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SOIL INVENTORY PREPARED FROM DIGITAL ANALYSIS OF SATELLITE MULTISPECTRAL SCANNER DATA AND DIGITIZED TOPOGRAPHIC DATA

R. A. WEISMILLER
I. D. PERSINGER
O. L. MONTGOMERY

The Laboratory for Applications of Remote Sensing
Purdue University West Lafayette, Indiana
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SOIL INVENTORY PREPARED FROM DIGITAL ANALYSIS
OF SATELLITE MULTISPECTRAL SCANNER DATA
AND DIGITIZED TOPOGRAPHIC DATA [1]

R. A. Weismiller, I. D. Persinger, and O. L. Montgomery[2]

ABSTRACT

A soil inventory of Chariton County, Missouri was prepared using computer-aided analysis of Landsat multispectral scanner (MSS) data to determine how soil maps produced by digital analysis of satellite MSS data can accelerate and improve the quality of the National Cooperative Soil Survey Program.

Landsat data collected on 15 April 1974 were spatially registered at a scale of 1:24,000 and overlaid with ancillary data in the form of digitized township, watershed and physiographic boundaries. The county was classified into 30 spectrally separable classes using computer-implemented pattern recognition techniques. Approximately 64 percent of the county was identified as bare soil and was classified into 14 spectrally separable soil classes. The remaining 36 percent was classified as forest, pasture, and close grown crops.

The digitized boundary data allowed the computer to manipulate, compile, extract and present spectral class information within topographic or political units. The physiographic boundaries were used to delineate three landscape positions of interest: 1) bottomlands, 2) gently sloping uplands and 3) moderately steep uplands. These delineations allowed the computer to differentiate between spectrally similar soils which occur on distinctively different landscape positions. Spectral classes of soil were correlated with individual soil series and taxonomic classifications for both the bottomland and uplands units.

While a spectral classification of soils alone cannot distinguish between widely different soils exhibiting similar spectral responses, it can aid in identifying meaningful divisions of soils. By combining digitized ancillary data with MSS data, a more detailed delineation of soils can be provided as compared to information derived solely from MSS data. Further refinement of this technique will continue to increase the usefulness of satellite MSS data as an aid in soil survey.

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[2]Research Agronomist, Agronomy Department/Laboratory for Applications of Remote Sensing (LARS), Purdue University, West Lafayette, Indiana; Assistant State Soil Scientist, USDA/Soil Conservation Service, Columbia, Missouri; formerly Graduate Research Assistant, Agronomy Department/LARS, presently Assistant Professor, Department of Natural Resources and Environmental Studies, Alabama A&M University, Alabama, respectively.

INTRODUCTION

As we become more aware that our natural resources are of a finite nature, a means must be developed to inventory these resources adequately and to monitor their use. Computer processing of satellite data provides the technology and the opportunity to observe, assess, evaluate and monitor the environment in a time span and with instruments never before available.

One of our most valuable but most often abused natural resources is our soils. If in the future we are to feed, house and clothe our ever expanding population adequately, it is critical that our soils resources be effectively managed. Modern soil surveys provide a rational means of determining the suitability potentials and limitations of varying soils to support agricultural production. In addition these surveys lend themselves to a scientific approach useful in many ways to land use and natural resource management programs.

Several states in the USA have undertaken accelerated survey programs to obtain this critical inventory of soil resources. However, soil mapping techniques are generally costly and time consuming. Thus, new remote sensing techniques are continuously being evaluated by researchers to determine where they are appropriate and applicable. Westin and Frazer (1) reviewed the characteristics of Landsat data and stated that because of the following characteristics these data are quite applicable to soil survey programs: a) synoptic view, b) multispectral data collection, c) ability to collect temporal data and d) the near orthographic aspect of the data.

The majority of the soil survey work conducted with Landsat data has been accomplished using photointerpretation of imagery to delineate soil associations (2,3,4,5,6,7,8). Limited work has been accomplished using a digital analysis approach of Landsat multispectral scanner (MSS) data as applied to soil survey (9,10,11). The Third Earth Resources Technology Satellite Symposium (Agriculture, Forestry and Range Resources)(12) reviews most of the photointerpretative and digital analysis literature.

This paper discusses a computer soils inventory project conducted in Chariton County, Missouri to determine how soil maps produced by digital analysis of satellite MSS data can accelerate and improve the quality of the National Cooperative Soil Survey Program in Missouri.

STUDY AREA

Chariton County, Missouri was selected as the study site because 1) a completed soil survey (13) was available to which the computer inventory could be compared, 2) soil and land use information was of importance to the SCS watershed management personnel and 3) the county was easily accessible for field work and verification.

Chariton County is located in north central Missouri and covers an area of approximately 195,065 hectares. It is bordered on the west and south by the Grand and Missouri Rivers, respectively. The soils of this area formed in deep loess and glacial till in the uplands and alluvial sediments in the floodplains. Three major land resource areas cover the county: 1) Iowa and Missouri deep loess hills, 2) Iowa and Missouri heavy till plain and 3) Central Mississippi valley wooded slopes. A large portion of the moderately steep upland areas is forested and the remaining area of the county is either in row crop, cereal grains or permanent pasture.

DATA SET FORMULATION

Landsat-1 MSS data collected on 15 April 1974 were utilized as the main data source for this study. This scene was selected because the data were 1) of high quality, 2) acquired when most cropland is in a bare soil state and 3) free of interfering atmospheric and surface conditions (i.e., clouds, haze, saturated soils, and standing water). Chariton County had received less than 0.5 inches of precipitation in the week prior to the Landsat overpass.

The Landsat MSS data were geometrically corrected (i.e., rotated, deskewed and rescaled to an approximate scale of 1:24,000)(14). That portion of the scene containing Chariton County was selected for further preprocessing. These data were registered to ground control points selected from USGS 7½ minute topographic quadrangles. This procedure produced a data set of an exact scale of 1:24,000 and registered geographic points in the data to their exact ground position. Using these same quadrangle maps, a number of topographic and political boundaries were digitized and subsequently overlaid and registered to the Landsat data. These boundaries included 1) county, 2) township, 3) watershed and 4) three physiographic position boundaries (bottomlands, 0-2% slopes; gently sloping uplands, 2-9% slopes; and moderately steep uplands, 9-20% slopes). Figures 1a, b, c, and d represent each of these boundaries, respectively. The resultant data set, thus, was limited to Chariton County and contained four channels of Landsat MSS data and three additional channels of data representing the township, watershed, and physiographic boundaries, respectively, at a scale of 1:24,000.

METHODS

Areas representative of the spectral nature of Chariton County were selected for input to a clustering algorithm program. This algorithm divided the MSS data into groups of sample points of similar spectral characteristics. A statistics processor was utilized to calculate the mean relative reflectance values and covariance matrices for each of these individual cluster groupings. Cluster groupings were either deleted, retained or combined based upon their statistical separability characteristics. This procedure indicated that there were 30 spectrally separable classes within the study area. The statistics developed on each of these 30 classes were used by computer-implemented pattern recognition techniques and a maximum likelihood Gaussian classifier to assign each of the data points to one of the 30 spectrally separable classes. This technique produced a classification results tape for the entire county. After classification, the ancillary boundary data were interfaced with the classification results tape to allow the extraction, manipulation and presentation of results information within digitized topographic and/or political boundaries.

Of major importance was the ability to use topographic data (e.g., physiographic position) to separate soils which were spectrally similar but genetically different. This technique effectively increased the number of informational classes that could be extracted from the spectral data. Additionally,

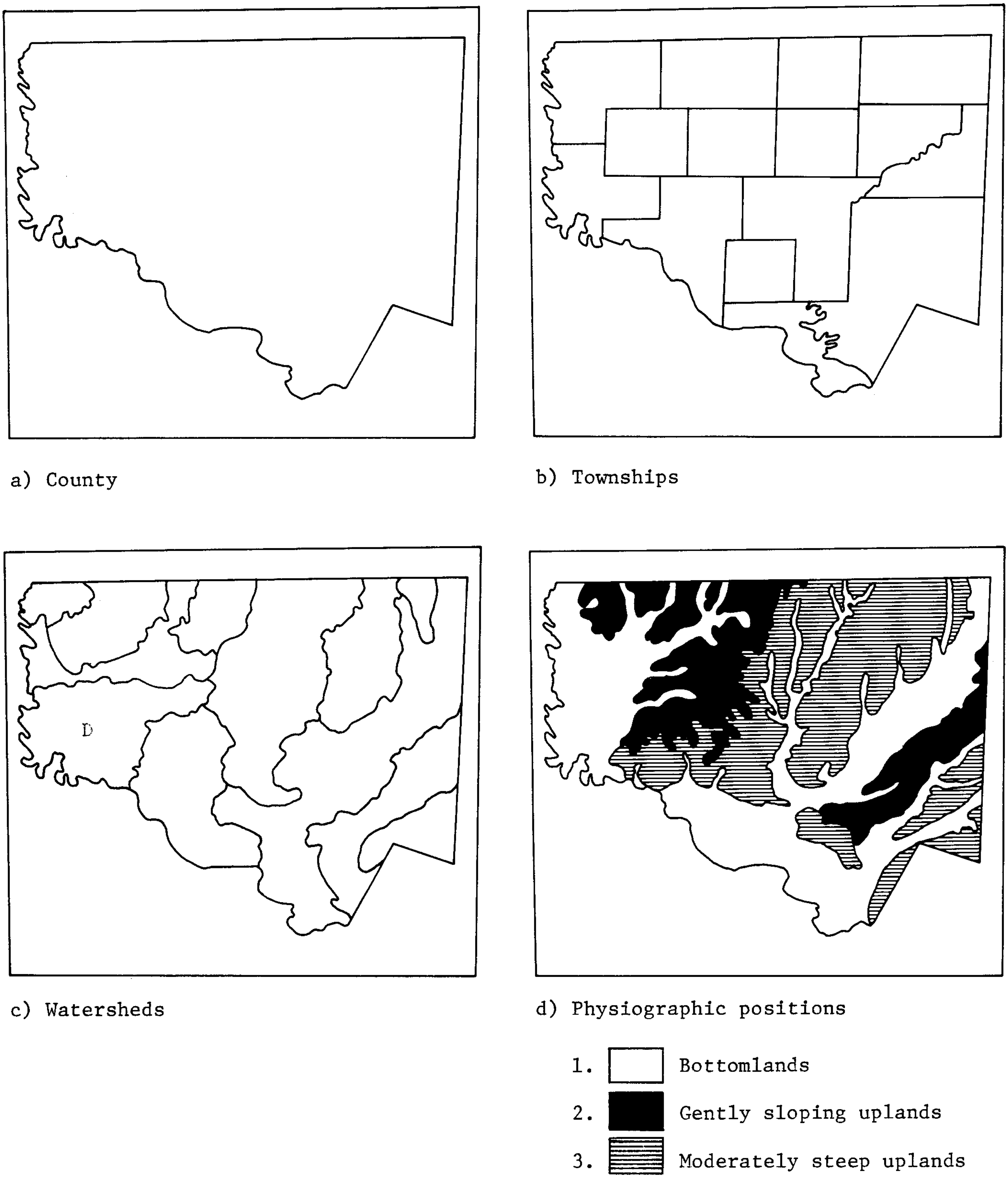


Figure 1. Boundaries Digitized and Overlaid on Landsat-1 Data

watershed boundaries allowed for the extraction and compilation of data within meaningful and manageable unit boundaries.

Alphanumeric, 1:24,000 spectral maps and area statistics representing each of the 30 classes inventoried were produced for each of the 12 watersheds. Within each watershed individual spectral maps and area statistics were produced for each of the three physiographic positions (i.e., bottomlands, gently sloping uplands and moderately steep uplands).

Evaluation of the resultant inventory was conducted by Missouri SCS field personnel. One hundred evaluation sites, each 16 hectares or more in size, were selected throughout Chariton County. For each site, the digital soils information was related to the soil survey and a correlation between the soils spectral properties and their soil series designation was conducted.

RESULTS AND DISCUSSION

Thirty spectrally separable classes were contained within the inventory of Chariton County. The informational classes represented by these 30 spectral classes, the relative proportion of each, and the number of spectral classes contained within each information class is given in Table 1.

Table 1. Information classes derived from digital analysis of Landsat-1 MSS data for Chariton County, Missouri.

Informational Class	Percentage of County Area	Spectral Classes Per Informational Class
Bare Soil	64	14
Pasture	16	4
Winter Wheat	1	2
Forest	11	3
Other Vegetation	< 1	4
Water	7	3

Table 2 compares the Landsat classification results with inventory data collected for Chariton County during the Conservation Needs Inventory (CNI) of 1970 (15) and a Missouri Department of Conservation, Forestry Division Inventory of 1974 (16). Since the Landsat data were collected in April, it was assumed that the 14 spectral classes of bare soil represented the area to be planted in summer crops. Thus, in this comparison the bare soil classes were equated to the corn and soybean classes of the CNI data.

Nearly 50 percent of the spectral classes describe 64 percent of the county area, e.g., bare soil (Table 1). The remaining spectral classes reflect similar proportions between the number of classes and the percentage of the county contained in these classes indicating that they appropriately represent the desired informational classes. The inventory data presented

Table 2. Comparison of land cover in Chariton County, Missouri.

Informational Class	Landsat Data Hectares	Conservation Needs Inventory Hectares	Missouri Department of Conservation, Forestry Division Hectares
Corn, Soybeans (Bare Soil)	77,974	67,813	---
Winter Wheat	8,079	11,997	---
Hay-Pasture	58,735	60,451	---
Forest-Bottomland	13,786	---	13,703
Forest-Upland	12,522	---	12,643
Forest-Total	26,308	23,958	26,346
Water	2,465	2,362	---
Urban	---	5,125	---
Federal Lands	---	4,320	---
Inventory Total	194,951	176,026	195,065

in Table 2 lend further support to the validity of the Landsat resource inventory. The classes of hay-pasture, forest (all three classes), and water are in exceptionally close agreement with data collected by traditional means. The variances associated with the winter wheat; corn, soybean (bare soil); urban and federal lands classes are undoubtedly due to the non-uniformity of classes inventoried, changes in farming practices, and the variation in the total area included in each inventory.

Within the vegetated portions of the county, the spectral properties of the soils were not directly observable. In these areas little effort was made to relate soil cover to soil type. Thus, the 14 spectral classes which describe the areas existing as bare soil (64% of county) were of major importance in the soil inventory.

Digital mapping of soils using Landsat data is based solely upon the surface reflectance properties of the various soils. Such distinguishing soil characteristics as parent material, profile development and landscape position are not observable with current satellite systems. Often widely different soils exhibit similar spectral responses and cannot be differentiated from one another using satellite data alone. However, appropriate ancillary data used in conjunction with the Landsat data can greatly increase the informational content of a spectral soils map.

Ancillary boundary data can be manually overlaid on Landsat data and the desired information extracted by visual means. Depending upon the amount of data being observed, this method often becomes quite burdensome and time consuming. However, if the ancillary data are supplied in a format such that the computer can accomplish the interaction of the two data sets many of the manual problems are overcome.

As previously stated, four channels of digitized ancillary boundary data were registered to the Landsat data. These boundary data allowed the computer to manipulate, compile, extract and present information within specific units. In this instance, physiographic boundaries were used to delineate three landscape positions of interest: 1) bottomlands, 2) gently sloping uplands and 3) moderately steep uplands. The physiographic boundary data were used to allow the computer to differentiate between spectrally similar soils which occur on distinctively different positions in the landscape. The county, township and watershed boundary data allowed for the presentation of information within desired political and geographical management units. Table 3 and Figure 2 illustrate the ability of the computer to interact the ancillary boundary data with Landsat data to present information extracted from subregions within the data set.

Table 3. Distribution of informational classes for the Salt Creek Watershed*, Chariton County, Missouri.

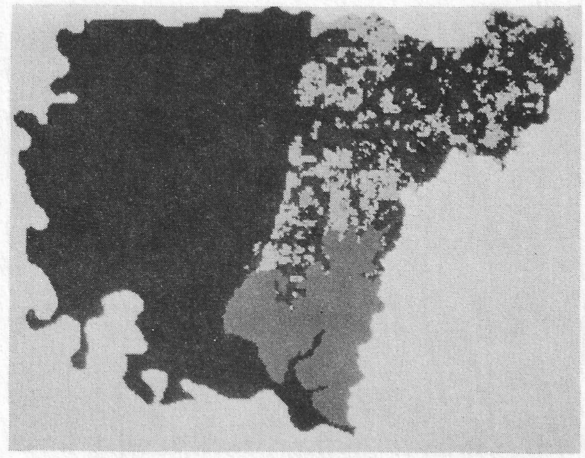
	Light Colored Soils**	Intermediate Colored Soils**	Dark Colored Soils**	Green Vegetation	Forest	Water	Total
			(in hectares)				
Bottomlands	589	6899	2591	1238	1738	84	13139
Gently Sloping Uplands	65	2211	80	3510	1331	1	7198
Moderately Steep Uplands	101	295	4	1979	394	1	2774
Total	755	9405	2675	6727	3463	86	23111
Percentage	3.3	40.7	11.6	29.1	15.0	0.4	100

*Watershed D, Figure 1c.
**Light, Intermediate, and Dark are subjective groupings of soils based upon their relative reflectance values.

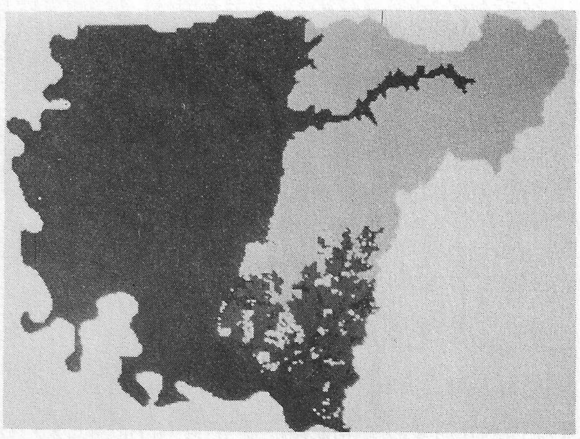
During field verification, the gently sloping and moderately steep positions were combined and considered as one physiographic unit, e.g., upland. Thus, the remainder of the discussion is limited to a bottomland unit and a combined upland unit. Tables 4 and 5 present the correlation of the spectral classes of soil with individual series and their taxonomic classification for the bottomland and upland units, respectively. Table 6 lists selected properties of these soils series.

It is readily observable from Tables 4 and 5 that there is not a direct one to one correlation between spectral classes and soil series or family. In some instances one spectral class may represent two or more

a) Bottomlands



b) Gently sloping uplands



c) Moderately steep uplands

Legend:

Light	Light colored soils*
Moderately Light	Intermediate colored soils*
Intermediate	Dark colored soils*
Moderately Dark	Green vegetation
Dark	Forest

*Light, Intermediate and Dark are subjective groupings of soils based upon their relative reflectance values.

Figure 2. Spatial Distribution of Informational Classes for the Salt Creek Watershed**, Chariton County, Missouri

**Watershed D, Figure 1c

Table 4. Correlation and classification of bottomland units in Chariton County, Missouri*

Spectral Class	Soil Series	Classification
		Fine, montmorillonitic, mesic
**A,C	Woodbury	Vertic Haplaquolls
B,D	Darwin	Vertic Haplaquolls
E	Bremer	Typic Argiaquolls
G	Chariton	Mollic Albaqualfs
I	Auxvasse	Aeric Albaqualfs
		Fine-silty, mixed, mesic
F	Kennebec	Cumulic Hapludolls
F	Keg	Typic Hapludolls
H	Dockery	Aquic Udifluvents
		Coarse-silty, mixed, mesic
J,K,L	Haynie	Mollic Udifluvents
		Coarse-loamy, mixed, mesic
N	Ankeny	Cumulic Hapludolls
		Sandy, mixed, mesic
O	Sarpy	Typic Udipsamments

*The spectral class symbol was compared to the soil series on 100 sites that were 40 acres or more in size. The table shows the dominant soil series that occurred for each spectral class.

**Alphabetical letters represent bare soil. The spectral reflectance from the soil surface in general increases from A to O.

Table 5. Correlation and classification of upland units in Chariton County, Missouri*

Spectral Class	Soil Series	Classification
		Fine, montmorillonitic, mesic
**F,G,H	Grundy	Aquic Argiudolls
H	Lagonda	Aquic Argiudolls
I	Edina	Typic Argialbolls
I	Gorin	Aquic Hapludalfs
J,K,L	Ladoga	Mollic Hapludalfs
L	Menfro	Typic Hapludalfs
		Fine-loamy, mixed, mesic
N	Lindley	Typic Hapludalfs

*The spectral class symbol was compared to the soil series on 100 sites that were 40 acres or more in size. The table shows the dominant soil series that occurred for each spectral class.

**Alphabetical letters represent bare soil. The spectral reflectance from the soil surface in general increases from F to N.

Table 6. Selected soil properties of some soils in Chariton County, Missouri.

Spectral Class	Soil Series	Landscape Position	Percent Slope	Surface Color	Surface Texture	Soil Drainage
			Bottomland Units			
A,C	Woodbury	Bottom	0-2	10YR2/1	SIC	Poorly
B,D	Darwin	Bottom	0-2	10YR3/1	SIC	Poorly
E	Bremer	Terrace	0-2	10YR2/1	SICL	Poorly
F	Kennebec	Bottom	0-2	10YR2/1	SIL	Moderately Well
F	Keg	Bottom	0-2	10YR2/1	SIL	Moderately Well
G	Chariton	Terrace	0-2	10YR3/2	SIL	Poorly
H	Dockery	Bottom	0-2	10YR3/2	SIL	Somewhat Poorly
I	Auxvasse	Terrace	0-2	10YR4/3	SIL	Poorly
J,K,L	Haynie	Bottom	0-2	10YR3/2	SIL	Moderately Well
N	Ankeny	Terrace	0-2	10YR2/2	FSL	Well
O	Sarpy	Bottom	0-2	10YR3/2	FS	Excessively
			Upland Units			
F,G	Grundy	Upland	2-9	10YR2/1	SIL	Somewhat Poorly
H	Grundy	Upland	9-14	10YR3/1	SIL	Somewhat Poorly
H	Lagonda	Upland	9-14	10YR3/1	SIL	Somewhat Poorly
I	Edina	Upland	0-2	10YR3/1	SIL	Poorly
I	Gorin	Upland	2-6	10YR3/1	L	Somewhat Poorly
J,K,L	Ladoga	Upland	2-35	10YR3/1	SIL	Moderately Well
L	Menfro	Upland	2-35	10YR4/3	SIL	Well
N	Lindley	Upland	14-35	10YR4/1	L	Well

soil series, and in other cases a single soil series may be represented by one or more spectral classes. In the bottomland unit all 14 spectral classes of soil were represented. These corresponded to 9 subgroups, 5 families and 11 soil series (Table 4). In the upland unit, (Table 5) only 8 of the 14 spectral classes of soil were represented, corresponding to 5 subgroups, 2 families and 7 soil series.

The six spectral classes which were represented in the bottomland but not the upland unit correspond to classes A,B,C,D,E, and O. Classes A,B,C, D, and E exhibit rather low spectral responses and correspond to the Vertic Haplaquolls and Typic Argiaquolls. Class O has a rather high relative reflectance and corresponds to the Typic Udipsamments.

Classes F through N exhibit intermediate relative reflectance values and are common to both the upland and bottomland units. Soils within these two landscape positions which are spectrally similar can be separated into their appropriate families and series by using the physiographic position boundary data incorporated within the data set. These spectral classes correspond to the Typic and Cumulic Hapludolls, Mollic and Aeric Albaqualfs, and Mollic and Aquic Udifluvents in the bottomlands and the Aquic Argiudolls, Typic Argialbolls and the Aquic, Typic, and Mollic Hapludalfs in the upland areas.

To illustrate quantitatively the spectral separability of soils, the mean relative reflectance values for five representative soils were plotted against their respective Landsat spectral band (Figure 3). In all cases the mean values are distinctly separable; and when represented in standard error form, the intervals overlap in only two instances.

CONCLUSIONS

The conventional differentiation of soils at the family and series level is based upon both surface and subsurface properties. As previously stated, computer mapping of soils using Landsat MSS data is based solely upon the reflectance of the soil surface layer. Multispectral data collected by Landsat have the unique characteristic of containing information from both the visible and reflective infrared portions of the spectrum and contain valuable information not available in black and white aerial photography or visual observations. Digital analysis of satellite MSS data can distinguish surface tones and provide information concerning related features such as moisture regimes, organic matter contents, gross surface textures and quantitative indications of mapping unit homogeneity.

While a spectral classification of soils alone cannot distinguish between widely different soils exhibiting similar spectral responses, it can aid in identifying meaningful divisions of soils. By combining digitized ancillary data with MSS data, a more detailed delineation of soils can be provided as compared to information derived solely from MSS data. This study utilized topographic boundaries to allow for the separation of spectrally similar soils and the presentation of data by landscape position, e.g., bottomlands and uplands. This technique effectively increased the informational content of the 14 spectral classes of soil to describe 14 subgroups, 7 soil families and 18 soil series classes. Further refinement of this technique and the inclusion of other pertinent ancillary data (i.e., parent material boundaries) will continue to increase the usefulness of satellite MSS data as an aid in soil survey.

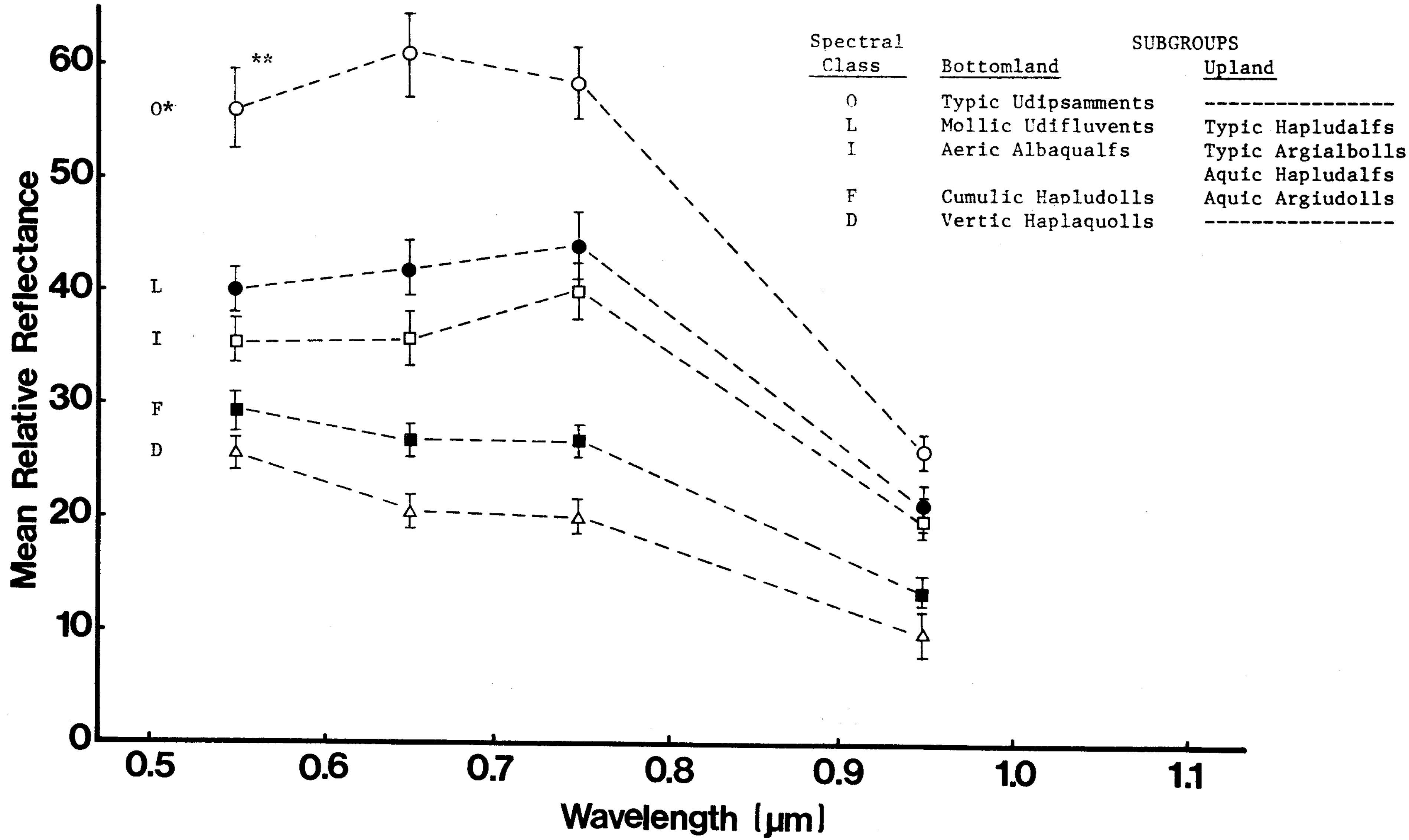


Figure 3. Landsat Relative Reflectance Values for Representative Spectral Soil Classes

* denotes spectral class

** one standard deviation

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