Hoffer

REMOTE SENSING FOR PLANNING RESOURCE CONSERVATION

By C.J. Johannsen and M.F. Baumgardner[1/][2/]

Introduction

Planning resource conservation must be closely related to the number of people in the world and their needs. If the population increase exceeds the number predicted, the necessity for resource inventories becomes even more critical.

Witness that the U.S. Bureau of the Census in 1947 predicted that the Nation would have a population of 145 million in 1950, of 153 million in 1960, and possibly 163 million in 1990. In reality, the U.S. census takers counted 179 million citizens as early as 1960. Today we number more than 200 million. It is now estimated that our country's tenancy in 1990 will be 288 million or 123 million more people than the 1947 projection for this date. The world population figures are even more staggering when we realize that more than a million human inhabitants are added each week.

The well-known British historian, Arnold J. Toynbee, in an address to the World Food Congress which met in Washington, D.C., in June 1963, said: "We must aim at establishing the planet's population at a figure that will allow a substantial part of our time and energy to be spent, not on keeping ourselves alive, but on making human life a more civilized affair than we have succeeded in making it so far."

[1/] Principal Researchers, Laboratory for Agricultural Remote Sensing (LARS) and also Instructor and Associate Professor, respectively, Department of Agronomy, Purdue University, Lafayette, Indiana.

[2/] Agricultural Experiment Station Journal No. 3439. This research was supported jointly by the U.S. Department of Agriculture and the National Aeronautics and Space Administration.

Along with the dramatic population increase there is also a rapid increase in the consumption of goods and services. In Table 1 a comparison can be made between the population increase and the increase in consumption of resources for the United States. Data is given for the years 1947, 1964, and 2000.

Table 1. Resource Conservation Needs Expand With Population.[1/]

United States Resources	1947	1964	2000
Population (x 10^6)	n.a.	195	362
Gross National Product (x 10^9 dollars)	282	516	1,956
Use of Minerals, worth of metals and non-metals in 1954 dollars (x 10^9)	3.2	6.0	17.4
Use of Energy (x 10^{15} btu's)	33.2	51.7	161.0
Water Use (x 10^9 gallons/day)	n.a.	325	900
Use of National Parks (x 10^6 visits/year)	28.5	112.0	250
Fishing Licenses (x 10^6 licenses/year)	12.6	20.2	48.4

1/ Adapted from Conservation Yearbook No. 2. 1966, U.S. Department of Interior, Washington, D.C.

The Data in Table 1 portrays vividly the urgency for more effective resource conservation planning if the provisions for agriculture, industry, recreation, and other vital needs are to be met. Our performance in resource conservation during the past 150 years can hardly be characterized by its brilliant accomplishments. We are surrounded by evidences of man's misuse and mismanagement of these resources.

The Water Resources Council reports that each year one and one-third billion cubic yards of sediment are deposited in the Nation's reservoirs. In addition, according to the Army Corps of Engineers, 450 million cubic yards of silt are dredged from the Nation's rivers and harbors each year, and it costs up to one dollar per yard for the dredging operation. Most of this silt comes from erosion of agricultural lands, but an increasing amount of it is caused by urban developments where needed conservation measures are not installed.

Urban sprawl has become a major concern of community and regional planners. Every year approximately two million acres of land are being diverted from agriculture to housing, industry, highways, public buildings, parks, and other uses prompted by population pressures. The result of man's misuse of land and water, his fouling of his environment, and his disregard for the needs of future generations cries out for action.

There is critical need for new ideas and techniques which provide more accurate and timely information for planning conservation measures and managing our natural resources. One of the newest techniques with an automatic data recording, storage and retrieval capability is remote sensing. Research results from the Laboratory for Agricultural Remote Sensing at Purdue University indicate that these techniques hold great promise as tools in resource conservation and management (1, 3, 4, 5, 6, 7, 8, 9, 10).

Remote Sensing Concepts

Conservationists are familiar with aerial photography as a tool in photogrammetric mapping, its utilitarian value as a base for planning, land measurement and soil mapping, its use in providing information about soils and vegetation which are important to resource surveys. Sucessful application of aerial photography has given encouragement to the development of a broader concept of aerial reconnaissance termed "multispectral remote sensing" in which other usable portions of the electromagnetic spectrum are also exploited to provide fundamental information about the materials or objects that have been sensed.

In conventional photography the energy being sensed is the sum of all radiation reflected from the field of view and for the wavelength band to which the photographic emulsion is sensitive. The radiation source is the sun. Photographic systems can measure or record energy from wavelengths of about 0.3 to 0.9 microns as shown in Figure 1. Reflective measurements, a phenomenon of energy up to 3 microns in wavelength, are important in research because of the range of response exhibited by different materials in this portion of the spectrum. Suits (12) points out that "solar reflectant power is decreased with increasing wavelengths until the radiation emitted by the object is dominant. The crossover point where the emitted radiation becomes dominant over the reflected radiation is at approximately 3μ."

It is seen in Figure 1 that there are three major types of radiation from 0.3 to 3 microns. They are ultraviolet (0.3 to 0.38μ), visible (0.38 to 0.72μ), and reflected infrared (0.72 to 3.0μ). Energy recorded in the 3 to 15μ portion of the spectrum is due primarily to emission from an object, which is a function of the true temperature and the emissivity of the object. The remaining portions of the spectrum are not considered of importance to the remote sensing applications which will be discussed here because of atmospheric absorption by CO_2, O_2, and H_2O, thereby preventing significant amounts of energy from being transmitted through the atmosphere between the earth's surface and the aircraft.

Since direct photographic techniques cannot be used effectively to record wavelengths of energy greater than 0.9μ, instruments such as optical mechanical scanners may be used to measure energy responses. The optical mechanical scanner systems may have a range from approximately 0.3 to 15μ, as indicated in Figure 1. With a scanner the energy responses of the selected wavelength bands are obtained in a series of contiguous scan lines recorded on magnetic tape. The scan lines may be placed line by line on a cathode ray tube to reproduce an image which may be viewed directly or photographed. For research purposes the scanner data may be converted from analog to digital form to allow the researcher to examine the data (6, 8, 10). Laboratory and field instruments to measure reflected and radiated energy from soils and vegetation are employed to supplement and interpret data obtained by the scanner.

Spectral Measurements of Soil and Vegetation

An understanding of reflective phenomena of plants at different stages of maturity and of plants under stress would greatly aid in the interpretation of scanner data. During the early stages of the growing season when vegetation is still sparse, it is essential to consider the reflective responses of soils caused by variations in texture, tilth conditions, and moisture content. To gain more information about these reflective phenomena, more than 2300 samples of plant leaves and soils were used in obtaining spectral data on a Beckman DK-2A spectroreflectometer during the summer of 1966. A datex encoder and punch card unit were used to record automatically the reflectance on computer punch cards at 10mμ intervals from 0.5 to 2.6μ with an accuracy to the nearest 0.1% reflectance. Calibration curves at 0 and 100% reflectance were also obtained and all data were then normalized to these calibration curves. This procedure allowed corrections to be made for possible changes in MgO standards, and for variations in instrument settings.

The soil samples represented many different textures, drainage classes, and moisture contents. Spectral reflectance measurements were also obtained from samples of clays. The particle size appears to have an effect on reflectance as shown in Figure 2a where the mean value curves of silt, clay, sand, and muck are presented. The Princeton silt which contains in excess of 90% silt has almost no organic matter and, therefore, had the highest reflectance at all wavelengths. The Pembroke clay (60% clay) has the most unique curve with a high response in the visible reflective region due to the reddish soil color and the distinct water absorption bands at 1.4 and 1.9μ. This curve closely resembles the curve for a sample of relatively pure kaolinite, an interesting observation in that the dominant clay mineral in the Pembroke clay soils is kaolinite (11).

Spectral measurements were obtained on the silt, clay and sand soils at moisture contents ranging between 1 and 6%, and for much at a mean moisture content of 18.9%. Muck would be expected to give greater reflectance if the moisture content is decreased. Figure 2b shows that with sand of different moisture levels there is a definite increase in reflectance with a decrease in moisture content. The water absorption bands at approximately 1.4 and 1.9μ become more pronounced with an increase in water content of the sand. One might speculate that the soil moisture content could be determined by measuring the reflectance response in these two bands and comparing this with adjacent wavelength bands. The wider response or values between these comparisons then indicate a higher moisture content. Hoffer and Johannsen (5) reported that spectral curves for samples of clay at high and low moisture contents had the same characteristic shape. Samples of higher moisture content gave a lower response in all wavelengths from 0.5 to 2.6μ as was shown in the curves for sand in Figure 2b. However, the response differences in the water absorption bands was the same for both high and low moisture contents in their data. This observation would not lend support to the speculation that soil moisture can be determined spectrally.

Spectral measurements of bentonite, muscovite, sepiolite, and kaolinite at 0.1% moisture contents were obtained. All spectral curves displayed strong water bands, suggesting that adsorbed and crystalline water in clay minerals may be a significant factor in the interpretation of the water absorption bands.

The laboratory spectrophotometer can be used to obtain spectral measurements on small portions of plant parts and very small amounts of soils. Remote sensing of environment requires that spectral measurements be made outside the laboratory. With field spectrometers and airborne scanners studies are conducted to examine the spectral characteristics of whole plants, a community of plants, or a mixture of cover types.

An airborne spectral scanner over a wheat field obtains an integrated response of the leaves, the plant stems, undergrowth, and the soil (9). Therefore, measurements of only wheat leaves in a spectrophotometer may be misleading in determining wavelengths that can be used for classification in separating wheat from other crops or soils (8, 10). When vegetation is dense and very little soil is visible, the measurements of leaf reflectance should be quite useful. Spectral response curves of wheat leaves and a silt loam soil are presented in Figure 3a. The wheat and soil have a similar response at about 0.5 to 0.54μ, but the reflectance of the wheat leaves decreases at approximately 0.64μ because of chlorophyll absorption and then increases rapidly. The response of the soil increases at a steady rate up through 1.0μ. The wheat, however, has a stronger response than does the soil beginning in the near infrared at about 0.70μ. This explains the strong response on color infrared film of green vegetation and the usually lower response for soils.

Figure 3b shows the mean response of green vegetation (mostly wheat and pasture), deciduous trees, soil and water of data obtained with an airborne scanner. A direct comparison between the scanner data and spectroreflectometer data cannot be made because of the lack of calibration. The scanner data does show a similar trend for green vegetation and soil as was recorded on the spectroreflectometer.

Analysis of Multispectral Data

Resource conservation planning requires information about large geographic areas. Certain kinds of information are needed at frequent intervals. The activities of man and the effects of weather can cause vegetation resources to change very quickly.

The use of remote sensing and automatic data processing techniques offers an opportunity to provide information about large geographic areas in a timely manner. Using and applying pattern recognition techniques to the multispectral data obtained from an airborne scanner, one can readily identify and map automatically different types of ground cover (5, 7, 9).

To apply pattern recognition techniques to such multispectral response data, the radiance (reflectance and emittance) of small areas on the ground is measured by the optical mechanical scanner simultaneously in several wavelength bands. By ordering the measured response values for each of the wavelength bands used, one then obtains a measurement vector for each cover type, species, or other material of interest. On the basis of these vectors, the pattern recognition categorizer is programmed to determine differences between the various materials. At this point, the categorizer is trained with the use of known target materials. The measurement vectors of unknown target materials, or test samples, can then be examined and classified(5).

These techniques were used on a portion of a flight line in south central Indiana to classify soil, water, and green vegetation. Figure 4 presents an aerial photograph of the flight area taken one week prior to the date of scanner data acquisition. To the right of the photograph are computer printouts of the same area. Separate classification of the soil and water areas are presented simply by not assigning symbols to the other categories.

Scanner data was obtained at 3200 feet above the terrain. Ground truth teams covered the area to verify field information used as training and test samples. Test sample areas were correctly recognized in the computer analysis with an accuracy of better than 92%.

An enlarged portion of the flight line is presented in Figure 5. An attempt was made to separate deciduous trees from other green vegetation such as wheat, alfalfa, clover and pasture. The accuracy appears to be quite good when comparing the T's on the printout with actual locations of trees on the accompanying photograph. An incorrect classification was made on some wheat fields, which were classified as a mixture of trees and green vegetation. Further investigations involving field and laboratory instruments as well as classification techniques should provide the reasons for these errors and improve future classification attempts.

Applications for Resource Conservation

A tremendous task lies ahead for the conservationist. The needs of future generations demand that man today find more effective and efficient methods for conserving and managing natural resources. Such a task requires information systems with certain characteristics. First, the system must have a capacity for obtaining, analyzing, storing, and retrieving large quantities of resources data. Second, the system must have the capability of making resources information available to the user in near real time. Third, the system must be economically feasible and sound. Remote sensing with an automatic data processing capability may possibly meet these requirements. The use of such techniques should provide conservationists and regional planners with current resource information from a large area, at a reasonable cost.

Since techniques are reported in this paper which show a high degree of accuracy in the automatic mapping of water, soil, and green vegetation, the potential applications of obtaining this type of data will be discussed.

1. Water. The capability to map bodies of water automatically adds a new dimension to the study of drainage patterns, stream flow, flooding conditions, inundation, and water subsidence. An operative system which could provide a map showing locations of water in near real time would be most beneficial in monitoring rising waters and flood conditions. After areas have been inundated, water maps provided time sequentially over a period of hours or days can give an indication of the rate of runoff and/or percolation. Such information would be very useful in pinpointing drainage problems and assisting in watershed management.

During periods of drought the automatic mapping of water would be useful in estimating the water reserve in farm ponds, lakes, and reservoirs. In agricultural areas immediately after heavy rains the mapping of areas under water could provide an estimate of the amount of crop damage and loss. Such information over a large geographical area could be used in adjusting crop yield predictions.

2. Soil. Early research results in measuring physical properties of soil suggest the possibility of obtaining measurements of several soil parameters by remote sensing techniques. The capability to determine soil moisture, color, texture, and mineralogy by remote means would certainly add new dimensions to soil studies and land use planning.

The present capability to identify, map, and measure soil areas automatically has many applications. Data collection at different seasons of the year could be used to determine the quantity of land under cultivation. This information could be used in the Midwestern U.S. to calculate the area of fall-plowed land, the area to be planted to small grain in the fall, and the area to be devoted to row crops such as corn or soybeans. This kind of information is invaluable to industries such as fertilizer companies who need to make long range plans for distribution, shipment, stockpiling, and storage of their products.

Eroded areas and barren areas where crops have been covered or removed by wind or water erosion could possibly be identified, measured, and mapped. Through monitoring systems, areas of serious wind erosion could be detected at an early stage.

Detection and mapping of soils approaching bareness in droughty and overgrazed situations would be of utility in range management. Periodic preparation of bare soil maps in the vicinities of metropolitan centers would give an accurate and clear record of the extent of changing land use patterns.

3. Vegetation. The capability to identify, map, and measure automatically on a large scale the areas covered by plant species is not yet possible, but research results with a few crop species show great promise for a future capability to differentiate species by these techniques (5, 7, 9). Presently it is a relatively simple

task to identify and map green vegetation. As has been reported in this paper, the capability to separate deciduous trees from other green vegetation in south central Indiana in late April proved quite sucessful.

Even the capability simply to separate green vegetation from all other cover types could be very useful. Periodic mapping of green vegetation in a temperate region could be used to measure the extent of winter crops, summer crops, perennial crops, deciduous forests, and coniferous forests.

Techniques for mapping green vegetation could be adapted for use in estimating area covered and severity of crop losses caused by wind, water, and hail. Such capabilities would be very helpful in mapping range, farm, and forestlands swept over by fire. Remote sensing techniques are currently being used for forest fire detection in the Northwest (2).

In summary, the possibilities for the future general use of remote sensing and automatic data processing techniques in obtaining and analyzing very rapidly regional and national resources data appear bright. These techniques may provide the most rapid and economic means for characterizing surface features of land and areas covered by vegetation and water.

Acknowledgement

The Beckman DK-2A spectroreflectometer used in this study is owned by the Office of Naval Research and was loaned to Purdue University by Mr. Charles Olson, School of Natural Resources, University of Michigan, to whom deep appreciation is expressed.

References Cited

1. Baumgardner, M.F., R.M. Hoffer, C.J. Johannsen, and C.H. Kozin. 1967. Contributions of Automatic Crop Surveys to Agricultural Development. Paper presented at AIAA 4th Annual Meeting, Anaheim, California, October, 1967.

2. Hirsch, S.N. 1968. Study of the Feasibility of Detecting Small Fires by Airborne Thermal Infrared Line Scanner. Quarterly Progress Report, NASA Contract No. R-09-038-002.

3. Hoffer, R.M. 1967. Interpretation of Remote Multispectral Imagery of Agricultural Crops. Ag. Expt. Sta. Res. Bul. 831. LARS Vol. 1, Purdue University.

4. Hoffer, R.M., C.J. Johannsen, and M.F. Baumgardner. 1966. Agricultural Applications of Remote Multispectral Sensing. Proc. Indiana Acad. Sci. 76:386-395.

5. Hoffer, R.M. and C.J. Johannsen. 1968. Ecological Potentials in Spectral Signature Analysis. Paper presented to Ecological Soc. Amer. Annual Meeting, Madison, Wisc. June, 1968.

6. Laboratory for Agricultural Remote Sensing, Purdue University. 1967. Remote Multispectral Sensing in Agriculture. LARS Annual Report, Vol. 2, Ag. Expt. Sta. Res. Bul. 832.

7. ------- 1968. Automatic Classification of Green Vegetation, Soil, and Water. Ag. Expt. Sta. Res. Progress Report 310.

8. ------- In press. Remote Multispectral Sensing in Agriculture. LARS Annual Report, Vol. 3.

9. Landgrebe, D.A. 1967. Automatic Identification and Classification of Wheat by Remote Sensing. Ag. Expt. Sta. Res. Progress Report 279, Purdue University.

10. Landgrebe, D.A. and T.L. Phillips. 1967. A Multichannel Image Data Handling System for Agricultural Remote Sensing. Paper presented at Computerized Imaging Techniques Seminar. Washington, D.C., June, 1967.

11. Post, D.F. 1967. Characterization and Genesis of the Clay Minerals in Limestone and Limestone Derived Soil. Ph.D. Thesis, Purdue University Library.

12. Suits, G.H. 1960. The Nature of Infrared Radiation and Ways to Photograph It. Photogrammetric Engineering XXVI (5):763-772.

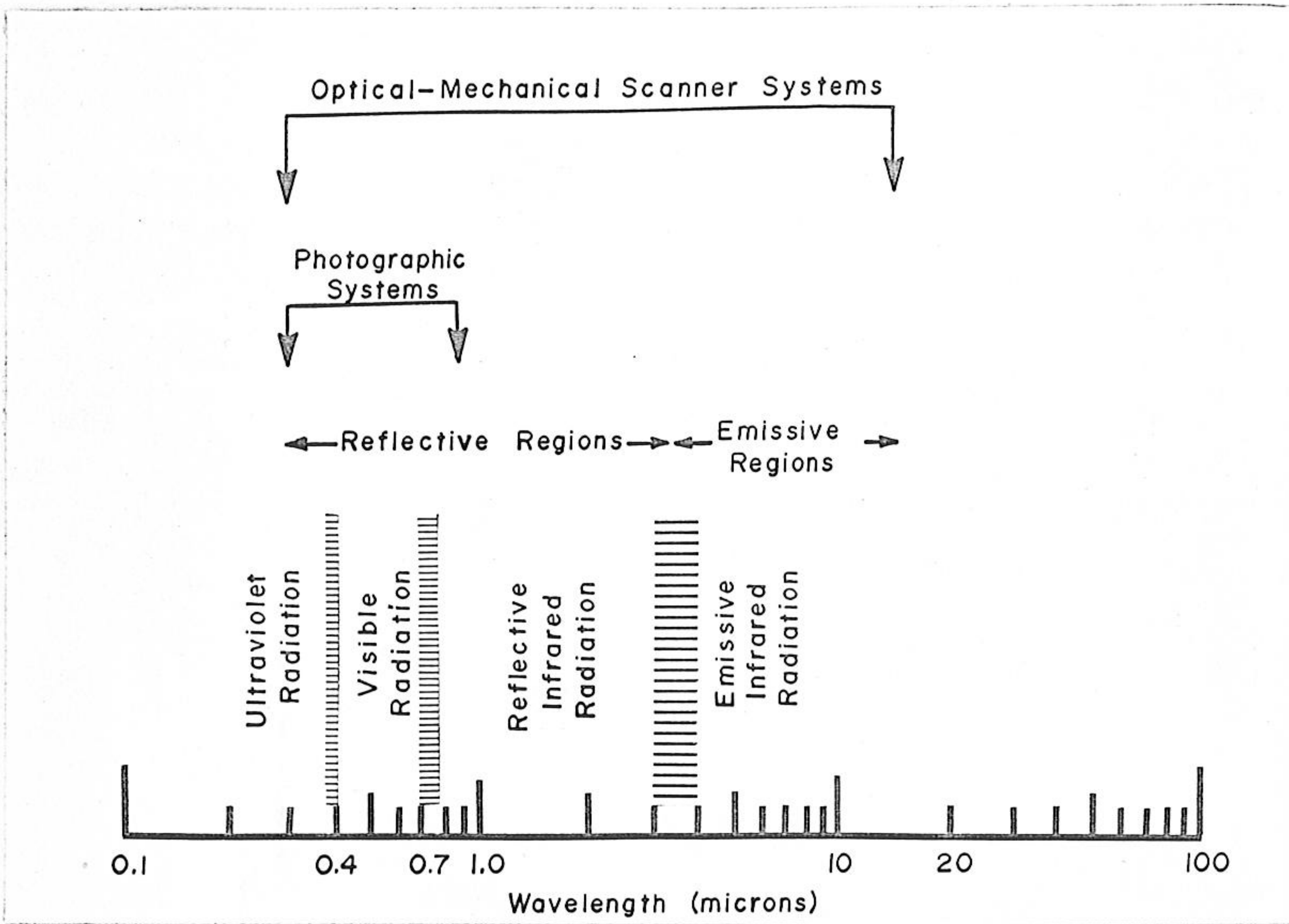
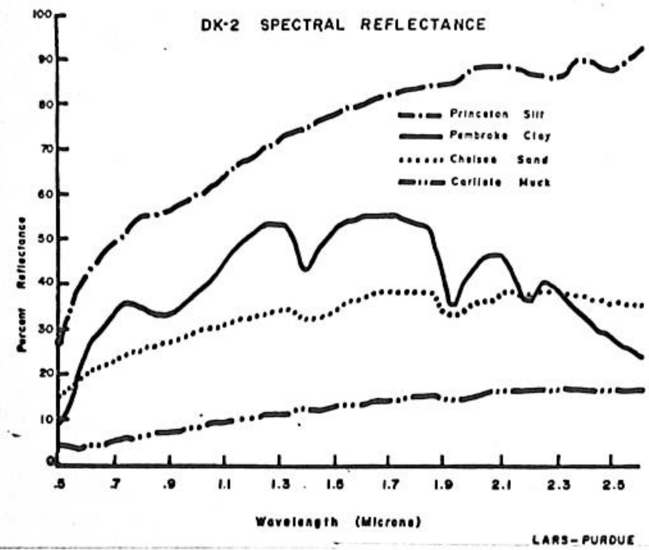


Figure 1. A portion of the electromagnetic spectrum.



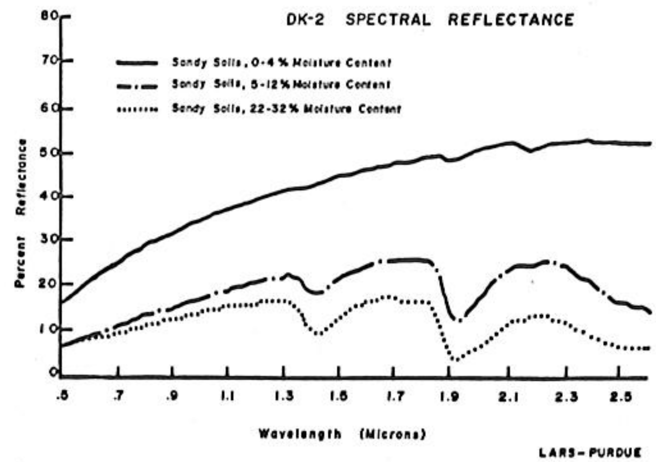
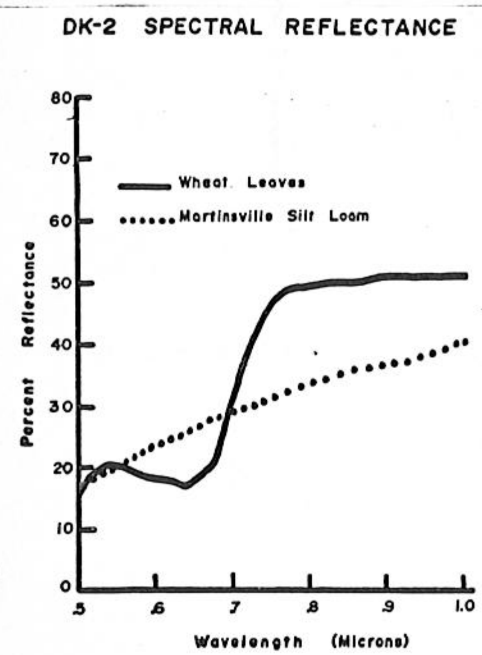


Figure 2a. Reflectance measurements from four soil types.

2b. Reflectance measurements from a soil at three moisture levels.



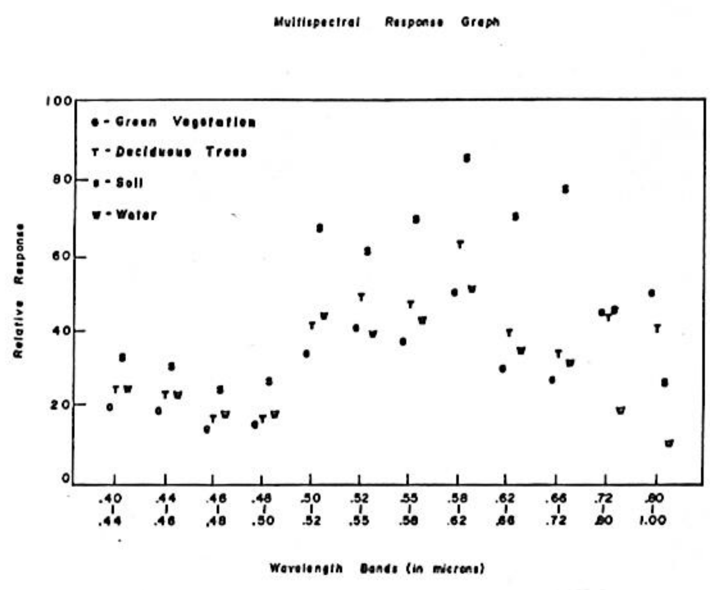


Figure 3a. Comparison of reflectance measurements of wheat and soil.

3b. Multispectral response graph.

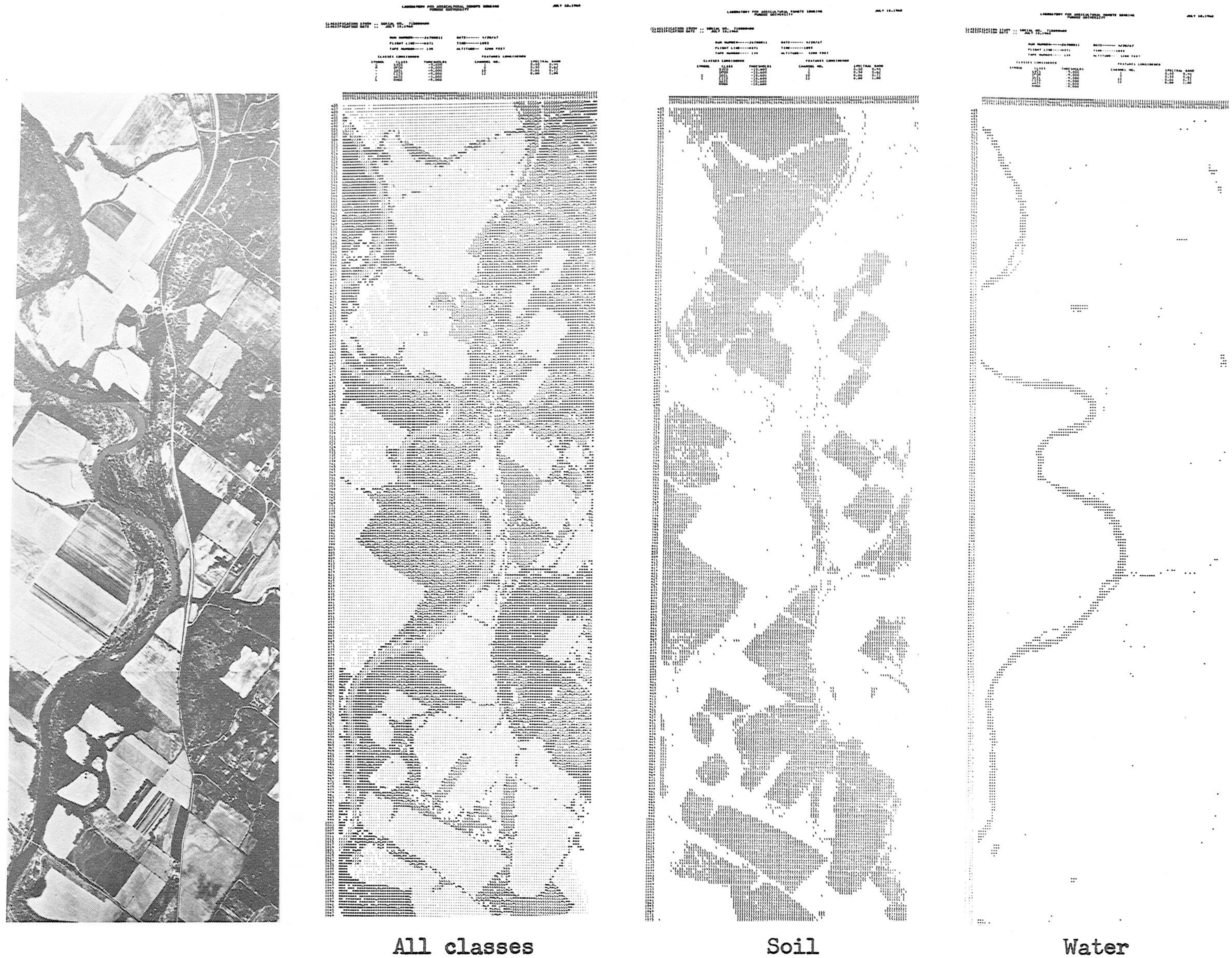


Figure 4. Aerial photograph and computer printouts showing automatic identification of trees, green vegetation, soil, and water.

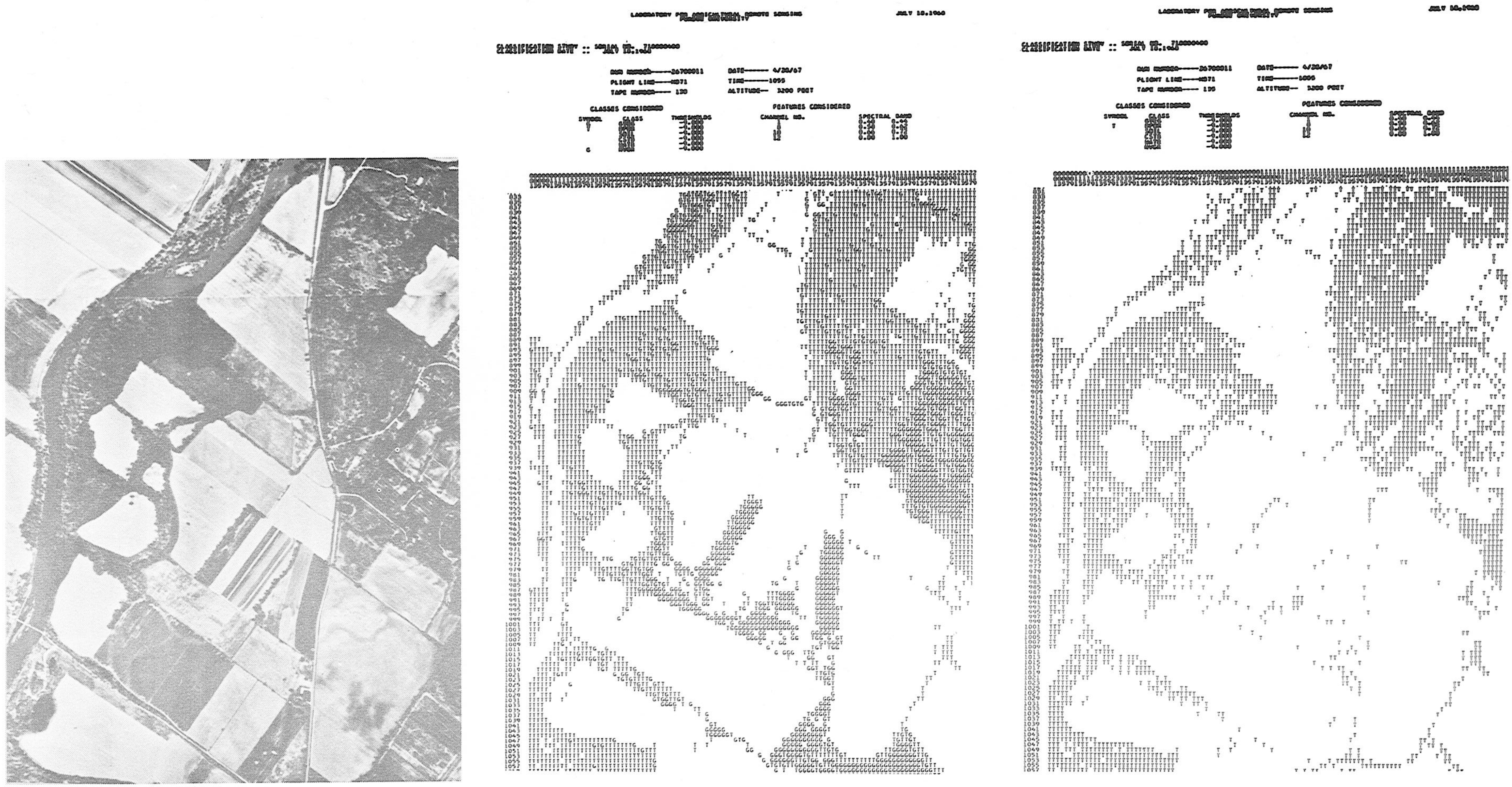


Figure 5. Aerial photograph and computer printouts showing the identification and separation of deciduous trees and green vegetation.