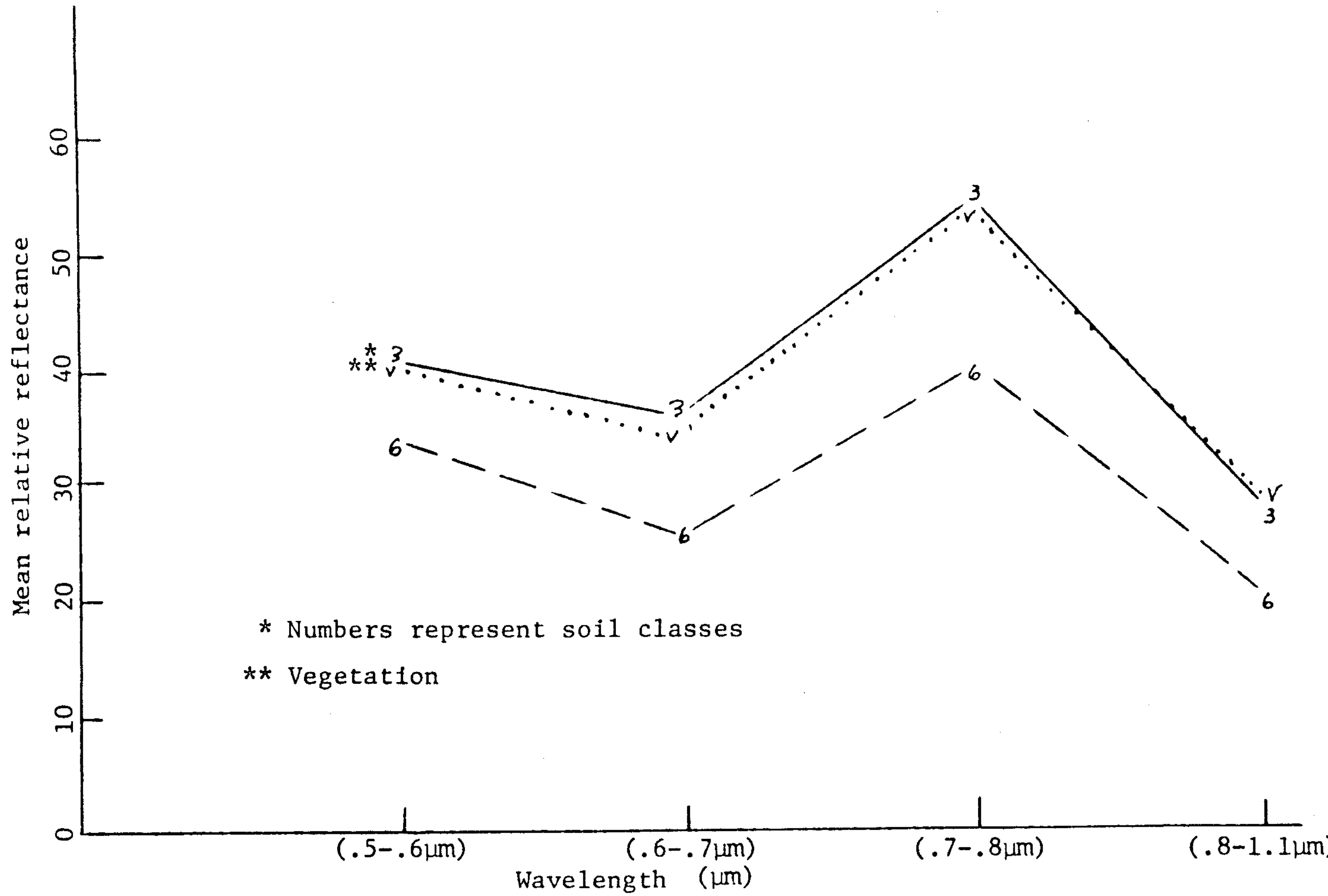
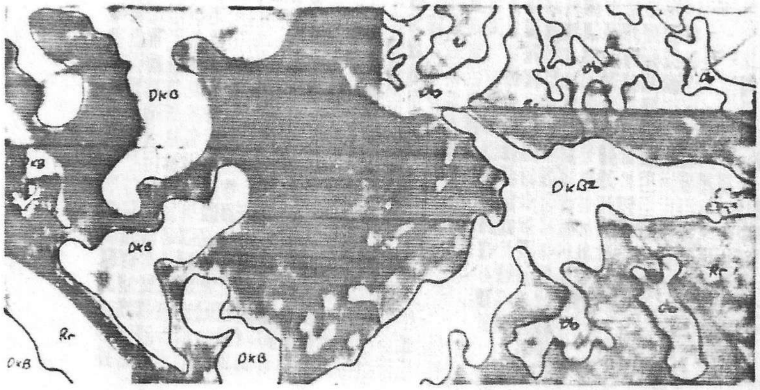


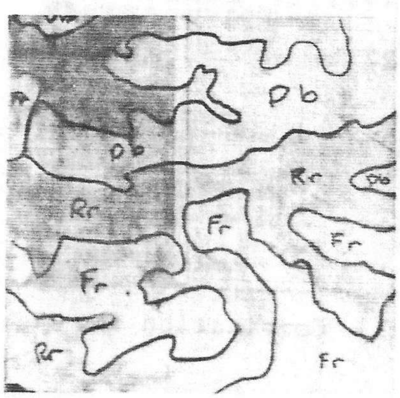
Figure 33. Soil-vegetation confusion classes--lacustrine.



<u>Legend 1</u>

Db - Darroch
DkB - Dickinson, 2-6% slope
DkB2 - Dickinson, 2-6% slope, moderately eroded
Rr - Rensselaer

Figure 34a. Soil map of T28N, R7W, Sec. 32, S½.

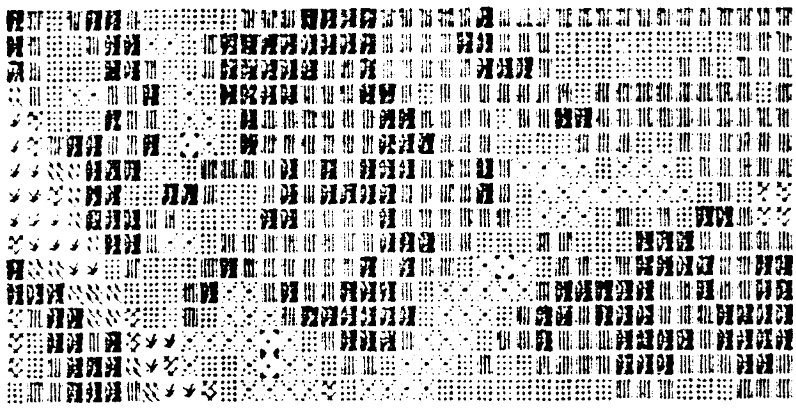


<u>Legend 2</u>

Db - Darroch
Fr - Foresman
Rr - Rensselaer

Figure 34b. Soil map of T28N, R7W, Sec. 31, NW¼.

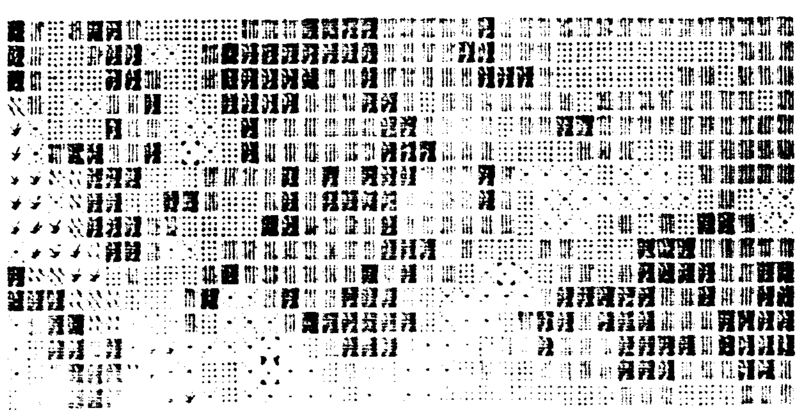
Combination one



Soil 1 | Soil 4 | Soil 7

Soil 2 | Soil 5 | Vegetation

Soil 3 | Soil 6



Vegetation

Combination two

Soil 1 | Soil 4 | Soil 6

Soil 2,3 | Soil 5 | Soil 7

Figure [illegible]. Combinations for T28N, R7W, Sec. 32, S½.

Combination three

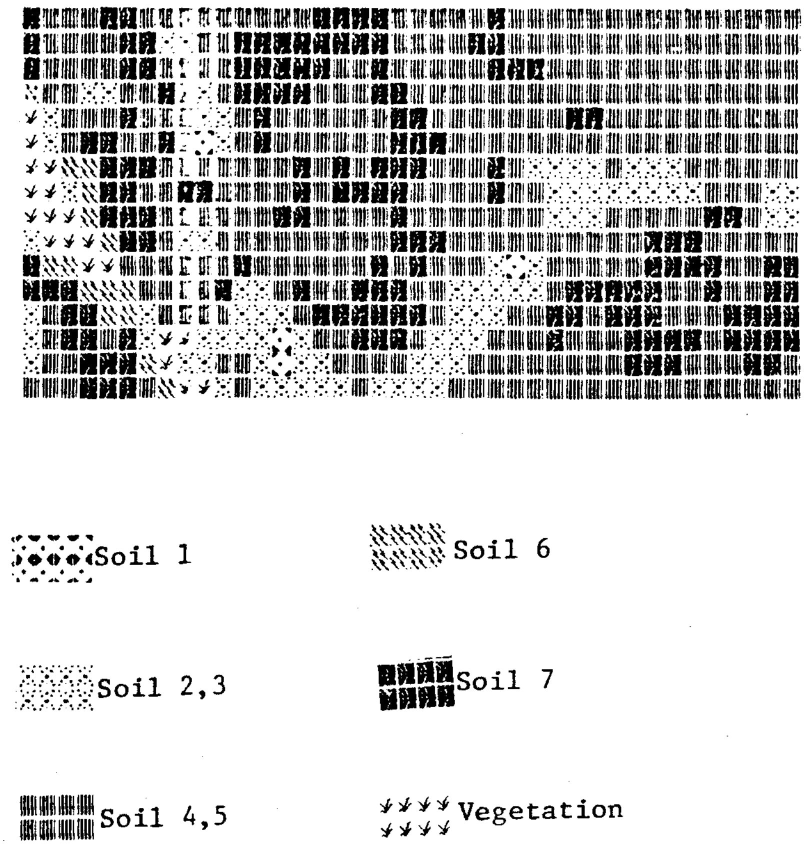


Figure 35. (Continued).

The vegetation class is dominantly somewhat poorly drained soils but has significant inclusions of well and excessively drained and very poorly drained soils. These results for the vegetation class are not consistent with the vegetation classes in the previous parent material area.

The following combinations of spectral classes are proposed based on the above analysis. Combination one is no combination. Combination two groups soils 2 and 3. Combination three groups 2 and 3 together and 4 and 5 together. The resulting maps displaying these combination are displayed in Figures 35 and 36. Soil maps are shown in Figures 34a and 34b.

Analysis of T28N, R7W, Sec. 32, S½ (mapped in this study) indicates that combination two is the best combination for this area. Combination three results in a loss of soil information and combination one appears too confusing. Analysis of the CNI quarter section (not mapped in this study) also indicates that combination two is quite adequate although combination one is not significantly different.

Figure 37 is a reclassification of T28N, Sec. 32, S½ elimination the soil-vegetation confusion classes 3 and 6. The changes are shown below.

Table 12. Soil-vegetation analysis, lacustrine

Soil-vegetation Confusion Class	Total Points in ¼ Section	Points after Reclassification	% Change
3	15	12 to vegetation	80%
		3 to soil 5	20%
6	15	11 to vegetation	73%
		4 to soil 7	27%

This indicates that soils 3 and 6 are influenced by vegetation. In both cases any data points that were reclassified as soil became soil of a lesser spectral magnitude. Combination two still appears to be the best of those considered for this area.

Ground Moraine, Alfisols

Table 13 indicates the relative percentage composition of the soil spectral classes for the ground moraine, Alfisol area. These soils include 14,080 acres representing 3.9% of the entire county. The curves of the spectral responses are shown in Figure 38.

In this parent material area two quarter sections (320 acres) were mapped, representing 2.27% of the ground moraine, Alfisol area. The composition of the eleven spectral classes of soils and the one combined vegetation class are described below. A separate class was not developed for water; therefore, it is classed as soil 11.

Soil 1 - This soil spectral class represents predominantly well drained soils (Octagon). The moderately well drained soils (Corwin) represent significant inclusions. The somewhat poorly drained soils (Darroch) represent relatively minor inclusions.

Soil 2 - This soil spectral class represents a wide range of soil drainage classes but has a equal precentage of moderately well drained (Corwin) and somewhat poorly drained (Darroch, Odell) soils. The well and excessively drained soils (Chelsea, Octagon) represent significant inclusions while the very poorly drained soils (Rensselaer) are only minor inclusions.

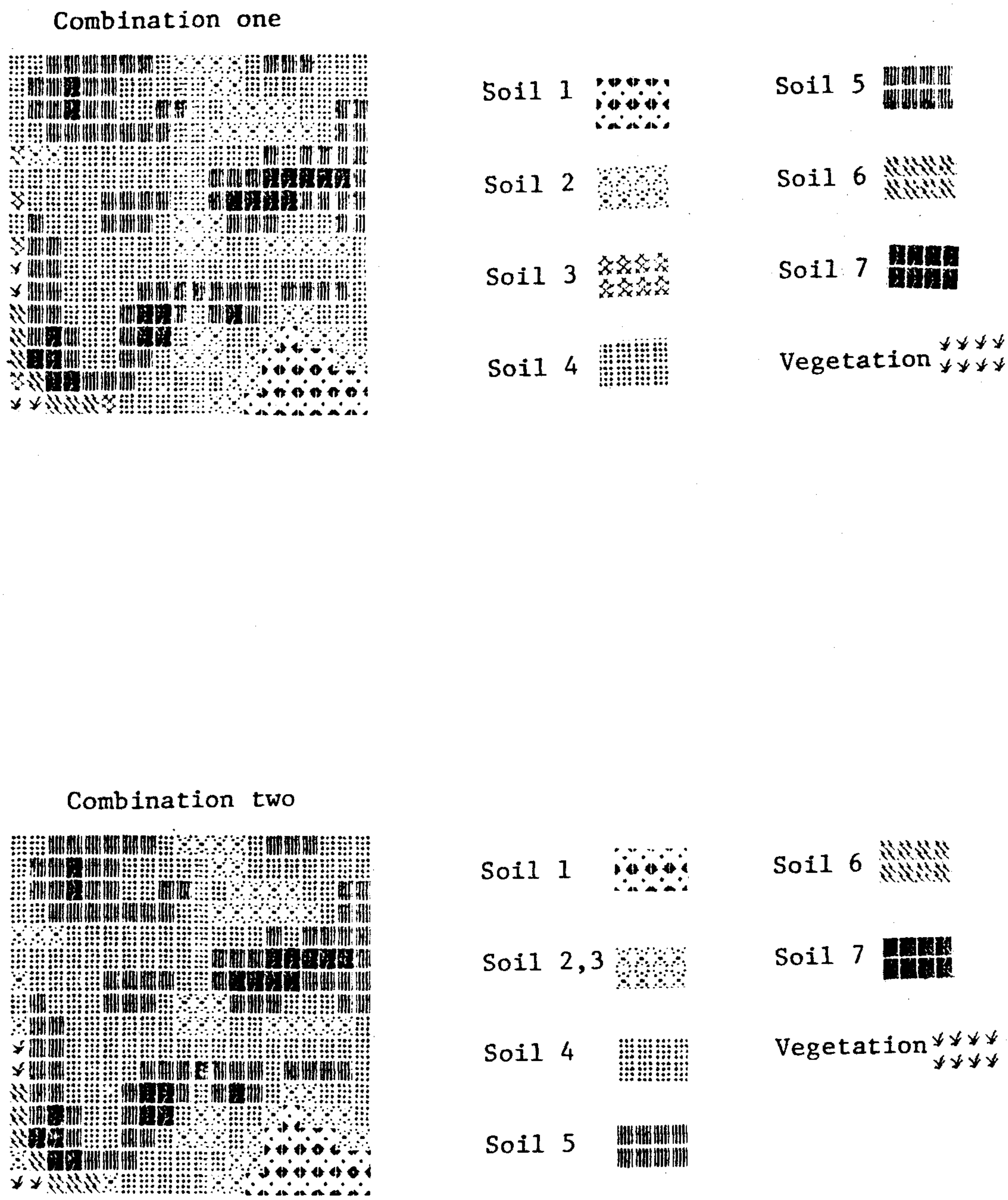


Figure 36. Combinations for T28N, R7W, Sec. 31, NW¼.

Combination three

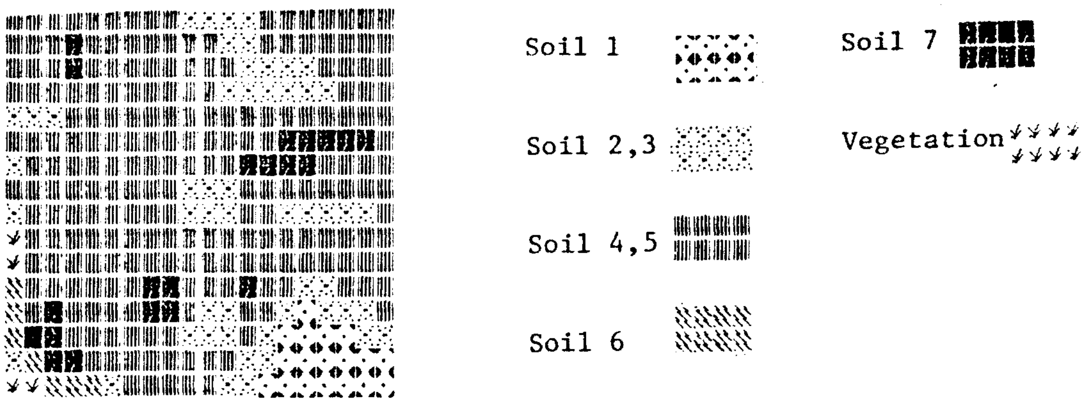


Figure 36. (Continued).

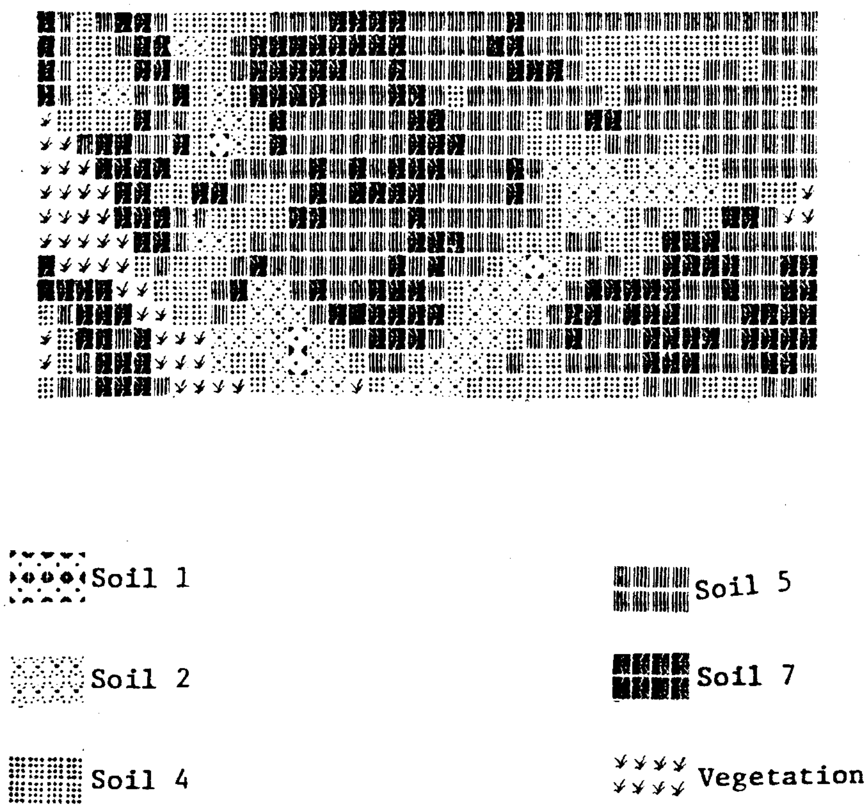


Figure 37. T28N, R7W, Sec. 32, S½, eliminating soil-vegetation classes 3 and 6.

Table 13. Dot grid count for ground moraine, Alfisols.

Class	ED - WD			MWD			SPD			VPD			T
		D	%		D	%		D	%		D	%	
Soil 1	Oc:10	10	56	Co: 6	6	33	Db:2	2	11				18
Soil 2	Ch: 1 Oc: 3	4	27	Co:5	5	33	Db:2 Od:3	5	33	Rr:1	1	7	15
Soil 3				Co:3	3	25	Od:9	9	75				12
Soil 4	Ch: 4	4	11	Co:15 Mo: 2	17	46	Od:7	7	19	Br:6 Rr:3	9	24	37
Soil 5	Ch: 2	2	24				Od:3	3	38	Br:3	3	38	8

Table 13. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 6	Ch:1		Co:13		Od: 9		Br:21 Rr: 4		48
	D	%	D	%	D	%	D	%	
	1	2	13	27	9	19	25	48	
Soil 7	Ch: 2		Co: 6		Db: 1 Od:10		Br:45 Rr: 2		66
	D	%	D	%	D	%	D	%	
	2	3	6	9	11	17	47	71	
Soil 8	Ch: 2				Od: 1		Br:18 Rr: 3		24
	D	%	D	%	D	%	D	%	
	2	8			1	4	21	88	
Soil 9			Co: 7		Od: 8		Br:50 Rr: 5		70
	D	%	D	%	D	%	D	%	
			7	10	8	11	55	79	
Soil 10			Co: 3		Od: 5		Br:30 Rr: 1		39
	D	%	D	%	D	%	D	%	
			3	8	5	13	31	79	

Table 13. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 11			Co:3		Od:7		Br:30		40
	D	%	D	%	D	%	D	%	
			3	7	7	18	30	75	
Veg	Ch:30								30
	D	%	D	%	D	%	D	%	
	30	100							
Total	55		63		67		222		407

Soil Key

Br - Brookston
Ch - Chelsea
Co - Corwin
Db - Darroch
Oc - Octagon
Od - Odell
Mo - Montmorenci
Rr - Rensselaer

Table Key

ED - excessively drained
WD - well drained
MWD - moderately well drained
SPD - somewhat poorly drained
VPD - very poorly drained
T - Total
D - Dots

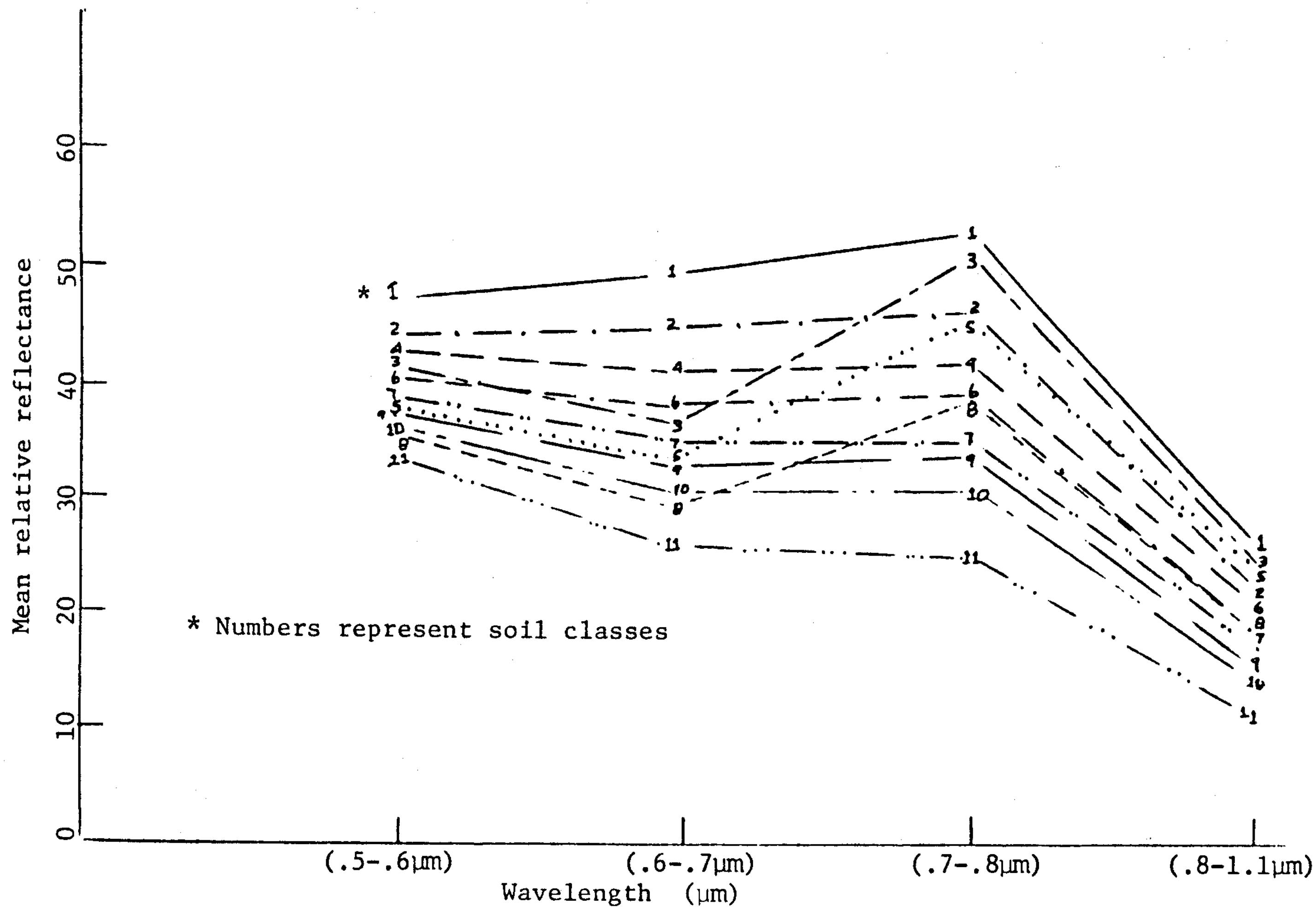


Figure 38. Soil spectral classes--ground moraine, Alfisols.

Soil 3 - This soil class is predominantly somewhat poorly drained soils (Odell). The moderately well drained soils (Corwin) represent significant inclusions. This class is a soil-vegetation confusion class.

Soil 4 - This soil spectral class represents moderately well drained soils (Corwin, Montmorenci). The very poorly drained soils (Rensselaer, Brookston) are significant inclusions as are the somewhat poorly drained (Odell). The excessively drained soils (Chelsea) represent only minor inclusions.

Soil 5 - This soil class represents the very poorly drained (Brookston) and somewhat poorly drained soils (Odell) equally. Excessively drained soils (Chelsea) are significant inclusions. This class is a soil-vegetation confusion class.

Soil 6 - This soil spectral class is predominantly the very poorly drained soils (Brookston, Rensselaer). The moderately well drained soils (Corwin) and somewhat poorly drained soils (Odell) are significant inclusions. The excessively drained soils (Chelsea) are only minor inclusions.

Soil 7 - This spectral class is predominantly very poorly drained soils (Rensselaer, Brookston). The somewhat poorly drained soils (Darroch, Odell) represent significant inclusions. The moderately well drained (Corwin) and excessively drained (Chelsea) soils are minor inclusions.

Soil 8 - This soil spectral class is predominantly very poorly drained soils (Brookston, Rensselaer). Excessively drained soils (Chelsea) and somewhat poorly drained soils (Odell) represent minor inclusions. This soil class is a soil-vegetation confusion class.

Soil 9 - This spectral class is predominantly very poorly drained soils (Brookston, Rensselaer). Moderately well drained soils (Corwin) and somewhat prooly drained soils (Odell) both are minor inclusions.

Soil 10 - This soil spectral class is predominantly very poorly drained soils (Brookston, Rensselaer). The somewhat poorly drained soils (Odell) represent significant inclusions. The moderately well drained soils repesent minor inclusions.

Vegetation - The vegetation class, as found on the sample quarter sections, as entirely well drained soils (Chelsea).

Discussion

In this material area the trend of increasing percent of very poorly drained soils with decreasing magnitude of spectral reflectance is evident (Figure 39).

All soil spectral classes in this parent material area represent a broad range of soils of all drainage classes. In addition, there are more distinct spectral classes in this parent material area than in any other parent material area, as illustrated below (Table 14).

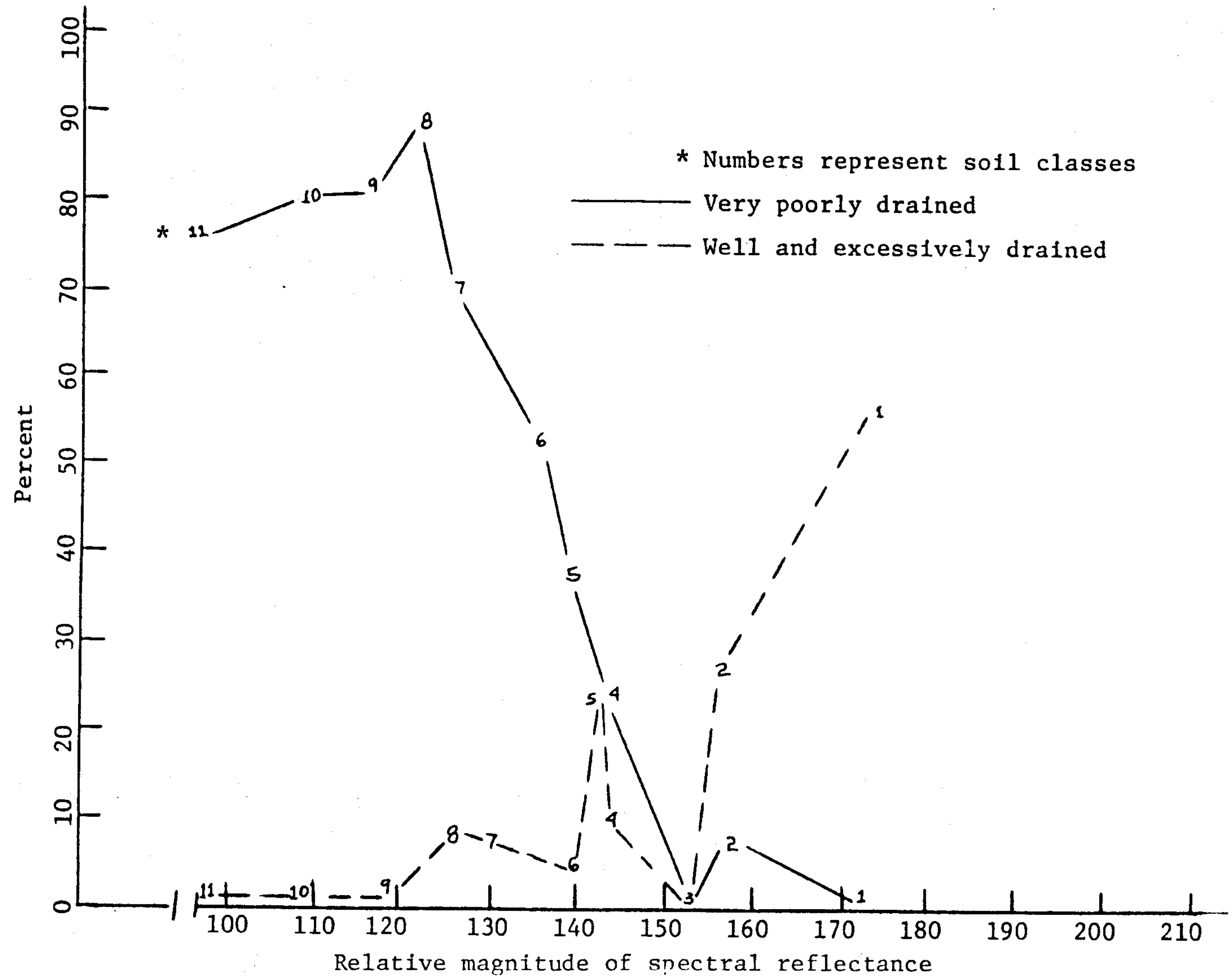


Figure 39. Relative drainage composition of spectral soil classes vs. magnitude (ground moraine, Alfisols).

Table 14. Comparison of number of spectral classes within parent material areas.

Ground Moraine, Alfisols	Other Parent Material Areas
11 spectral classes	Outwash - 8 spectral classes Outwash/till - 8 spectral classes Rolling moraine - 10 spectral classes Lacustrine - 7 spectral classes Ground moraine, Mollisols - 8 spectral classes

The reasons behind so many spectral classes are elusive. The nature of the till area and the averaging effect, as described before, may contribute to the large number of classes. There may have been different cultural practices in this area, hence creating distinct spectral classes. Relatively few sample points used in the training for creation of the spectral statistics may have contributed to the problem.

Soil 1 is the only spectral class that represents well drained soils. Soils 2 and 4 show a broad range with soil 2 representing moderately well and somewhat poorly drained soils equally. Soils 3, 5 and 8 are soil-vegetation confusion classes (Figure 40). Soils 6 and 7 are increasingly poorly drained soils but have significant inclusions of soils of other drainage classes. Soils 9, 10 and 11 are also predominantly poorly drained soils but also contain a significant percentage of soils of other drainage classes. The vegetation class in this area was entirely well drained. This is not consistent with the vegetation classes found in the previously described parent material areas.

Based on the results found, certain combinations of spectral classes can be made in the final display map. Combination one is no combination. Combination two groups soils 9, 10 and 11 together. Combination three groups soils 6 and 7 together and 9, 10 and 11 together. The results of these combinations are presented in Figures 41 and 42. Soil maps are shown in Figures 43a and 43b.

Comparing the three spectral maps to the mapped photo for T27N, R6W, Sec. 29, SE¼ (mapped for this study), it appears that combination three is adequate and results in no significant loss of soil information. A similar comparison for the CNI plot (not mapped in this study) supports the conclusion that combination three is adequate for mapping.

Figure 44 illustrates the result of a reclassification of T27N, R6W, Sec. 8, SE¼ eliminating the soil-vegetation confusion classes 3, 5 and 8. The changes are indicated below (Table 15).

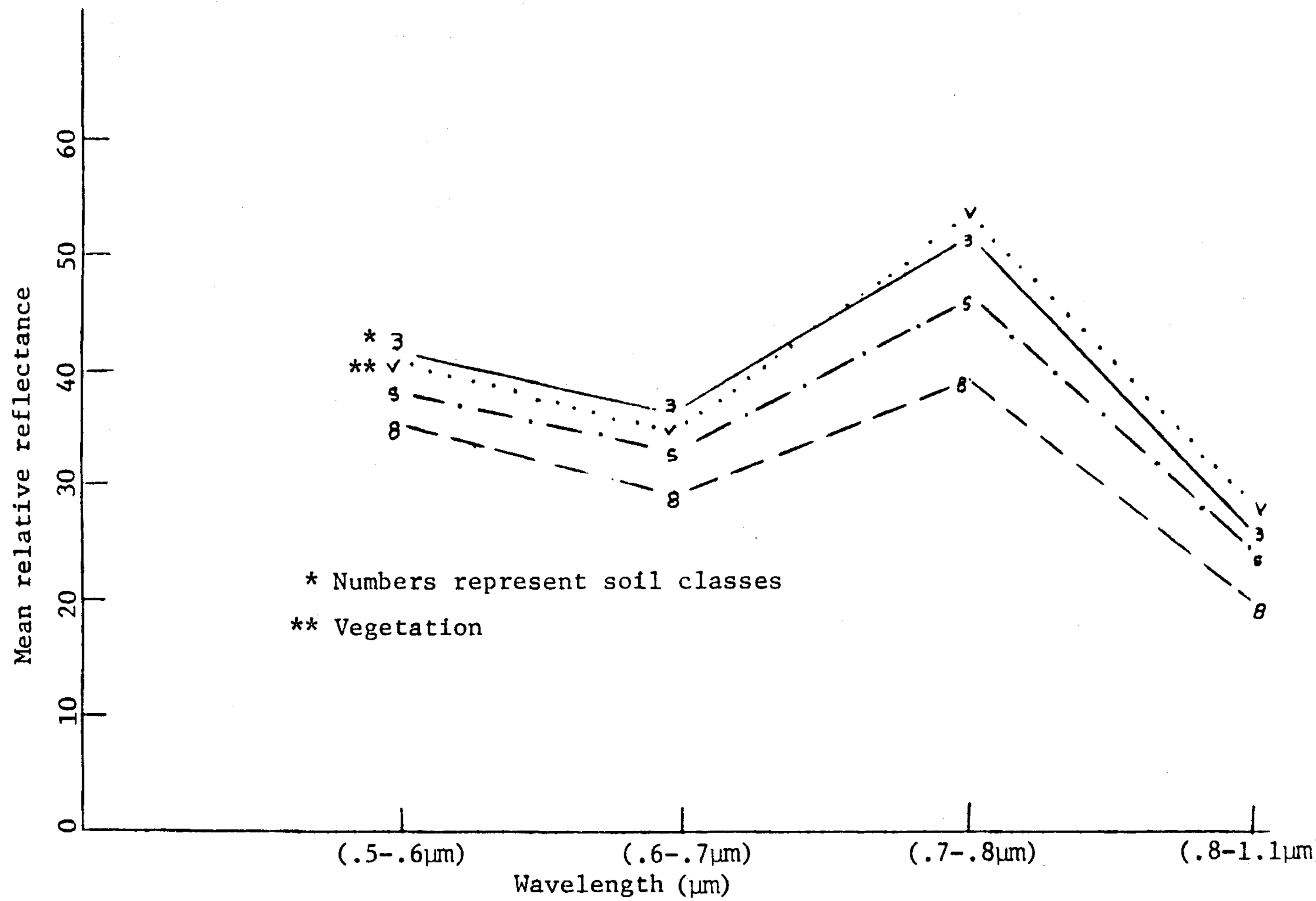
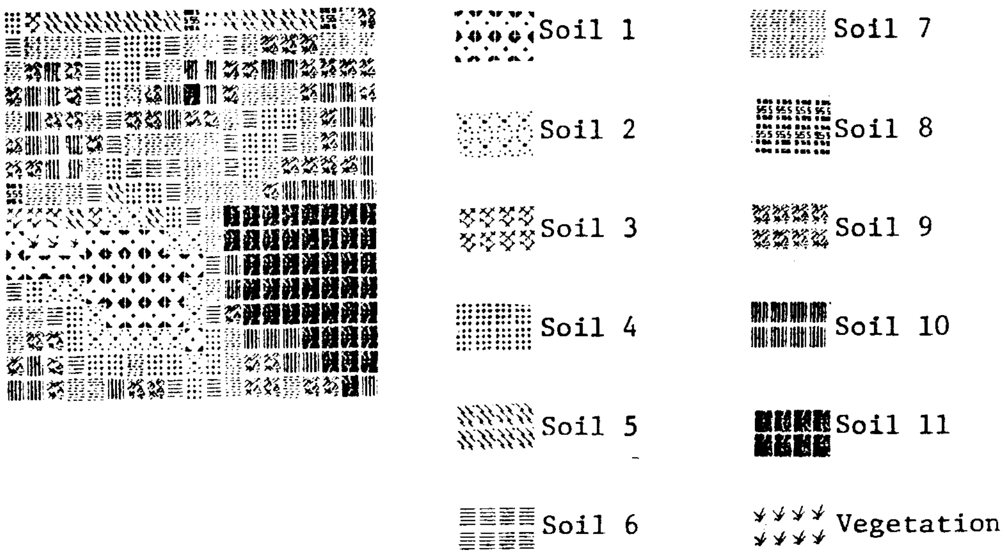


Figure 40. Soil-vegetation confusion classes--ground moraine, Alfisols.

Combination one



Combination two

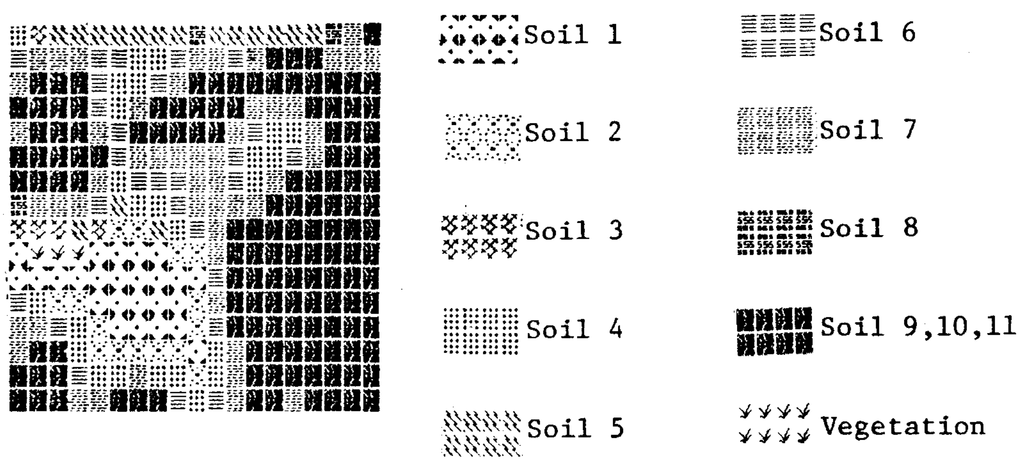


Figure 41. Combinations for T27N, R7W, Sec. 29, SE¼.

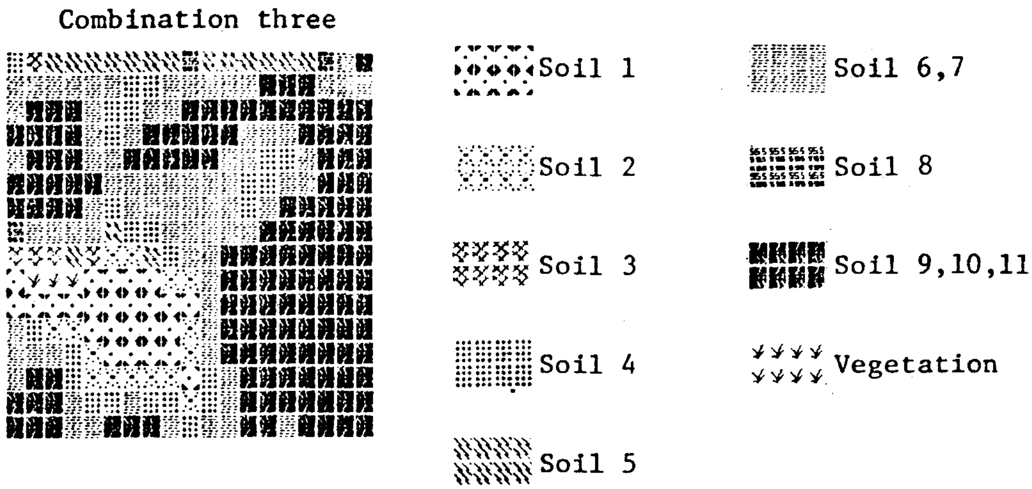


Figure 41. (Continued)

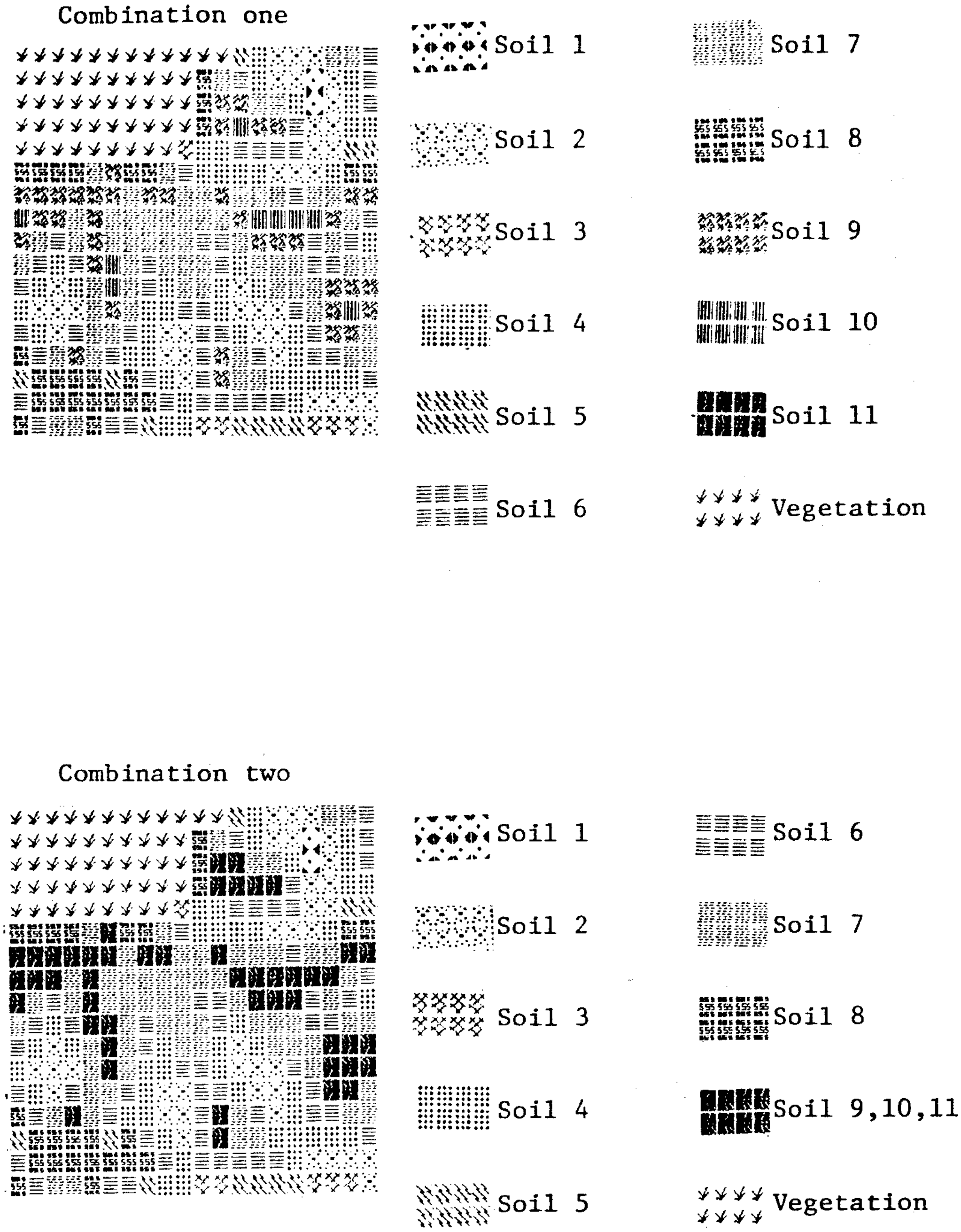


Figure 42. Combinations for T27N, R6W, Sec. 8, SE¼.

Combination three

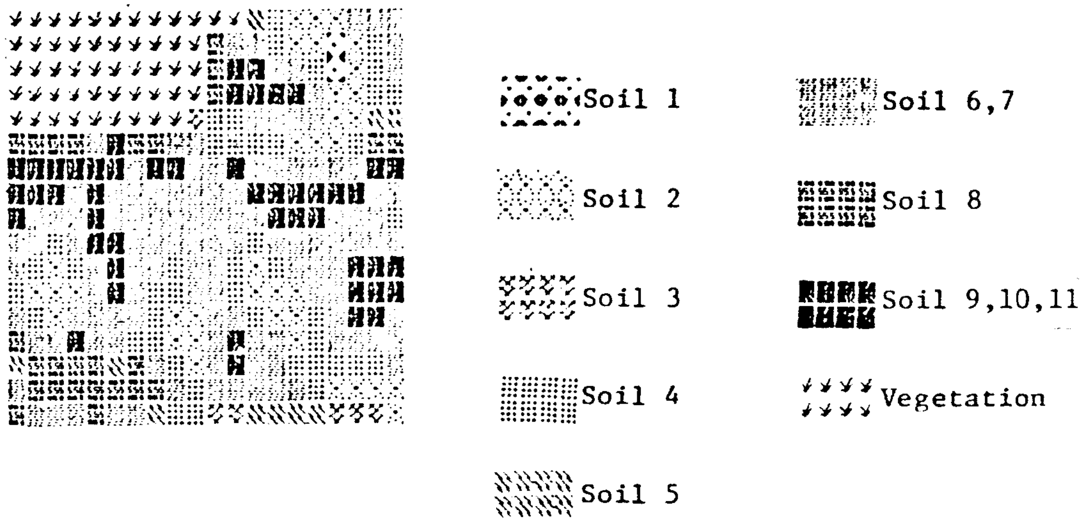
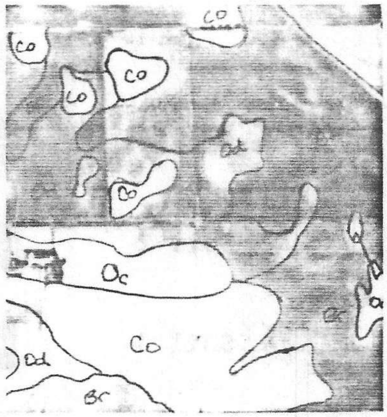


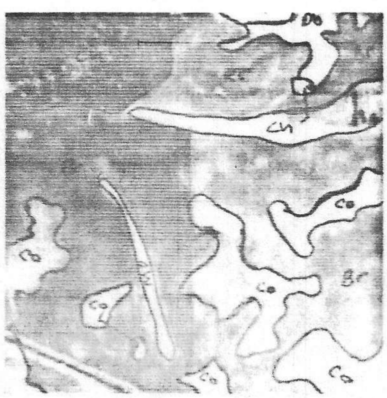
Figure 42. (Continued).



Legend 1

Br - Brookston
Co - Corwin
Oc - Octagon
Od - Odell

Figure 43a. Soil map of T27N, R7W, Sec. 29, SE¼.



Legend 2

Br - Brookston
Ch - Chelsea
Co - Corwin
Db - Darroch
Mo - Montmorenci
Rr - Rensselaer

Figure 43b. Soil map of T27N, R6W, Sec. 8, SE¼.

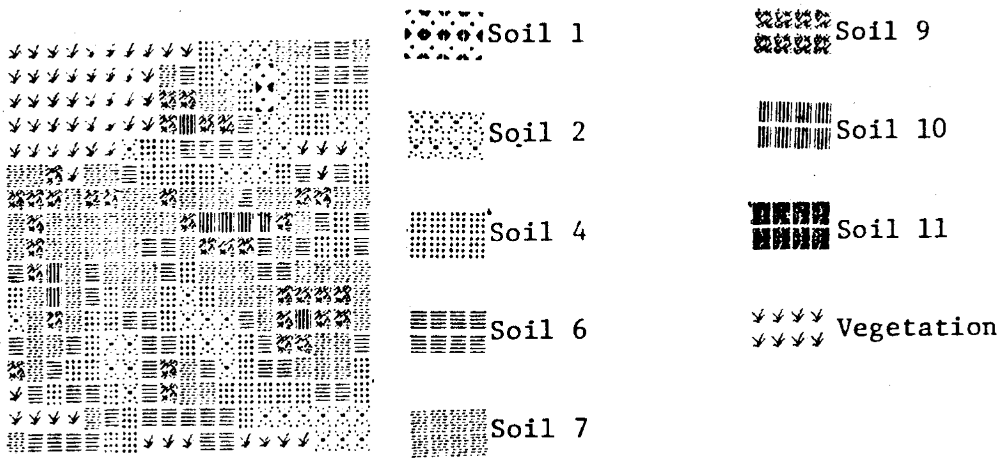


Figure 44. T27N, R6W, Sec. 8, SE¼, eliminating soil-vegetation classes 3, 5 and 8.

Table 15. Soil-vegetation analysis, ground moraine, Alfisols.

Soil-vegetation Confusion Class	Total Points in ¼ Section	Points after Reclassification	% Change
		5 to vegetation	83%
3	6	1 to soil 2	17%
		5 to vegetation	55%
		3 to soil 6	33%
5	9	1 to soil 4	12%
		15 to vegetation	60%
		7 to soil 6	28%
8	25	3 to soil 7	12%

This indicates that all these soils are dominated by vegetation. Points in soils 5 and 8 that are reclassified as soil classes split between the next highest and next lowest magnitude soil class. It should be noted that relatively few points exist for soils 3 and 5. The combination of spectral classes recommended before should remain the same.

Ground Moraine, Mollisols

Table 16 indicates the relative percentage composition of the soil spectral classes for the ground moraine, Mollisol area. These soils include approximately 16, 640 acres, representing 4.6% of the entire county. The curves of the spectral responses are shown in Figure 45.

In this parent material area four sections (640 acres) were mapped, representing 3.85% of the ground moraine, Mollisol area. The composition of the eight spectrally separable classes and the combined vegetation class is described below. No separate class was developed for water; therefore, water bodies are classified as soil 8.

Soil 1 - This soil class represents predominantly somewhat poorly drained soils including Odell and Conover. There are also a high percentage of well drained (Parr) and moderately well drained (Corwin, Montmorenci) inclusions. A minor amount of inclusions of very poorly drained soils (Wolcott) are found.

Table 16. Dot grid count for ground moraine, Mollisols.

Class	Ed - WD		MWD		SPD		VPD		T
Soil 1	Jc: 1 Pc:26		Co:12 Mo: 9		Cn:33 Od:37		Wo: 7		124
	D	%	D	%	D	%	D	%	
	26	21	21	17	70	56	7	6	
Soil 2	Pc: 2		Co:14 Mo: 4		Cn:48 Od:13		Wo:33		114
	D	%	D	%	D	%	D	%	
	2	1	18	16	61	54	33	29	
Soil 3	Pc: 5		Co: 3		Cn: 6 Od:11		Wo:10		35
	D	%	D	%	D	%	D	%	
	5	14	3	8	17	49	10	29	
Soil 4	Pc: 9		Co: 6 Mo: 4		Cn:28 Od:20		Wo:38		105
	D	%	D	%	D	%	D	%	
	9	8	10	10	48	46	38	36	
Soil 5	Pc: 7		Co: 1		Cn:13 Od:10		Wo:17		48
	D	%	D	%	D	%	D	%	
	7	15	1	2	23	48	17	35	

Table 16. (Continued).

Class	ED - WD		MWD		SPD		VPD		T
Soil 6	Pc: 4		Mo:4		Cn:28 Od:16		Wo:92		144
	D	%	D	%	D	%	D	%	
	4	3	4	3	44	30	92	64	
Soil 7					Cn: 4		Wo:51		55
	D	%	D	%	D	%	D	%	
					4	7	51	93	
Soil 8							Wo: 8		8
	D	%	D	%	D	%	D	%	
							8	100	
Veg	Pc:10		Co:3		Cn:12 Od:21		Wo:20		68
	D	%	D	%	D	%	D	%	
	10	15	5	7	33	49	20	29	
Total	63		62		300		276		701

Table 16. (Continued).

Soil Key

Cn - Conover
Co - Corwin
Jc - Jasper
Mo - Montmorenci
Od - Odell
Pc - Parr
Wo - Wolcott

Table Key

ED - excessively drained
WD - well drained
MWD - moderately well drained
SPD - somewhat poorly drained
VPD - very poory drained
T - Total
D - Dots

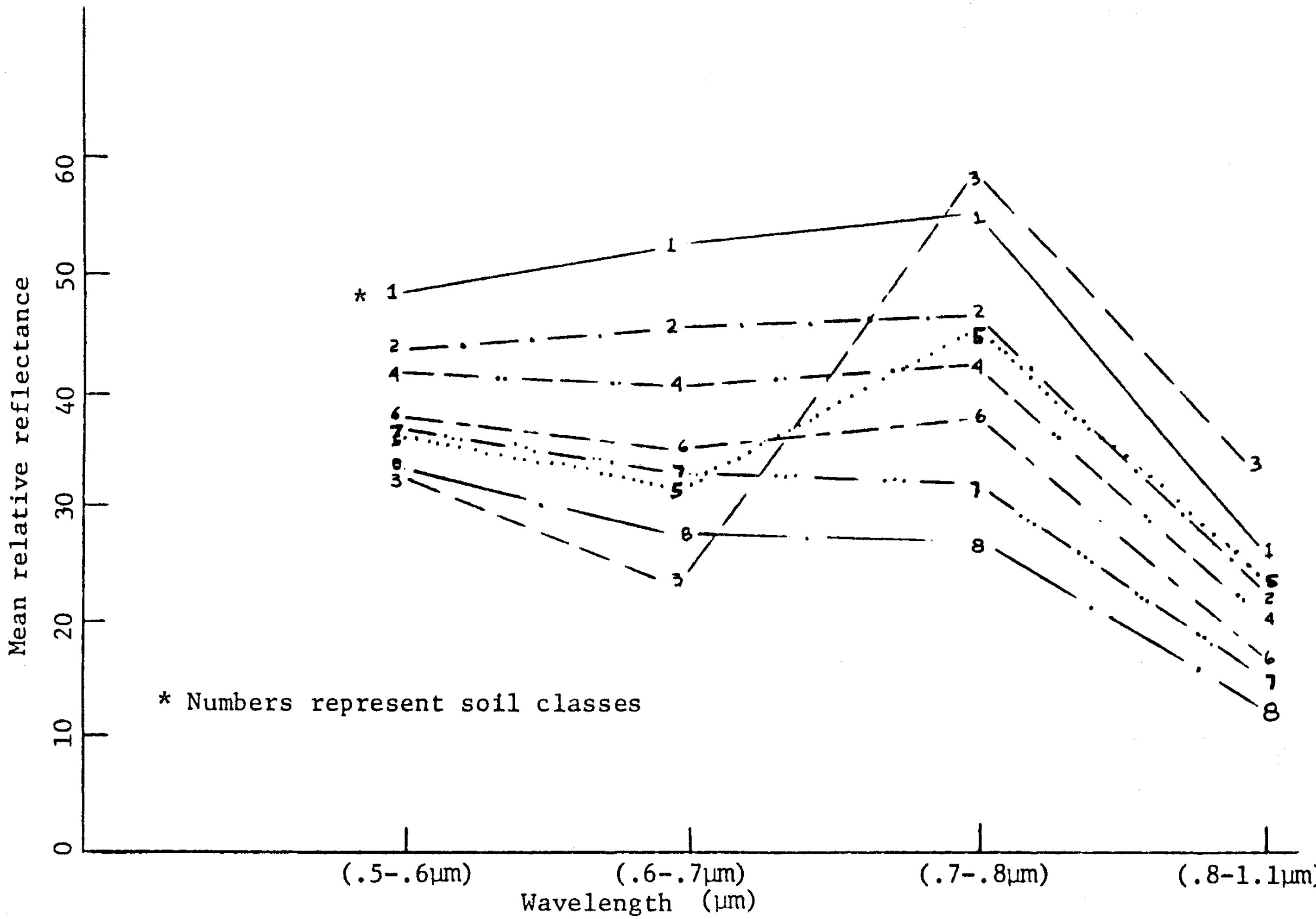


Figure 45. Soil spectral classes--ground moraine, Mollisols.

Soil 2 - This soil spectral class is also dominated by the somewhat poorly drained soils (Odell, Conover). The very poorly drained soils (Wolcott) represent significant inclusions, as do the moderately well drained soils (Montmorenci, Corwin). The well drained soils represent only minor inclusions.

Soil 3 - This soil spectral class is dominantly somewhat poorly drained soils (Odell, Conover). There are also significant inclusions of very poorly drained soils (Wolcott). Well drained (Parr) and moderately well drained soils (Conover) are also present. This class is a soil-vegetation confusion class.

Soil 4 - This spectral class is predominantly somewhat poorly drained soils (Odell, Conover). There are significant inclusions of very poorly drained soils (Wolcott). Relatively minor inclusions of well drained (Parr) and moderately well drained (Corwin) soils also occur.

Soil 5 - This soil spectral class is dominantly somewhat poorly drained soils (Odell, Conover). Very poorly drained soils (Wolcott) represent significant inclusions. Minor inclusions of well drained (Parr) and moderately well drained (Corwin) soils are present. This class is a soil-vegetation confusion class.

Soil 6 - This soil spectral class is dominated by very poorly drained soil (Wolcott). Significant inclusions of somewhat poorly drained soils are also present (Odell, Conover). Minor inclusions of well drained (Parr) and moderately well drained.

Soil 7 - This soil spectral class is predominantly very poorly drained soils (Wolcott). Minor inclusions of somewhat poorly drained soils (Conover) are also present.

Soil 8 - This soil spectral class represents very poorly drained soils entirely.

Vegetation - This spectral class represents a broad range of soils. Somewhat poorly drained soils (Odell, Conover) predominate but well drained soils (Parr) and very poorly drained soils (Wolcott) are significant inclusions.

Discussion

The consistent trend of magnitude versus spectral class is evident in this parent material area (Figure 46).

Soil spectral classes in this parent material area show a wide range of percentages of all drainage classes of soils. This trend is consistent with the wide range of drainage classes found in the other till parent material areas.

Of all spectral classes found in this parent material area none dominantly represent well drained or moderately well drained soils. Soils 1,2,3,4 and 5 are dominated by the somewhat poorly drained soils with varying amounts of inclusions in the other drainage classes. In all cases these

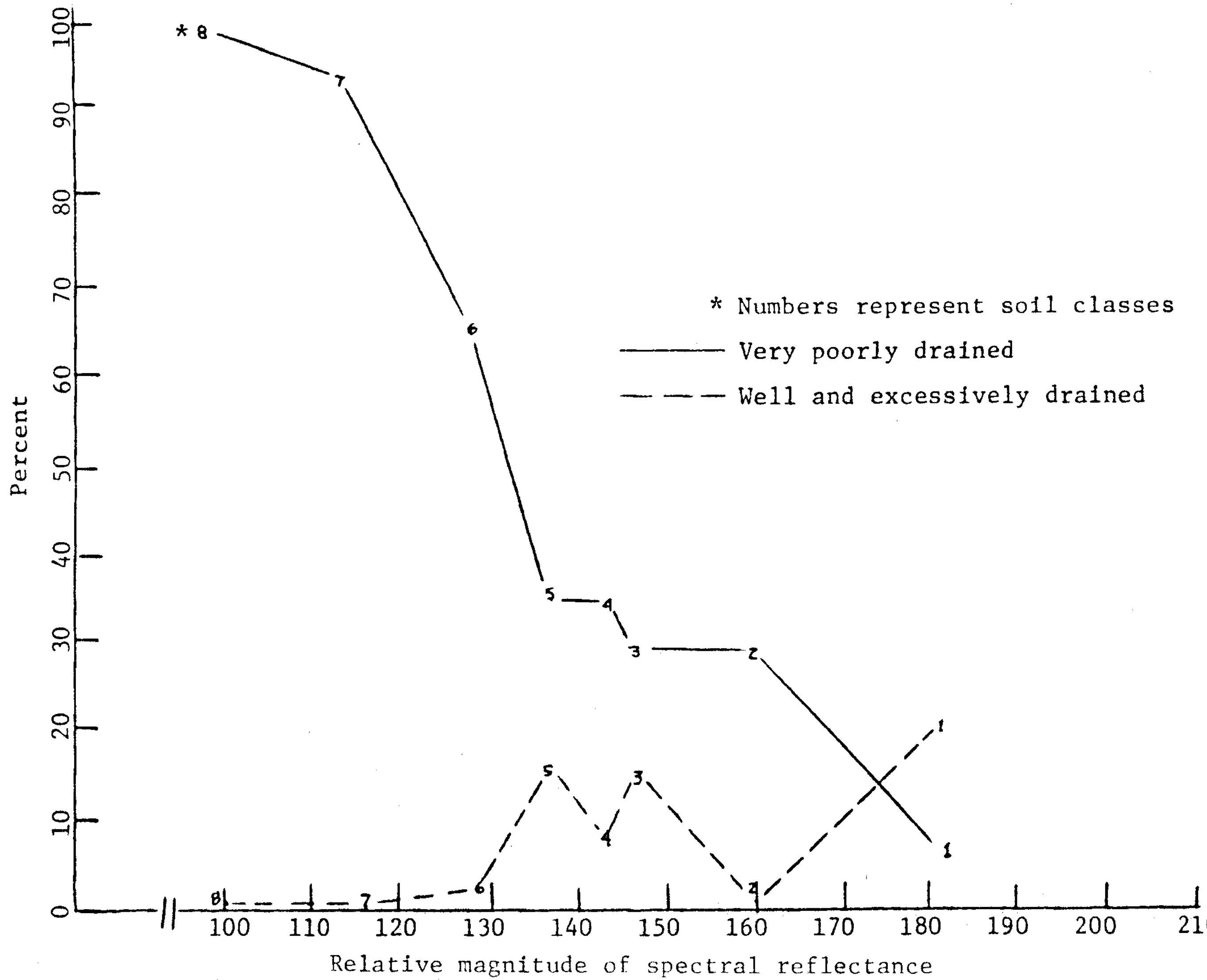


Figure 46. Relative drainage composition of spectral soil classes vs. magnitude (ground moraine, Mollisols).

inclusions are significant.

Soils 3 and 5 are soil-vegetation conflusion classes. The spectral curves of these two soils are presented in Figure 47. Soil 6 is increasingly poorly drained with significant inclusions of somewhat poorly drained soils. Soils 7 and 8 are dominantly very poorly drained soils with only minor inclusions of other soil drainage classes. The vegetation class was predominantly somewhat poorly drained soils, but there were significant inclusions of soils of other drainage classes. This vegetation class indicates no trend when compared to the vegetation classes in the other parent material areas.

Based on the analysis some combinations are possible on the final spectral map. Combination one is no combination. Combination two groups soils 2 and 3 together, 4 and 5 together, and 7 and 8 together. Combination three groups soils 2,3,4 and 5 together and soils 7 and 8 together. The results of these combinations are shown in Figures 48 and 49. Soil maps are Figures 50a and 50b.

Comparing the above combination to the conventional soils map for T27N, R7W, Sec. 28, E½ (mapped for this study) indicates that combination two is the best combination of those considered. Combination three results in too much of a loss of soil information while combination one results in a map that is confusing to interpret. This area is a good example of the problem. that a soil-vegetation confusion class may cause. The rectangular area located in the upper center of the half sections is actually a soil-vegetation confusion class, and the poorly drained Wolcott soil is masked and erroneously mapped as a somewhat poorly drained soil.

Comparison to the conventional soils map to the spectral map for T27N, R7W, Sec. 14, NW¼ (mapped in the CNI study) supports the conclusion that combination two is the ideal combination. On this quarter section; however, combination three would also seem adequate.

Figure 51 shows T27N, R7W, Sec. 28, E½ reclassified eliminating the soil-vegetation classes 3 and 5. Results are presented below (Table 17).

Soil 3 should be eliminated entirely from the classification as a soil class. Soil 5 is predominantly vegetation and should be interpreted as such. Those data points that were reclassified as soils were equally split between the soil class of the next highest and next lowest magnitude.

Table 17. Soil-vegetation analysis, ground moraine (Mollisols).

Soil-vegetation Confusion Class	Total Points in ¼ Section	Points after Reclassification	% Change
3	30	30 to vegetation	100%
		32 to vegetation	76%
		5 to soil 4	12%
5	42	4 to soil 6	12%

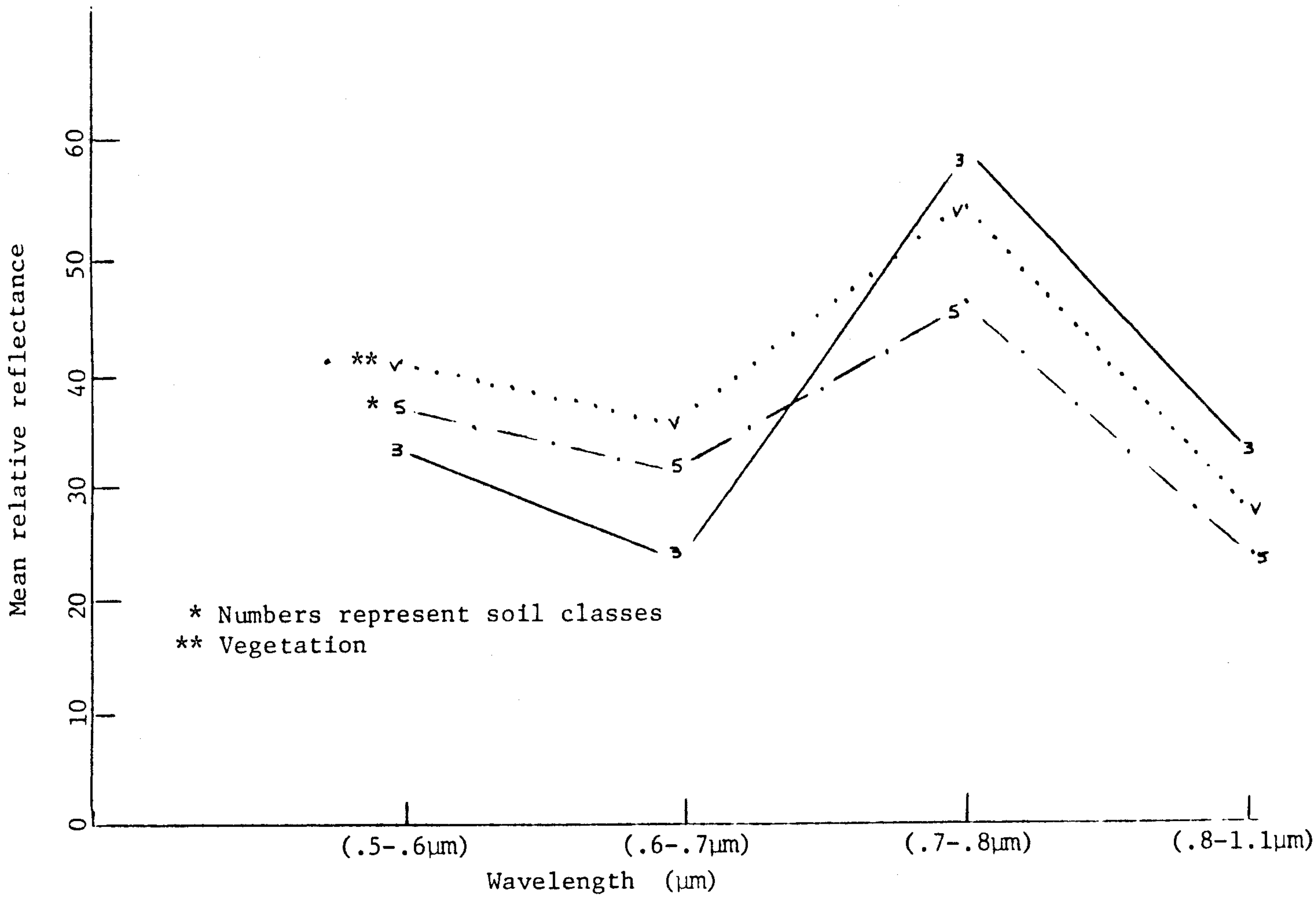
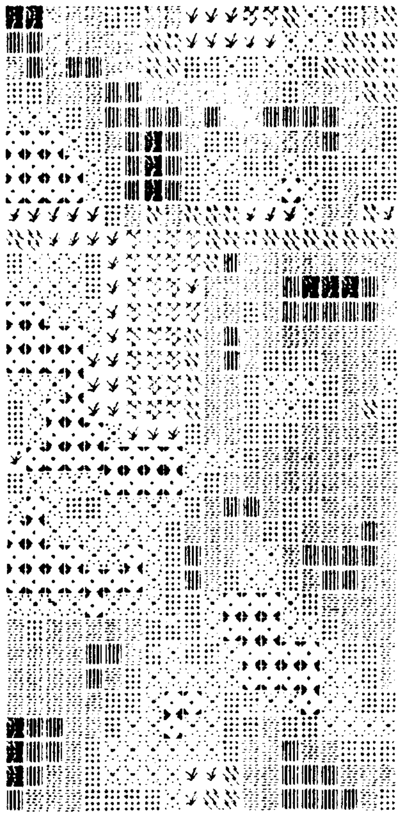
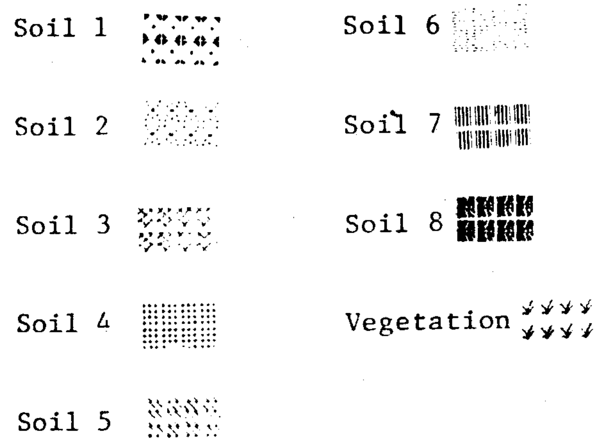


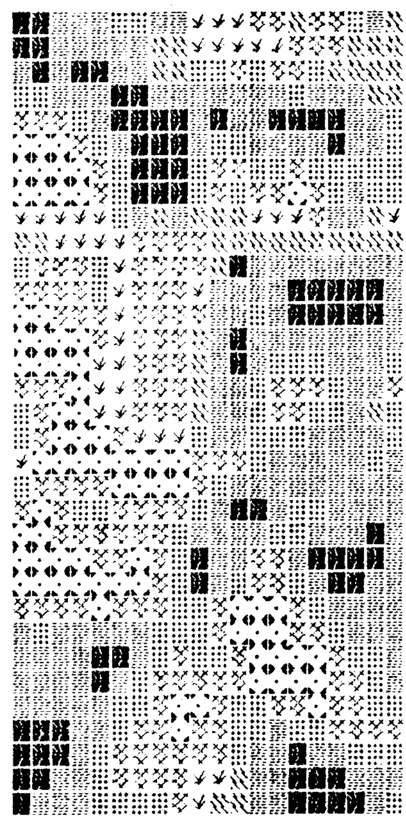
Figure 47. Soil-vegetation confusion classes--ground moraine, Mollisols.

Combination one





Combination two



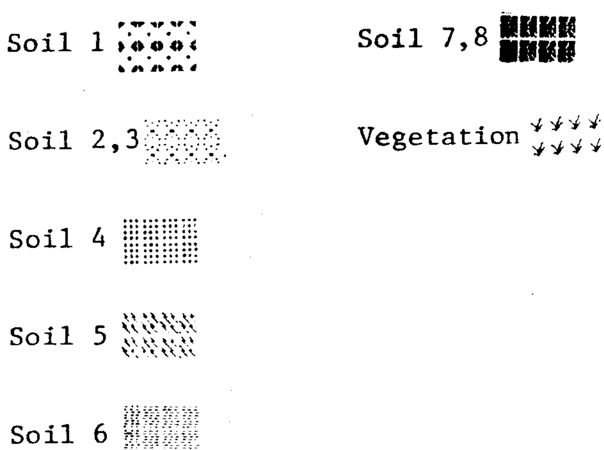


Figure 48. Combinations for T27N, R7W, Sec. 28, E½.

Combination three

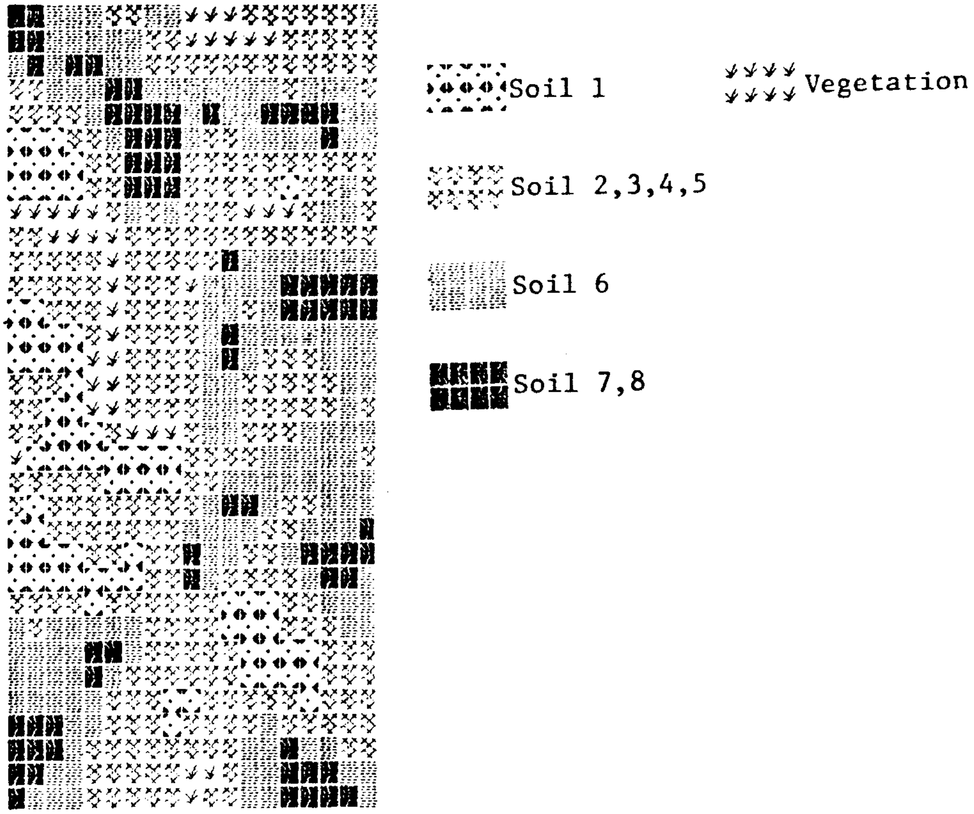
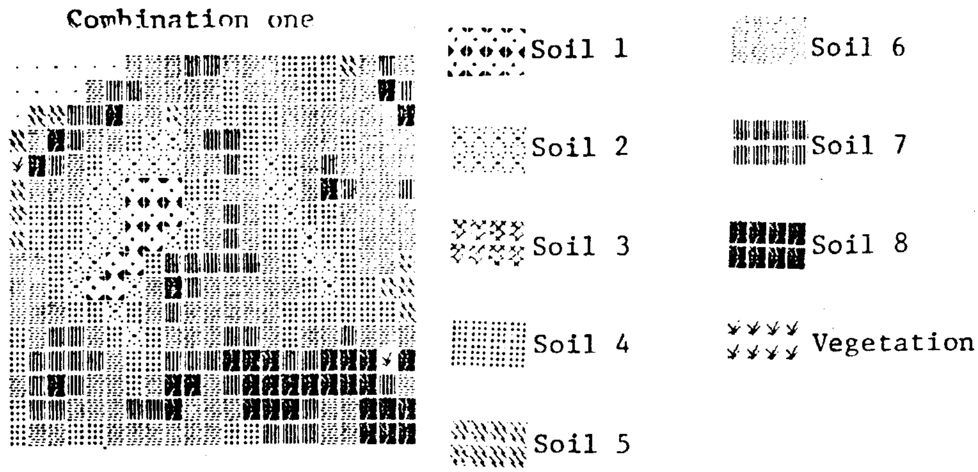


Figure 48. (Continued).



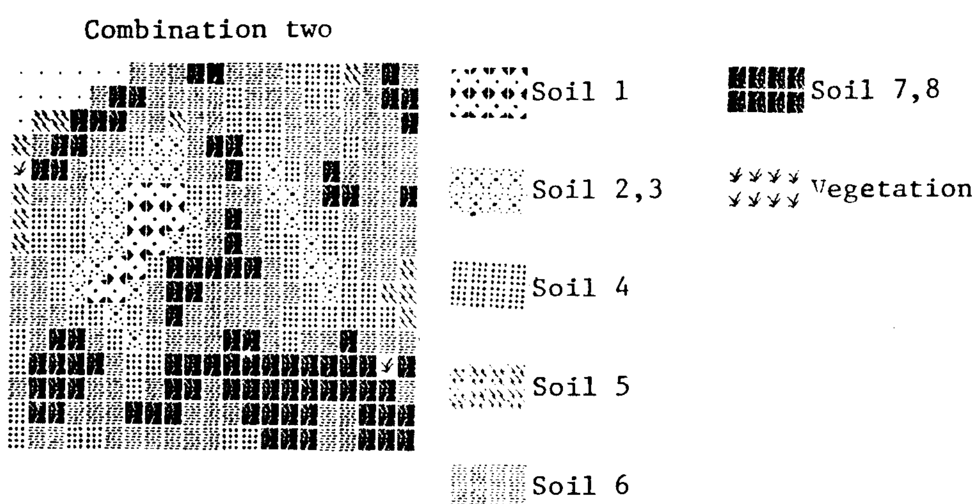


Figure 49. Combinations for T27N, R7W, Sec. 14, NW¼.

Combination three

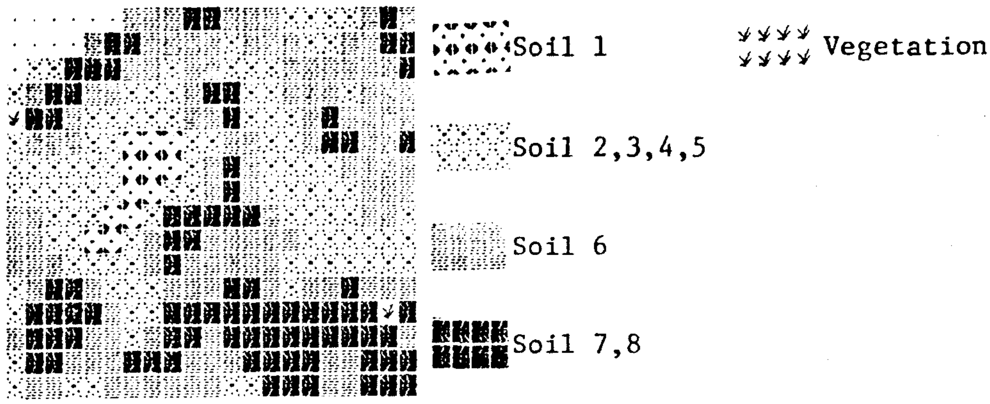
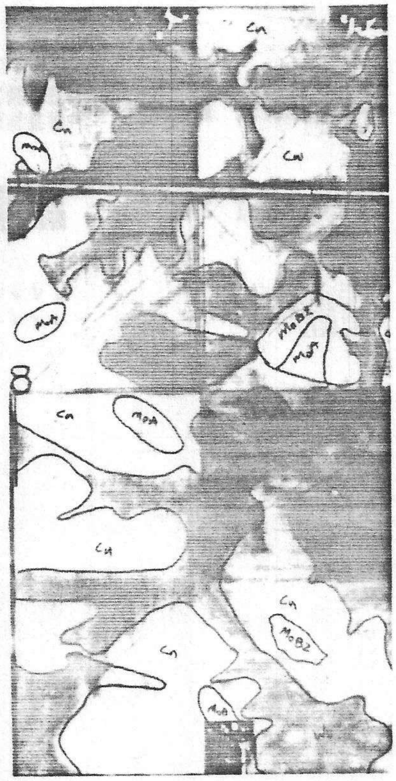


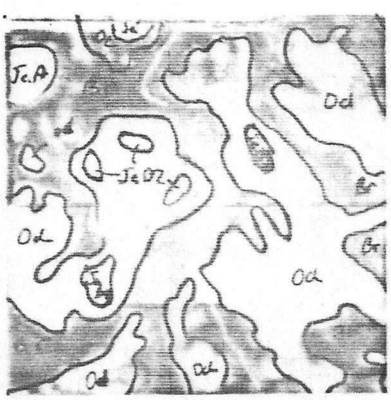
Figure 49. (Continued).



Legend 1

Cn - Conover
MoA - Montmorenci, 0-2% slope
MoB2 - Montmorenci, 2-6% slope, moderately eroded
Wo - Wolcott

Figure 50a. Soil map of T27N, R7W, Sec. 28, E½.



Legend 2

Br - Brookston
JcA - Jasper, 0-2% slope
JcB2 - Jasper, 2-6% slope, moderately eroded
Od - Odell

Figure 50b. Soil map of T27N, R7W, Sec. 14, NW¼.

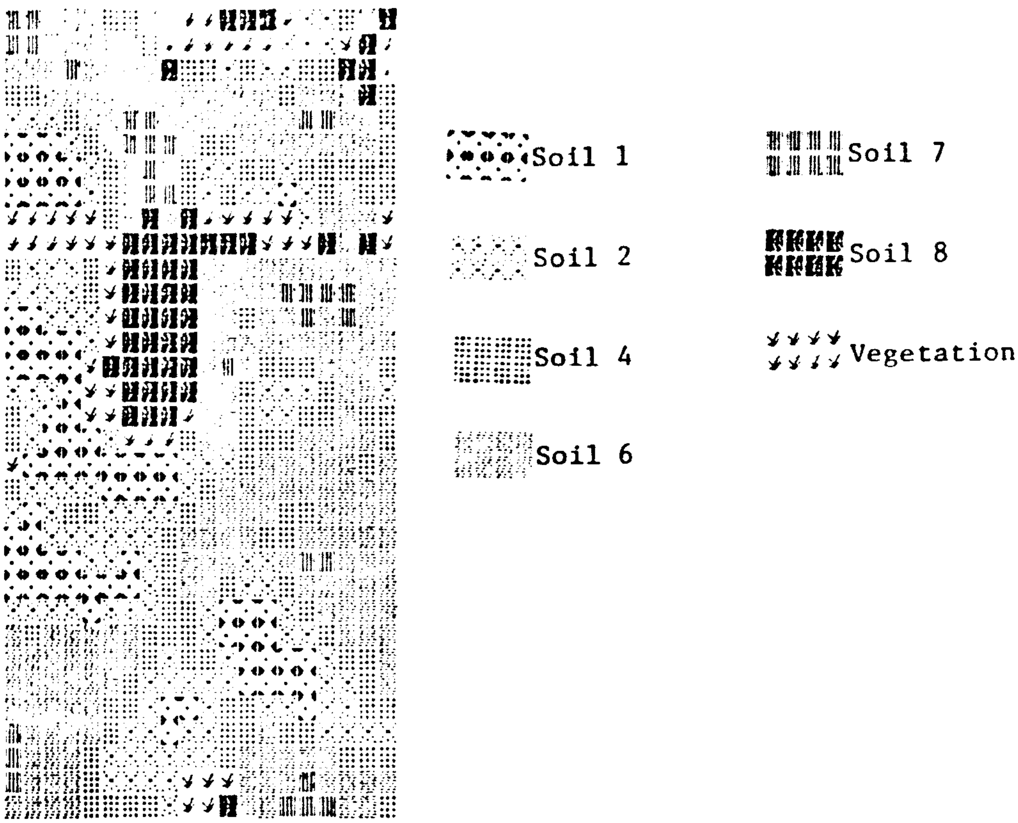


Figure 51. T27N, R7W, Sec. 28, E½, eliminating soil-vegetation confusion classes 3 and 5.

The suggested combination two should be valid if the soil-vegetation confusion classes are eliminated.

Surface Conditions Affecting Spectral Response

In many instances there were distinct spectral classes that were found to represent the same soil. For example, it is evident, in the outwash area (Table 5), that soil spectral classes 8 and 9 represent basically the same group of soils: Gilford, Mussey, Maumee, Adrian, Sebewa and Rensselaer. Combinations of these two classes were proposed earlier for display on the final spectral map. Likewise, combinations of distinct spectral classes for other soils in other parent material areas were recommended because of similar compositions. The question, then, is if these spectral classes represent the same soils, why are they spectrally distinct.

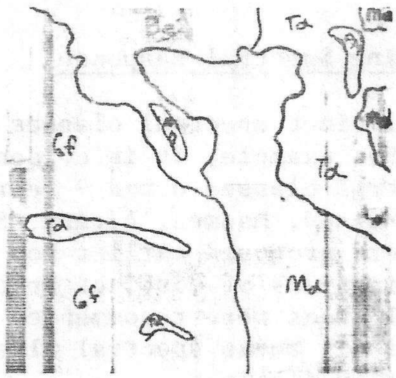
Unfortunately, since the Landsat data were collected in June of 1973, the photography in May of 1976, and the field observations and mapping performed in the spring of 1978, the reasons behind the differing spectral responses can only be speculated upon. This was done by noting conditions in the field that, in the opinion of the author, could possibly affect the spectral response of soil.

While there are likely many reasons and surface conditions that will affect the spectral response of soils, only the major ones are discussed here. These are: vegetation-soil confusion classes, surface moisture conditions, subsurface horizon exposure, separated sand occurring on the surface, cultivated versus crusted soil, and textural and organic matter differences.

The first of these, soil-vegetation confusion classes, was discussed previously. These soil-vegetation complexes seem to pose the most widespread problem in the interpretation of remotely sensed data for soil survey. If these classes are known, however, they can be used in an interpretive manner with the surrounding soil classes.

Surface moisture conditions were, in at least one instance, noticed to change the soil spectral response. Figure 52a is an aerial photograph of T32N, R6W, Sec. 12, SE¼. The area directly south of the mapped portion is displayed as soil 9. This soil, upon field investigation, was of the Gilford series, the same soil that was found in the mapped quarter section. It was noted, however, that the surface of the soil was extremely wet. Upon further investigation, it was found that this field did not have a tile drainage system, hence retained the moisture longer than did the adequately drained Gilford soil directly to the north. Figure 53 is the spectral map.

Reasons for this darker class can be explained because water has a characteristically low reflectance, particularly in the third and fourth Landsat bands (0.7-0.8 and 0.8-1.1 micrometers). The presence of free water on the surface or among the soil particles would influence the spectral characteristics of the soil, resulting in a unique spectral class. Figure 52b is a ground view of this area.



Legend

Be - Brems
Gf - Gilford
Md - Maumee
Pn - Plainfield
Td - Tedrow

Figure 52a. Soil map of T32N, R6W, Sec. 12, SE½.

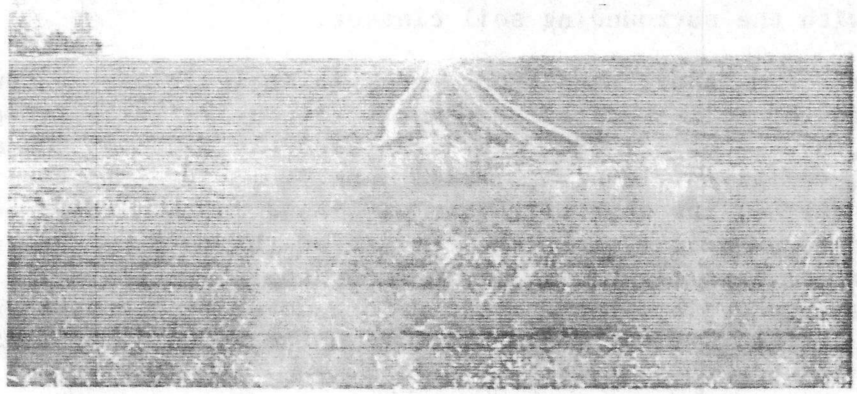


Figure 52b. Ground view of area.

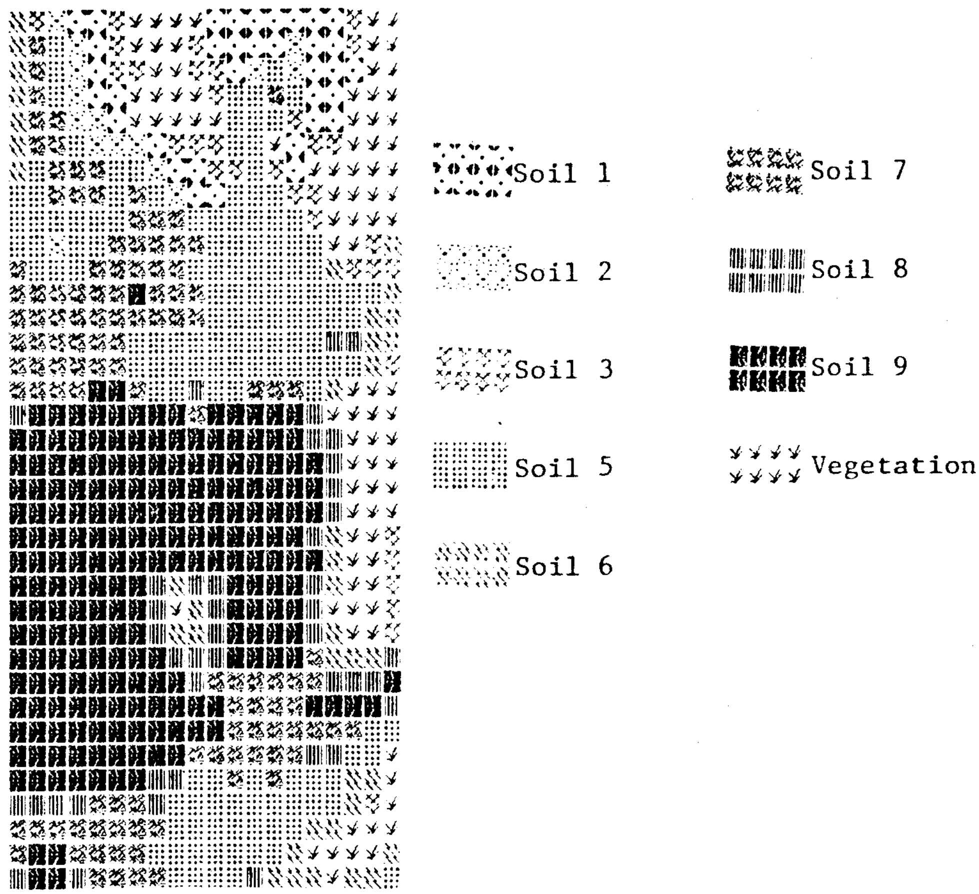


Figure 53. Spectral map showing effects of moisture.

Presence of a exposed subsurface horizon has also been noted to affect spectral response. Note in Figure 55 soil 5 occurs along the southern edge of the quarter section. This soil, based on field investigation (Figure 54), is still a poorly drained soil but shows up a lighter class. In this instance the spoils from the ditch, a much lighter colored subsurface horizon, were exposed. The result is that the spectral data indicate a lighter soil. While this is a confusion factor in instances such as this quarter section, the delineation of an exposed subsurface horizon has been found by others to be a potentially powerful tool in mapping severe soil erosion (54).

Clean washed sand occurring on the surface has also been found to affect spectral response, particularly in the outwash area. An example is presented in T32N, R6W, Sec. 12, SE¼ (Figure 56). Note in the northeast part of the quarter section that the somewhat poorly drained Tedrow soil appears as soil 1, the brightest soil. This contradicts the trend of poorer drainage with decreasing magnitude of spectral reflectance. Field checking revealed large amounts of clean, washed medium sands in the lower spots of the furrows. Figures 57a and 57b illustrate the occurrence of sand in this quarter section. After cultivation the sand is separated from the finer particles by the action of falling rain. The cleaned sand particles are bright, hence reflect brightly. As is indicated by Figure 57b, there is, in any one area, approximately an equal percentage of clean washed sand and darker soil. This then would average out to approximate a somewhat brighter soil, therefore, a lighter spectral class.

A similar effect was noted because of crusting of the soil. In the instance noted, the soil was fall plowed and had formed a crust over the winter (Figure 58b). During the spring preparation of the soil the farmer disked the soil, therefore, breaking the crust. The result was a darker surface color and a lower spectral reflectance (Figure 58b). Cultural practices have been found by others to affect multispectral response of soil (60).

Figure 59 shows the spectral map of T29N, R6W, Sec. 15, NW¼, and Figure 60 is the aerial photo of this quarter section. Note that in the southern part of this quarter section soil 1 and 2 appear. Upon field investigation this area was equally a well drained soil (Chelsea) and a somewhat poorly drained soil (Haskins). It is believed that this light class is, at least in part, caused by the crusting.

Differences in surface texture have been noted to change the spectral response of soils. Figures 48a and 49 show the soils map and spectral map for T27N, R7W, Sec. 28, E½. Note in the NE¼ of the southern half of this area soil 7 occurs in the midst of soil 6. Both soil spectral classes represent poorly drained soils, but field investigation revealed that the surface texture of soil 7 was dominantly silty clay loam while soil 6 has a surface texture of silt loam. This area was also a slight topographic low and appeared wetter than the surrounding soil 6. The difference in texture, topographic position, and wetness are all likely to influence the spectral response in this area.

High organic matter amounts have also been noted to mask other soil

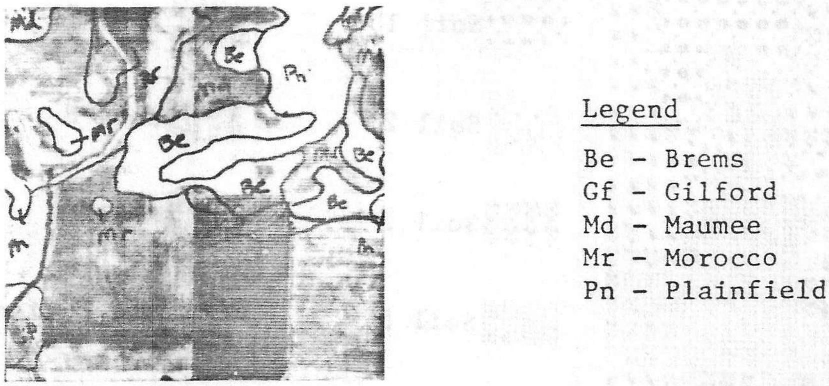


Figure 54. Soil map of T28N, R6W, Sec. 2, SE¼.

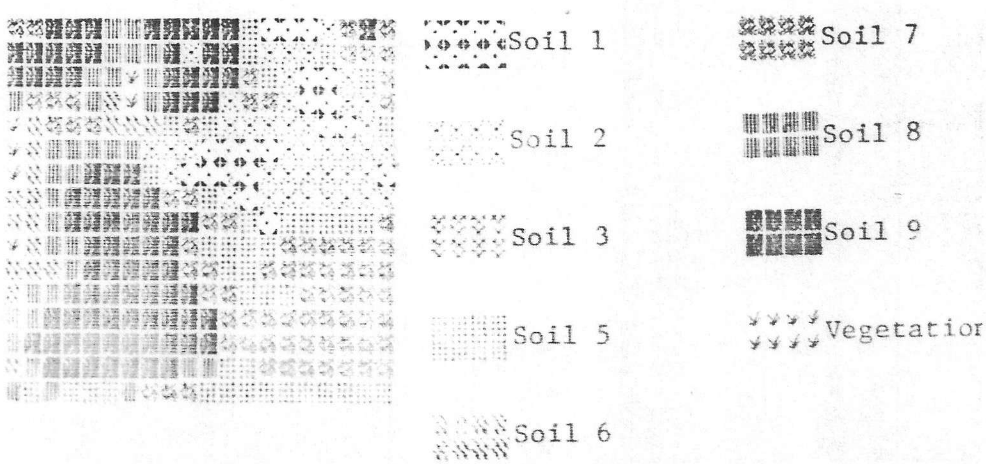


Figure 55. Spectral map showing effects of subsurface horizon exposure.

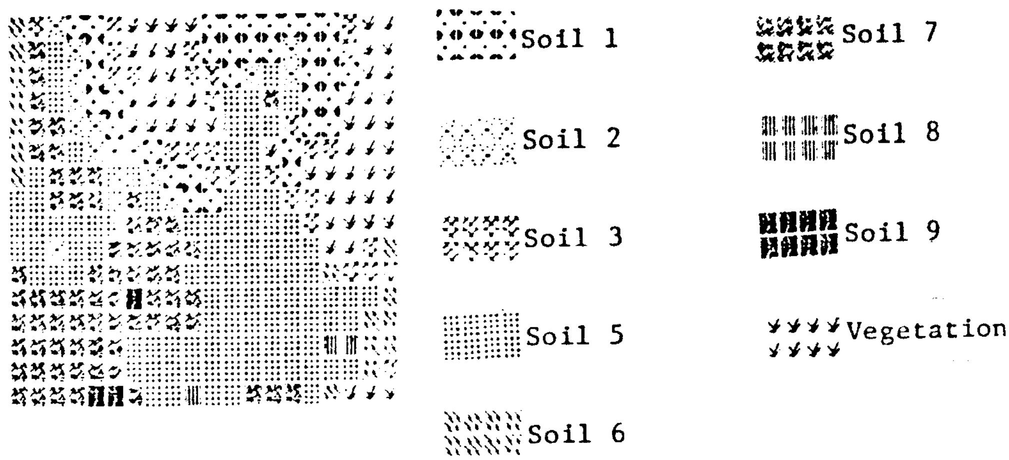


Figure 56. Spectral map showing effect of free sand.

Figure 57a. Washed sand on surface.

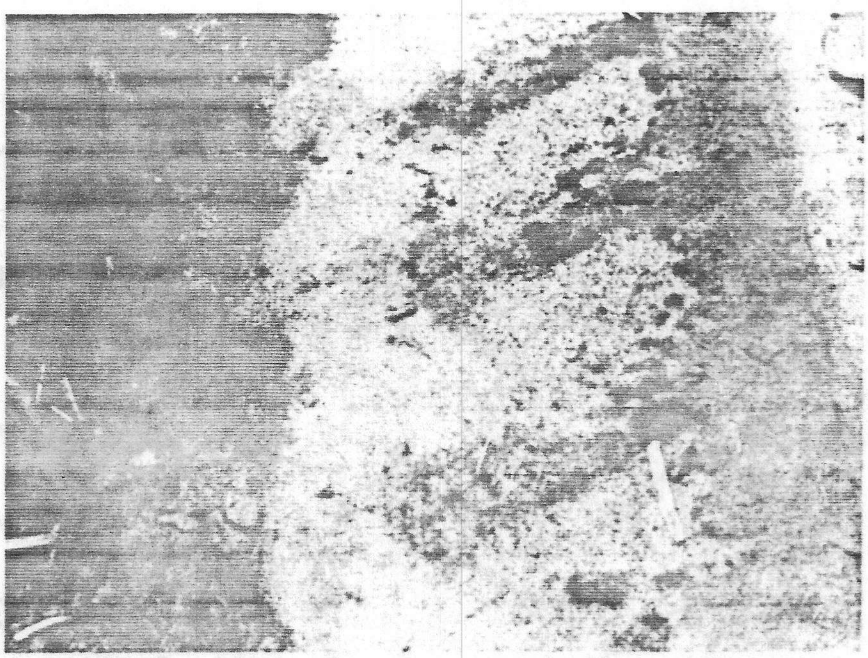


Figure 57b. Washed sand in furrow.

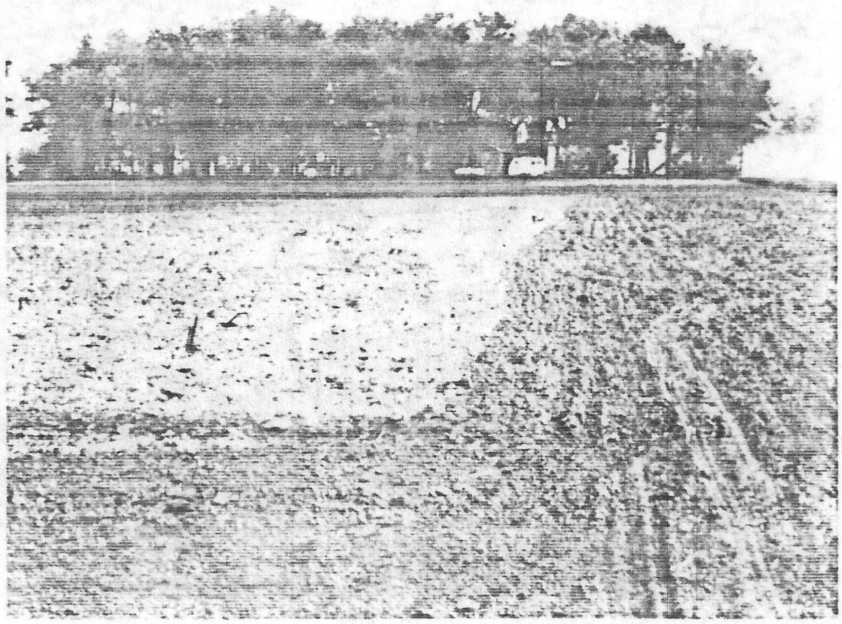


Figure 58a. Disked versus crusted soil.

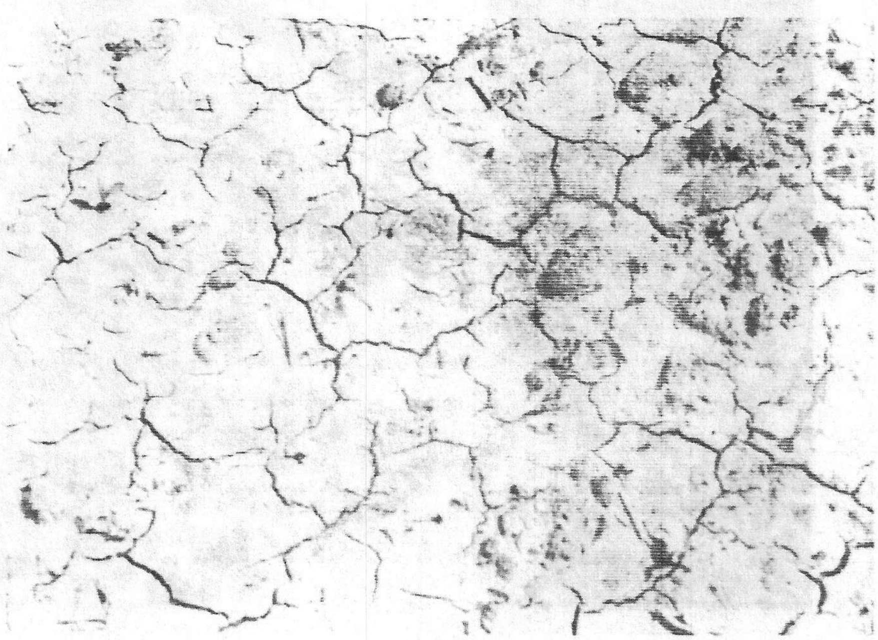


Figure 58b. Crusted soil.

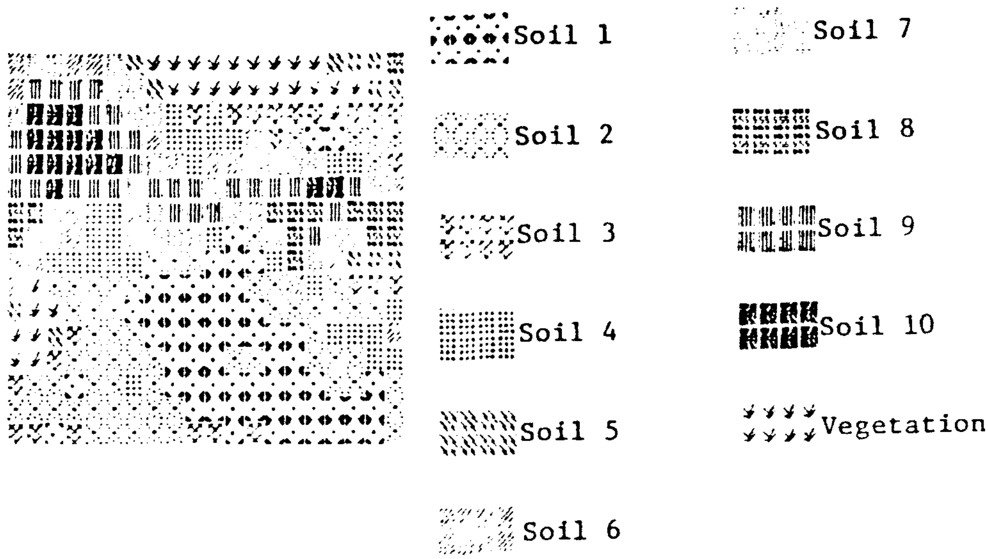


Figure 59. Effects of crusting on spectral response.

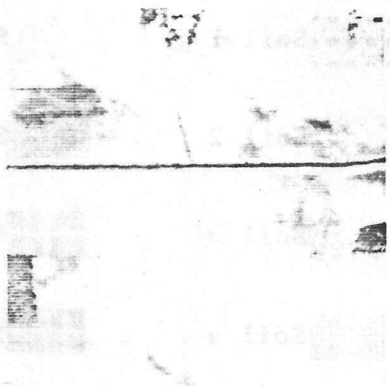
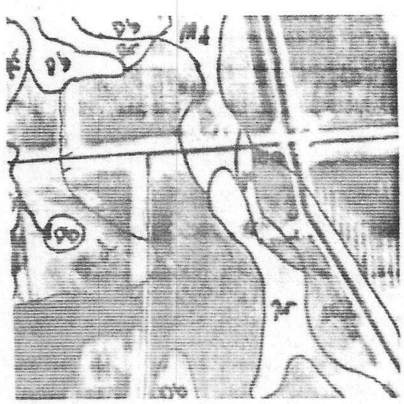


Figure 60. Aerial photo of T29N, R6W, Sec. 14, NW¼.



Legend

Db - Darroch
Ho - Houghton
Md - Maumee
Rr - Rensselaer

Figure 61. Soil map of T30N, R5W, Sec. 17, SE¼.

differences. Figures 61 and 62 are an area mapped during the CNI study, and the corresponding spectral map of T30N, R6W, Sec. 17, SE¼. While this area was not mapped in the course of this study, field checking revealed that the CNI mapping was correct, and the soils were either muck or soils having a high amount of organic matter (estimated greater than 5%).

SUMMARY AND CONCLUSIONS

In this study soils found within Jasper County, Indiana were correlated to a spectral soils map produced by computer-aided analysis of Landsat MSS data. The spectral map, completed in a previous study, contained fifty-two spectral soil classes in six parent material areas. From the resulting correlation, a descriptive legend was developed for each soil spectral class.

To achieve the correlation, twenty-eight 160 acre sites were randomly chosen throughout the county. The soils at these sites were inventoried by combining conventional soil mapping techniques and area sampling. The field mapped areas were located on the spectral map and by overlaying the spectral map, the conventional soil map, and a dot grid, a count of the relative amount of soils for each spectral class was made. Percentages were calculated and a descriptive legend for each soil spectral class was developed. These descriptive legends identify the dominant soils represented by the spectral class, as well as soils that are significant inclusions.

In addition to developing a legend for each soil spectral class, various factors involved in the analysis and interpretation of remotely sensed data for soil survey were identified. These factors included: soil-vegetation complexes, crusting of the surface soil, subhorizon exposure, soil surface moisture, organic matter content texture, and free sand on the surface. Of these, the soil-vegetation complexes presented the most widespread problem in interpreting the spectral data. The other factors all altered the spectral response of the soil to some degree, but their influence appeared rather localized.

Specifically, the findings and conclusions of this research are:

1. Of the sampling techniques considered a combination soil mapping and area sampling offered the most practical method for gathering soils data.

2. Using the dot grid count a relative percentage composition of soils can be calculated for each spectral class. From these percentages, a legend describing the dominant soil(s) and inclusions can be developed.

3. The internal drainage class seems to be correlated with magnitude. For every parent material area, the more poorly drained soils had a lower magnitude of reflectance. Likewise, the better the drainage, the greater the magnitude of reflectance.

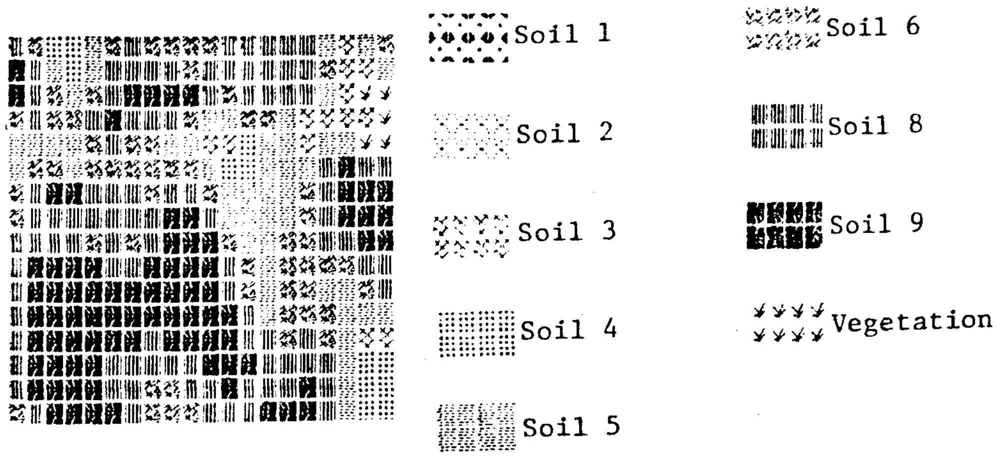


Figure 62. Effects of organic matter on spectral response.

4. Soil spectral classes seem to be predominantly one internal drainage class.

5. While soil series were not consistently spectrally separable in this study, it is felt that if the soil surveyor knows the internal drainage (from the spectral map) and parent material for a particular area, a prediction of a soil series (or group of soil series) can be made for that area.

6. Soil-vegetation complexes and resulting confusion classes can occur in the calculation of the spectral statistics. Preliminary investigation of these soil-vegetation confusion classes indicate that they are affected by vegetation to varying degrees. It is recommended that these confusion classes be maintained because of potential loss of useful soil information if deleted.

7. Distinct soil spectral classes can be very similar in soil series composition. These distinct spectral classes are likely to be attributable to overriding surface conditions such as crusting, subsurface horizon exposure, sand on the surface, or an extremely wet surface.

In summary, the major soil characteristics affecting spectral reflectance, hence the mapping of soils using Landsat data, are:

a. Soil series and related internal drainage;
b. Presence of vegetation that does not mask but strongly influences soil spectral reflectance;
c. Surface moisture conditions at the time of data collection;
d. Crusting conditions at time of spectral data collection;
e. Free washed sand on the surface;
f. Surface texture;
g. Organic matter content; and
h. Subsurface horizon exposure, including erosion.

SUGGESTED RESEARCH

Results of this research indicate that Landsat data can be utilized in soil survey. Some improvements that may increase the use and reliability of the Landsat data are:

1. Develop a sampling scheme of soils that is more amenable to a quantitative analysis. This would include:

   a. Determining the minimun area and/or sample size to adequately sample any area;
   b. Determining the method of sampling, i.e., simple random sampling of stratified random sampling;
   c. Determining, if stratified random sampling is used, what the units should be, i.e., parent material, topography.

2. If possible, coordinate the time of all data collection within, at least, one season. For example, collect the Landsat data, aerial photography, and ground soil mapping within the spring of one year.

3. Determine the need for incorporating ancillary data as parent material areas, into a spectral soils map. If the need is present, at what point does the cost of incorporation become prohibitive? Is there a limit on geographical size for incorporation of ancillary data? Is incorporation of more than one type of ancillary data necessary and/or practical?

4. Improve the techiques of registration of the Landsat data to ground control points as well as improving the ability for locating points on the ground in relation to the Landsat data.

5. Although no consistent correlation was present in this study between vegetation and soils, it is assumed that mapping native vegetation as soil indicator species is possible in other areas of the country and the world. A study performed in an appropriate area could do much to determine the validity of this assumption.

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