LARS Information Note 063075

Quantitative Inventorying of Soil and Land Use Differences by Remote Sensing

J. B. Peterson

The Laboratory for Applications of Remote Sensing

Purdue University, West Lafayette, Indiana

1975

LARS Information Note 063075

Quantitative Inventorying of Soil and Land Use Differences by Remote Sensing

J. B. PETERSON, PROFESSOR OF AGRONOMY AND ASSOCIATE DIRECTOR,
LABORATORY FOR APPLICATIONS OF REMOTE SENSING, PURDUE UNIVERSITY

Invitational Paper, Annual Meeting Soil Conservation Society of America, San Antonio, Tex. Aug. 1975.

This work was sponsored by the National Aeronautics and Space Administration under Grant No. 150051 86A and Contract No. 7633-52-12805.

Remote sensing is the acquisition and interpretation of special measurements made of an object from a distant location. Currently the term is commonly used in reference to information regarding the earth's surface secured on high flying platforms such as aircraft or satellite. An early form of this type of data gathering was aerial photography. Although aerial photography from balloons was used in the Civil War, the technique received little attention until World War I. Remote sensing technology has advanced through color photography; color infrared photography, called camouflage detection film; electromagnetic methods combined with photography; and eventually to completely electromagnetic techniques embodied in the single aperture, multispectral scanner.

Paralleling these changes have been advances in computer techniques especially in the areas of pattern recognition and machine-aided analysis of remotely sensed data. Through the use of such devices as densitometers, it was found that radiation measured in photography could be quantized. This suggested the possibility of developing ways of digitizing remotely-sensed data and developing digital computer analysis techniques for handling them. The same principle was applied to data acquired by electronic techniques as such methods began to replace photography as a major means of collecting remotely sensed information. Without the early development of computer-based means of mechanically processing such data, the volume of data which can now be obtained from high flying platforms could not be handled effectively.

Also concurrently great advances have been made in the applications of the technology to studies of natural phenomena, particularly those that can be measured directly on the earth's surface or interpreted from ıch measurements.

Black and White Aerial Photography

The mapping of soil, soil erosion and land use has always been one of the major activities of agriculturists, especially those interested in soil and water management and conservation and lately in the general area of land use. After World War I remote sensing techniques to identify and delineate different kinds of soils by black and white photography developed rapidly (45, 37, 28, 29). Cobb and Baldwin experimented with the use of aerial photography in soil mapping as early as 1918 (30, 14). In 1929, T.M. Bushnell (8), reported the first aerial photographing of an entire county, Jennings County, Indiana, for the cooperative soil survey of the U.S. Department of Agriculture and the state experiment stations. An Eastman camera with a 10-inch focal length lens was used.

When the Soil Erosion Service, forerunner of the Soil Conservation Service, earnestly began its field work in 1933, transition between using plane tabled maps and aerial photographs as base maps was underway. In a few years all soil surveyors were sketching boundaries directly on aerial photos in the field. At the time of Bushnell's report, an extensive bibliography on aerial photography had already developed (9, 6).

Color and Color Infrared Photography

With the advent of color and color infrared photography in the 1930's, research was instigated principally by the military to test its usefulness as an aid to mapping landscapes. Research comparing black-and-white photographs with color and color infrared was carried on extensively by civilians following World War II (1, 16, 46, 20, 49). In reviewing the studies of research on color photography in 1960, Colwell (15) found color better than black-and-white alone in most cases except for hazy weather where black-and-white was superior at high altitudes. The potential of infrared photography as an aid to interpreting the earth-scene appeared to be especially favorable (33, 10 , 50 , 51).

False Color Photography

It was discovered that for specialized purposes better identification and separability of ground features could often be obtained by producing on film colors quite different from those of the true scene, that is by "false colors." This method utilized spectral regions to emphasize differences between particular objects which in true colors are visually quite similar.

The principles of false-color systems were used during World War II. Kodak Ektachrome Aero Film (Camouflage Detection, then known as Kodacolor Aero Film, Camouflage Detection), supplied to the Allied Armed Forces in 1942 was excellent for this purpose (48). Kodak's film emphasized the difference in infrared reflection between green vegetation and most visually similar green paints. By the 1960's marked advances had been made in producing aerial film.

Photo Interpretation

Along with the development of technology for aerial photography, research was directed to use and interpretation. As the multidisciplinary needs of remote sensing science and technology became more and more obvious; geographers, geologists, soil scientists, foresters, land use specialists and others actively experimented with the new techniques as they developed. The interpretation of aerial photography became a special field of technology with its own society and journals and its own discipline in many universities. The use of aerial photographs as base maps for soil surveys was well established by 1938 (30, 3) and had become standard procedure in the national cooperative soil survey conducted at that time by the cooperating state agricultural experiment stations and the Soil Conservations Service, U.S.D.A.

Separation of Imagery into Discrete Spectral "Bands" and Quantitative Characterization of Reflectance

As attention turned to discriminating among such varied objects as soils and plants in photography taken from aircraft an awareness grew of the value of using different wavelength bands (25). Although large differences in spectral responses or tones are frequently apparent in aerial photography, many objects are difficult to differentiate because they have similar responses in particular portions of the spectrum. It was found that this problem could be overcome by using different discrete bands of imagery achieved through different combinations of filters and film types (25, 24, 2). It was also obvious that to be useful the relative radiance in each band would need to be expressed quantitatively.

Although adding greatly to the capacity to interpret photography the imaging of data in discrete wavelength bands which could be evaluated quantitatively greatly complicated the job of the photointerpreter because of the added complexity and volume of data. This served to emphasize the need for computer-based techniques for handling and analyzing the data. The need to quantify reflectance and emittance data registered on photography from various targets (35, 24, 43) was further motivated by the frequency of error inherent in subjective "by the eye" estimates. Early approaches to achieve this end used such devices as densitometers to evaluate quantitatively the relative difference in density, tone or color, of black and white or color photographs (16, 25, 29, 24).

By using quantitative data from discrete wavelength bands of the optical spectrum to characterize the reflectance and emittance properties of targets, investigators were able to provide an accurate and effective basis for distinguishing and identifying remotely-sensed targets. An example comparing the reflectance curves of dry Chalmers Silty Clay Loam and a corn leaf as obtained with a DK-2 spectrophotometer is shown in Figure 1.

Development of Multispectral Scanner (MSS) for High Flying Platforms

In order to extend the sensed imagery further into the infrared region of the spectrum it was necessary to find a method other than chemical photography. This led to the use of electro-optical detectors which required a scanning technique to transfer the radiant energy from the target scene to magnetic tape. Such a device was developed by the military and when the information was declassified following World War II it was quickly improved upon and adapted to remote sensing use by civilian researchers, particularly the group at the Environmental Research Institute of Michigan (ERIM) formerly the Institute of Science and Technology (IST) (23).

By 1971 under NASA support, ERIM had modified its original multipath, multispectral airborne scanner system to provide all spectral bands along a single optical line of sight (Figure 2). This greatly simplified the processing of the data since previously the choice of spectral bands for machine processing had often been limited to those few grouped in one of four separate optical paths. After the modification, any of the multispectral bands selected from throughout the ultraviolet, visible and infrared regions could be processed together.

Advantages (39) of the improved MSS as developed by Michigan included: an output signal in electrical form which could be readily transmitted, recorded, analyzed and otherwise processed as desired; detectors with a wider dynamic range than photographic film and a reversible detection process.

Data from this Michigan MSS were used in the Southern Corn Leaf Blight Experiment, the first large scale use of remote sensing data in an integrated study of a large extent of the earth's surface. The multispectral scanner designed for the LANDSAT satellite series is based on the early Michigan work.

Development of Computerized Methods for Handling Multispectral Scanner (MSS) Data

With the advent of multispectral scanners and their adaptation to use in aircraft and spacecraft the potential data flow from such devices exceeded processing capabilities. This stimulated research to improve computerized methods of handling such large volumes of data (19). During this period, mainly the mid-nineteen sixties, research concentrated on machine processing methods which would make it possible to keep ahead of the data flow and make the results of analyzed earth imagery available quickly after its gathering. Landgrebe and associates (21, 36) proposed and successfully demonstrated that a type of multivariant analysis known as pattern recognition when used on multispectral data could provide an efficient and accurate means for identifying and measuring the areal extent of crops and other earth cover types.

A software system, known as "LARSYS," was developed and documented by members of the LARS staff (47). The procedures for computerized handling and analyzing data from multispectral scanners were enough advanced by 1971 to make feasible the Corn Blight Watch Experiment (42).

Application of Remote Sensing to Soil Science

Since most soil scientists, particularly those involved in soil genesis and classification, are knowledgeable of the applications of the ordinary aerial black-and-white, color and color infrared photography, I shall concentrate principally on use and potential in soil science of multispectral data. Time does not permit a complete review of the ever increasing volume of investigations of the applicability of remote sensing to soil studies. I shall trace, however, the evolution of the technology using suitable examples.

Early in the 1960's certain discrete wavelength bands and combinations of these bands were found to be more discriminating in characterizing soil differences than were the usual photographs. Condit (17) using a laboratory spectrophotometer to secure multiband data found the spectral reflectance of a wide range of soils could be predicted accurately from measurements using five wavelengths between .32 and 1.0 micrometers. Anuta (2) in applying pattern recognition techniques to 4 channels of Apollo 9 data for the Imperial Valley, California, was able to differentiate barley, sugar beets, alfalfa, bare soil, salt flats and water. Hoffer and Johannsen (25) using a Beckman DK-2 Spectrophotometer secured reflectance curves showing distinct spectral signatures among leaves and soils of different colors and different moisture contents.

Measurements of radiation from samples of seven Indiana soil series (13) encouraged attempts to characterize different soils by reflectance curves. Mollisols were separated from Alfisols. However, in this study soil series with similar surface colors were not readily separated by spectral response. Dry soils showed higher reflectance than wet soils and crusted surfaces than uncrusted. Montgomery and Baumgardner (44) studied reflectance from samples of 71 benchmark soils. They found multispectral measurements with a field spectroradiometer to be highly correlated with cation exchange capacity and silt content. From his research, Kristof (31) was encouraged by the possibility of using as a soil classification method, multispectral imagery in different wavelength bands secured by scanners mounted on aircraft and analyzed by automatic techniques. He successfully used data secured by the optical mechanical scanner on an aircraft platform to differentiate levels of soil organic matter in a bare soil field (5). Linear regression of organic matter content and wavelength response gave an r value of 0.74. Surface soil areas of different organic matter levels over a 40 km flight line in central Indiana were delineated and mapped successfully with multispectral data and automatic data processing (32).

Data secured in the 1971 Corn Blight Watch Experiment at 5,000 feet were also used to test feasibility of using computerized MSS data to distinguish Udalf from Udoll soil suborders along the boundary of the classical "Prairie Point" which protrudes into Indiana from the west.* Although the

*Peterson, J.B., S.J. Kristof, J.E. Cipra, and A.L. Zachary, "Delineation of Udolls from Udalfs using Multispectral Scanner Data." Abstract. 1972. Meetings Western Soc. Soil. Sci., Salt Lake City.

colors of zonal surface soils being compared were very close in hue, chroma and value, judged by the Munsell soil color chart, many of the samples being only one color chip apart on a wet soil basis, good separation was achieved. Results of the analysis are shown in Figure 3 where bars representing the standard deviation from the mean of relative spectral responses for 13 spectral bands show high reflectance from the bare surfaces of Udalf over the Udoll soils in every case.

Also using data from the 1971 Corn Blight Watch Experiment, Cipra et al. (12) by defining spectral classes quantitatively were able to define three of five soil mapping units in a 12-mile flightline in Indiana.

With the successful launching of LANDSAT-1 a great amount of spectral data from the soils over the world became available. By this time computerized procedures for handling and analyzing such volumes of data had advanced enough to permit timely and effective use of the statistics from satellites. The MSS subsystem of LANDSAT-1 gathers data by imaging the surface of the earth in four spectral bands simultaneously through the same optical system. When LANDSAT imagery was compared to a soil association map of Tippecanoe County, Indiana (11), after processing both photographically and by computer analysis, four groupings of 13 soil associations were separated.

Typical of the many examples of a growing proficiency in utilizing satellite data to characterize and delineate soils objectively and quantitatively are the studies by Baumgardner and Henderson (4) of the soils of Crosby County, Texas; by Westin (52) in South Dakota and Seevers (48) in Nebraska.

Baumgardner was able to identify changes in soils from heavy clays of the north to sandy soils in the south. Westin with LANDSAT-1 imagery identified and refined maps of soil associations in South Dakota. Negative prints produced from LANDSAT-1 band 7 imagery were used to produce a base map at 1:1,000,000 for a soil association values map of the state. Seevers accomplished a delineation of 7 soil associations in the Nebraska sand hills with multitemporal imagery.

More recently, Westin et al. (53) interpreted LANDSAT color composite transparencies, single band transparencies and enlargement prints to produce a soil scape map for 4,000 hectares at a cost of 2¢ per hectare.

The value of the synoptic view provided by satellite imagery is clearly apparent in a recent discovery in central Indiana* of a buried preglacial valley, an important tributary of the Teays preglacial river system. The valley was readily discernable in classified LANDSAT imagery of June 9, 1973, because its freshly tilled surface Aquoll and Udoll soils were much darker than the Udalfs in the surrounding landscape.

Of significance is the fact that there seems to be no other record of the continuity of this 65 km stretch of narrow, meandering, continuous prairie. Soil surveyors in making two detailed soil survey maps per county in the last 60 years for three counties encompassing the buried valley have not commented

---

* Peterson, J.B., F.E. Goodrick and W.N. Melhorn. 1975. Delineation of the boundaries of a buried preglacial valley with LANDSAT-1 data. pg. 52. NASA Earth Resources Survey Symposium (Abstracts). June 1975, Houston, Texas.

on the continuity of the stretch of prairie soils. Furthermore geologists who have been searching for the exact location of the valley since 1915 were unsuccessful until the LANDSAT data provided a synoptic view (Figure 4).

Radar

While research was expanding the recordable range of radiant energy to include wavelengths of 0.3 to 14 μm, other research was exploring the possibilities of radar (17, 38, 41). Radar is an active system which carries its own source of energy and operates in the microwave portion of the EM spectrum. These two characteristics give it a nearly all-weather, 24-hour imaging capability, a capability not possible by other remote sensing systems.

Large areas of vegetative patterns have been identified by radar. It has been effectively used to distinguish land forms which influence soil characteristics such as erosional and depositional forms, moraines, slope, relative relief, drainage net works, etc. (22, 40, 34, 46, 7).

Commenting on the state of the art in 1974, Drake et al. (18) suggests that side looking radar (SLAR) systems have great potential for earth resource purposes.

Potential of Remote Sensing as an Aid in Mapping and Inventorying Land Use and Soils

1. Data availability.

Continued availability of data from high flying platforms can be expected; from aircraft with certainty and from satellites with a high degree of expectancy because of practical, technical and strategic reasons. Satellite data can be expected to be available in a continually uniform format, readily obtainable, from a single source, providing a homogenous data base of land resource information.

2. Potential for further development.

Recent important improvements in the technology are being refined and perfected. These include such innovations as the capability to:

a. Analyze data from repetitive overflights of LANDSAT on a multitemporal basis through data registration and overlay techniques;

b. Rectify imagery to near orthographic scales thus making possible maps of precise geographic correctness;

c. Increase the resolving power of sensors on future satellites.

3. Low cost per unit area.

Increasingly lower costs per hectare of landscape are becoming possible for processing, analysis, interpretation and preparation in user-compatible format.

4. Improved data formatting.

There is an inherent great analytical advantage in quantitative data possible in the remote sensing approach and in the ease of handling great volumes of such data with mechanical processes now available and still being improved such as LARSYS.

5. Rapid and efficient coverage of large areas.

Currently securing, processing, analyzing and preparing data for large areas of landscape in user-understandable format can be accomplished rapidly and efficiently by remote sensing techniques. These processes which utilize multispectral sensors, digital data format and computerized techniques are continually being improved.

6. Broad spectrum multiband sensor systems.

There are possibilities for capitalizing on the broad spectral range and multiband approach available in present scanning sensing systems, which users are rapidly learning to exploit as tools in target analysis, identification and delineation.

7. Ready accumulation of quantitative data per identifiable unit of landscape.

Quantitative data on a two dimensional basis can be secured and analyzed rapidly by remote sensing techniques. Once in a two-dimensional spatial arrangement such data can be expressed as statistics or in map form. Furthermore it is possible through computerized techniques to overlay one set of remotely-sensed data with data taken at different times and also with various kinds of data from other sources. In addition the scale can be adjusted to convenient dimensions and to provide a uniform scale for overlaying various sets of data.

References Cited

1. Anson, A. 1968. Developments in aerial color photography for terrain analysis. Photogram. Eng. 34: 1048-1057.

2. Anuta, P.E. and R.B. MacDonald. 1971. Crop surveys from multiband satellite photography using digital techniques. Remote Sensing of Environ. 2: 53-67.

3. Baldwin, M., C.E. Kellogg, and J. Thorp. 1938. Soil classification. In Soils and Men: Yearbook of of Agriculture. U.S. Dept. of Agr. p. 979-1001.

4. Baumgardner, M.F. and J.A. Henderson, Jr. 1973. Mapping soils, crops, and rangelands by machine analysis of multitemporal ERTS-1 data. In Third Earth Res. Tech. Satellite-1 Symp. NASA, Washington, D.C. Paper A13. Vol. I. p. 205-223.

5. Baumgardner, M.F., S.J. Kristof, C.J. Johannsen, and A.L. Zachary. 1970. Effects of organic matter on the multispectral properties of soils. Proc. Ind. Acad. Sci. 79: 413-422.

6. Belcher, D.J. 1945. The engineering significance of soil patterns. Photogram. Eng. 11: 115-148.

7. Bryan, M.L. 1974. Extraction of urban land use data from multiplexed synthetic aperature radar imagery. In Summaries: Ninth Int. Symp. on Remote Sensing. ERIM, Ann Arbor. p. 26-27.

8. Bushnell, T.M. 1929. Aerial photographs of Jennings County. Proc. IN. Acad. Sci. 39: 229-230.

9. Bushnell, T.M. 1929. Aerial photography and soil survey. American Soil Survey Assoc. Bul. 10: 23-28.

10. Cantrell, J.L. 1964. Infrared geology. Photogram. Eng. 30: 916-922.

11. Cipra, J.E. 1973. Mapping soil associations using ERTS MSS data. LARS Information Note 101773. Purdue University, Lafayette, IN.

12. Cipra, J.E., M.L. Baumgardner, E.R. Stoner, and R.B. MacDonald. 1971. Measuring radiance characteristics of soil with a field spectroradiometer. Soil Sci. Soc. Amer. Proc. 35: 1014-1971.

13. Cipra, J.E., P.H. Swain, J.H. Gill, M.L. Baumgardner, and S.J. Kristof. 1972. Definition of spectrally separable classes for soil survey research. LARS Print 100372. Purdue University, Lafayette, IN.

14. Cobb, W.B. 1922. Possibilities of the airplane in soil survey work. Amer. Soil Survey Assoc. Bull. 4: 77-79.

15. Colwell, R.N. 1960. Some uses and limitations of aerial color photography in agriculture. Photogram. Eng. 22: 220-222.

16. Colwell, R.N., W. Brewer, G. Landis, P. Langley, J. Morgan, R. Rinker, J.M. Robinson, and A.L. Storem. 1963. Basic matter and energy relationships involved in remote reconnaissance. Photogram. Eng. 29: 761-799.

17. Condit, H.R. 1970. The spectral reflectance of American soils. Photogrammetric Eng. 36: 955-966.

18. Drake, B., R.A. Shuchman, R.F. Rawson, F.L. Smith, and R.W. Larson. 1974. Feasibility of using multiplex SLAR imagery for water resource management and mapping vegetation communities. In Summaries: Ninth Int. Symp. on Remote Sensing of Environment, ERIM, Univ. Mich., Ann Arbor. p. 23-25.

19. Erickson, J.D. 1972. A summary of Michigan program for earth resources information systems. In 4th Ann. Earth Resources Pro. Rev. NASA, MSC, Houston. II: 28-1-10.

20. Fischer, W.A. 1958. Color aerial photography in photogeologic interpretation. Photogram. Eng. 24: 545-549.

21. Fu, K.S., D.A. Landgrebe and T.L. Phillips. 1969. Information processing of remotely sensed agricultural data. Proc. of the IEEE 57: 639-653.

22. Gerlach, A.C. 1968. Advances in geographic and thematic mapping applications of remote sensor data. In Proc. Fifth Symp on Remote Sensing of Environment. Willow Run Laboratories. IST, Univ. Michigan, Ann Arbor. p. 191-197.

23. Hasell, P.G., Jr. 1972. Michigan experimental multispectral scanner system. 4th Ann. Earth Resources Pro. Rev. NASA, MSC, Houston. II: 34-1-34-13.

24. Hoffer, R.M. 1967. Interpretation of remote multispectral imagery of agricultural crops. Lab. for Applications of Remote Sensing. Vol. 1. Purdue Agr. Exp. Sta. Research Bull. 831.

25. Hoffer, R.M., C.J. Johannsen, and M.F. Baumgardner. 1966. Agricultural applications of remote multispectral sensing. Proc. Ind. Acad. Sci. 76: 386-395.

26. Hoffer, R.M., and C.J. Johannsen. 1969. Ecological potentials in spectral signature analysis. Chap. 1. In Remote sensing in Ecology. P.L. Johnson (Ed.) Univ. GA. Press, Athens, Georgia. pp 1-16.

27. Holmes, R.A. and R.B. MacDonald. 1969. The physical basis of system design for remote sensing in agriculture. Proc. of the IEEE 57: 629-639.

28. Joerg, W.L.G. 1923. The use of airplane photography in city geography. Annals of Assoc. Amer. Geographers. 13: 211.

29. Johnson, G.R., and R.R. Platt. 1930. Peru from the air. Special Publication 7, American Geographical Society, New York.

30. Kellogg. 1938. Recent trends in soil classification. Soil Sci. Soc. Amer. Proc. 3: 253-259.

31. Kristof, S.J. 1971. Preliminary multispectral studies of soils. J. Soil and Water Cons. 26: 15-18.

32. Kristof, S.J., M.F. Baumgardner, and C.J. Johannsen. Spectral mapping of soil organic matter. 1974. ITC Journal. 4: 479-489. (Enschete, The Netherlands).

33. Kuhl, A.D. 1970. Color and IR photos for soils. Photogram. Eng. 36: 475-482.

34. Kunzel, K.F., D.H. Pettyjohn, D.H. Staelin, and J.W. Waters. 1974. Signature of various earth surfaces measured by the Nimbus-5 microwave spectrometer. In Summaries: Ninth Int. Symp. on Remote Sensing of Environment. IREM, Ann Arbor, Michigan. p. 28-29.

35. Laboratory for Agricultural Remote Sensing. 1967. Introduction and program background. In Remote multispectral sensing in agriculture. (Annual Report). Purdue Agr. Exp. Sta. Bull. 832. Vol. 2. p. 4-5.

36. Landgrebe, D.A., and Staff. 1967. Automatic identification and classification of wheat by remote sensing. LARS Information Note 21567. Purdue University, Lafayette, IN.

37. Lee, W.T. 1922. The face of the earth as seen from the air. Special Publication 4. American Geographical Society, New York.

38. Lewis, A.J. 1974. Geomorphic-geologic mapping from remote sensors. In Estes, J.E., and L. Senger (Eds.). Remote Sensing. Hamilton Pub. Co., Santa Barbara, CA. p. 105-126.

39. Lowe, D.S. 1968. Line scan devices and why use them. In Proc. of the Fifth Symp. on Remote Sensing of Environment. IST, Willow Run Laboratories, Univ. MI, Ann Arbor. p. 77-101.

40. MacCauley, J. 1972. An evaluation of radar imagery in areas of alpine glaciation. In Radar Remote Sensing for Geoscientists. CRES. Univ. of Kansas, Lawrence, KS. p. 4: 2-1 - 4: 2-12.

41. MacDonald, H.C. 1970. Geologic evaluation of radar imagery. Darien Province, Panama. Modern Geol. 1:1-63.

42. MacDonald, R.B., M.E. Bauer, R.D. Allen, J.W. Clifton, J.D. Erickson, and D.A. Landgrebe. 1972. Results of the 1971 corn blight watch experiment. Eighth Int. Symp. on Remote Sensing of Environment. IREM, Ann Arobr, Michigan, p. 52-190. Also LARS Print 100272. Purdue University, Lafayette, IN.

43. Meyer, V.I., C.L. Wiegand, M.D. Heilman, and J.R. Thomas. 1967. Remote sensing in soil and water conservation research. Proc. Fourth Int. Symp. on Remote Sensing of Environment. IST, Willow Run Laboratories, Univ. of MI, Ann Arbor. p. 801-813.

44. Montgomery, O.L. and M.F. Baumgardner. 1974. The effects of the physical and chemical properties of soil on the spectral reflectance of soils. LARS Information Note 112674, Purdue University, Lafayette, IN.

45. Morain, S.A. 1974. Interpretation and mapping of natural vegetation. Estes, J.E., and L.W. Senger (Eds.). Remote Sensing. Hamilton Pub. Co., Santa Barbara, CA. p. 127-165.

46. Peterson, R.M. 1970. Thematic mapping and geographical interpretation with radar imagery of the Wasatch Range, Utah. In Fifth Semi-Annual Tech. Report-Project THEMIS, CRES, Univ. of KS, Lawrence. p. 183-185.

47. Phillips, T.L. 1973. LARSYS, Version 3, Users Manual, Volumes 1,2, and 3. LARS, Purdue University, Lafayette, IN.

48. Seevers, P.M., D.T. Lewis, J.V. Drew, 1973. Application of ERTS-1 imagery in mapping and managing soil and range resources in the sand hills region of Nebraska. In Third Earth Res. Tech. Satellite-1 Symp. NASA, Washington, D.C. Vol. I., Paper A14, p. 225-232.

49. Smith, J.T., Jr. 1963. Color--a new dimension in photogrammetry. Photogram. Eng. 29: 999-1013.

50. Swanson, L.W. 1960. Photogrammetric surveys for nautical charting, use of color and infrared photography. Photogram. Eng. 26: 137-141.

51. Tarkington, R.G., and A.L. Sorem. 1963. Color and false-color films for aerial photography. Photogram. Eng. 29: 88-95.

52. Westin, F.C. 1973. ERTS-1 MSS imagery: its use in delineating soil associations and as a base map for publishing soils information. In Third Earth Res. Tech. Satellite-1 Symp. NASA, Washington, D.C. Vol. I. p. 183-204.

53. Westin, F.C., C.J. Frazee and V.I. Myers. 1975. LANDSAT-1 data, its use in a soil survey program. NASA Earth Resources Survey Symposium. Abstracts. JSC, Houston, Texas. p. 52.

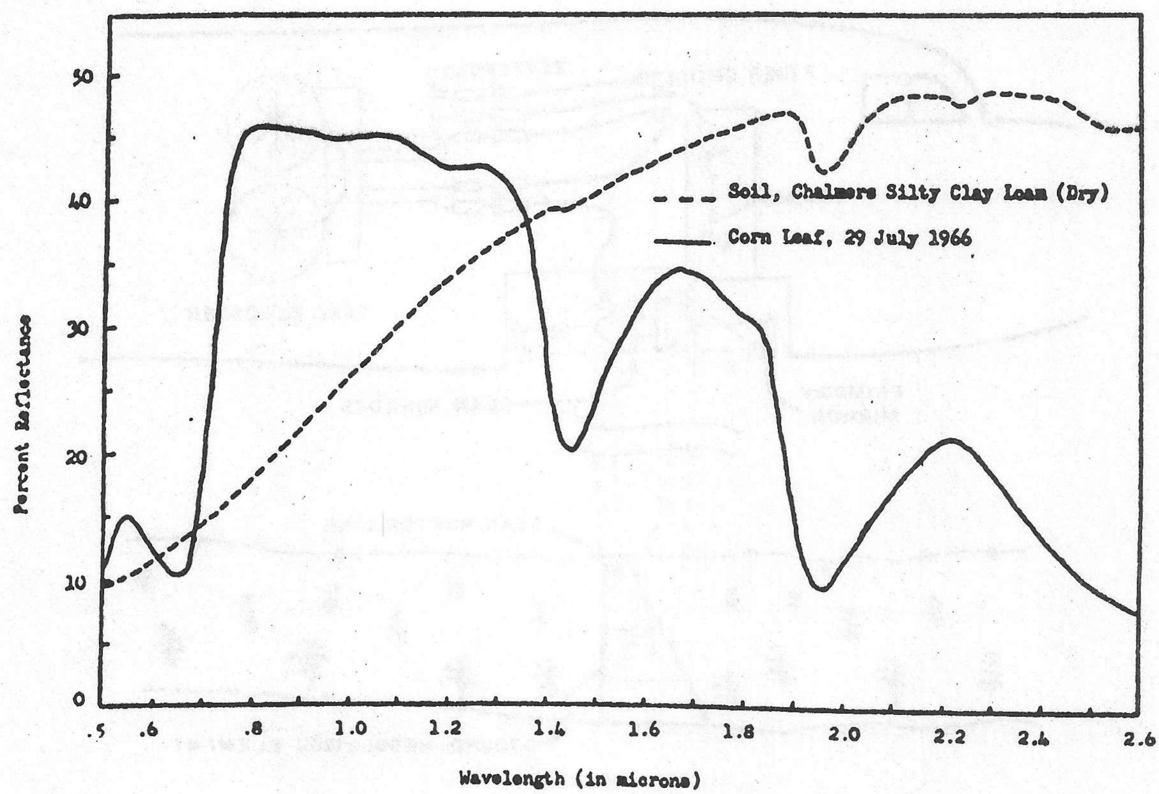

Figure 1 Reflectance Curve of dry Chalmers Silty Clay Loam and a Corn Leaf

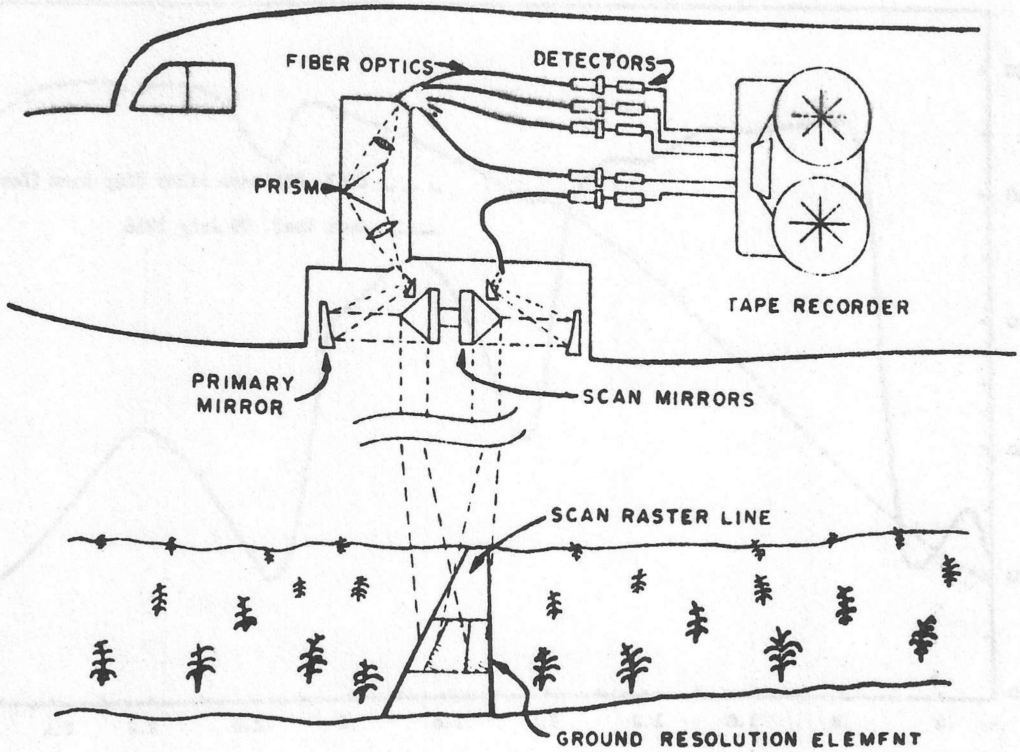

Figure 2 Single Aperture Multispectral Scanner

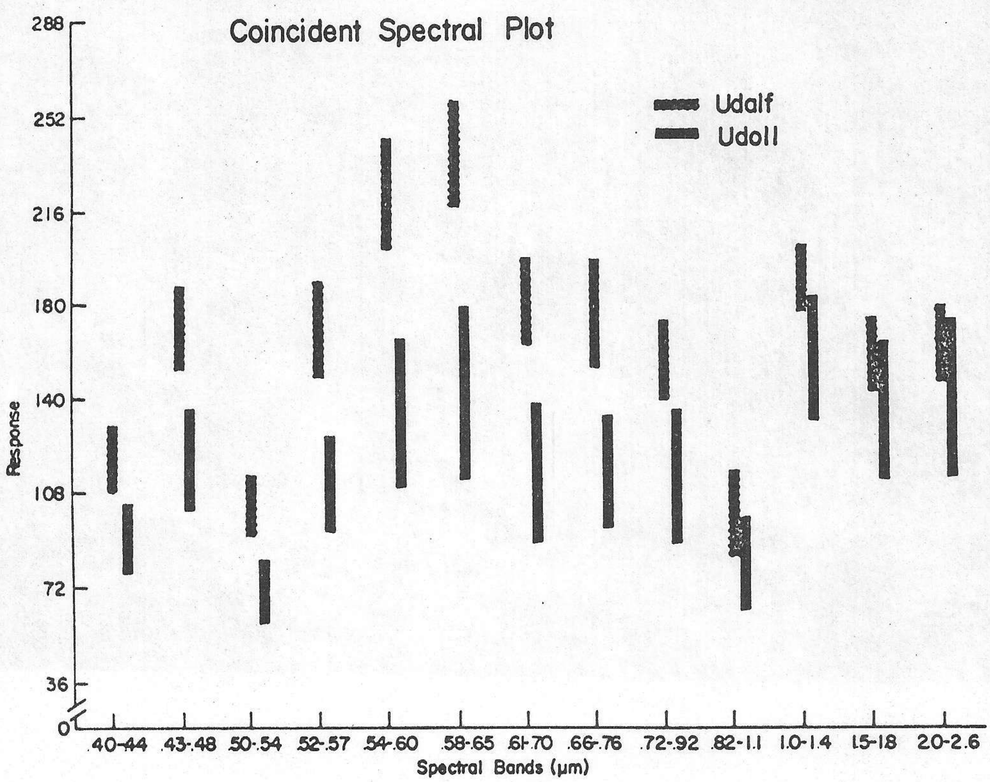

Figure 3 Coincident Spectral Plot Showing Higher Reflectance from Udalf than Udoll Soils over 13 Spectral Bands

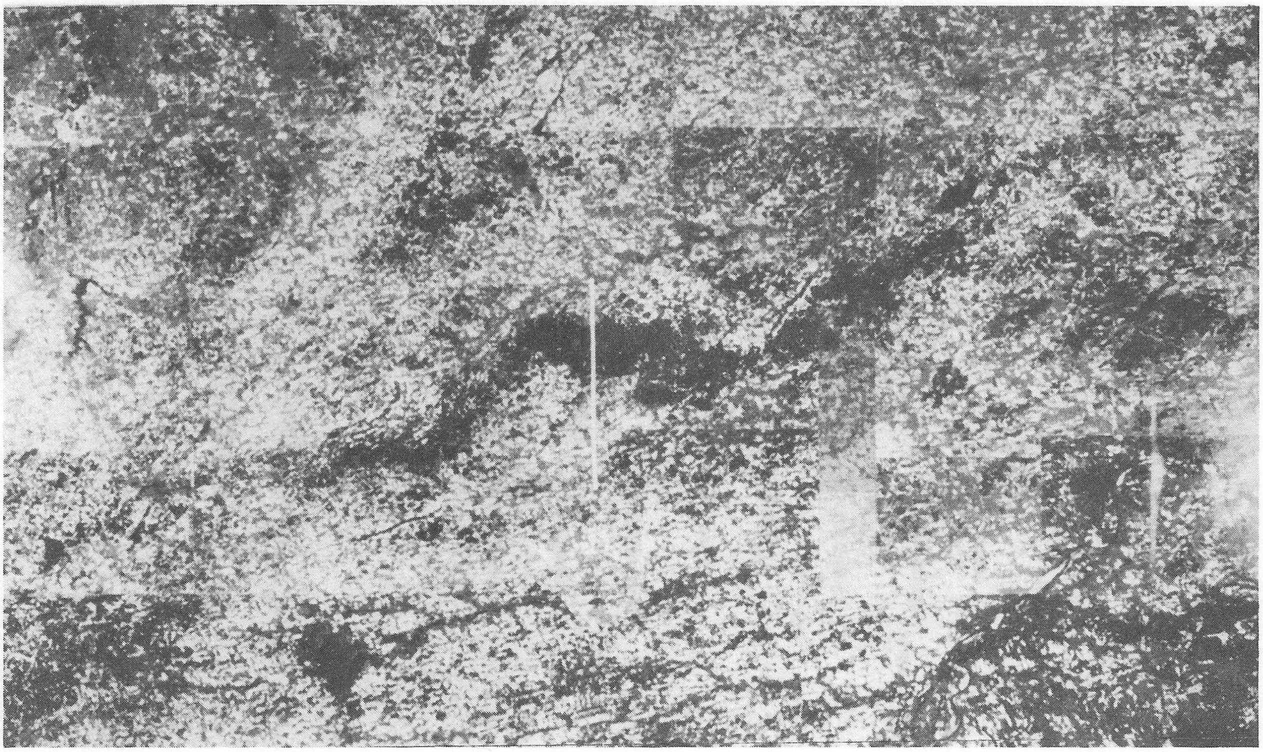

Figure 4 Classified LANDSAT-1 Data Trace Darker Colored Aquoll and Udoll Soils on the Surface of a Buried Preglacial Valley Among Udalf Soils for 65 km in West Central Indiana. A-Frankfort B-Kokomo.