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THE ROLE OF REMOTE SENSING TECHNOLOGY IN FUTURE AGRICULTURAL INFORMATION SYSTEMS[1]

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I am grateful for this opportunity to share with you some of my thoughts and concerns on the efficient delivery of accurate, useful, timely, and cost-effective information to the agricultural decision-maker and policy-maker. As representatives of the Agricultural Research Institute in this assembly, we are concerned principally with defining and developing support, both public and private, for those areas of research which will improve the quantity and quality of agricultural products.

It is from the perspective of a university teacher and a research scientist that I share these thoughts with you.

My remarks will address briefly five areas of concern:

- the global food/population equation
- the value of information
- new information technologies
- new possibilities for inventorying and monitoring agricultural resources
- research priorities for the 1980's.

The Food/Population Equation

During the past decade increasing attention, with frequent expressions of alarm, have been given to the global food/population dilemma. However, even prior to the 1970's over a period of two centuries thoughtful and concerned persons wrestled with problems related to the carrying capacity of the world. Since 1798, when Thomas Malthus published "An Essay on the Principle of Population," there have been repeated warnings that the human population, subject to exponential increase, could -- or at some time surely would -- overtake food supplies, which Malthus assumed could increase only arithmetically.

Across the centuries there have been localized famines and some food shortages of wide extent. The 20th century has witnessed major shortages during the years following World War I, in the late 1940's and early 1950's after two years of drought on the Indian subcontinent and in the early 1970's when world grain production dropped 35 million tons. Yet it has been only since 1960 that large numbers of people and national and world leaders began to appreciate the serious and chronic nature of the world food problem.

Even the most optimistic projections give cause for concern in providing food for the global population during the years ahead. There is urgent need for more accurate, effective, and repetitive food and population information which can carefully monitor significant changes in population statistics and food supply.

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Recently Dudal (1978) summarized the results of numerous studies related to the world's capacity to feed a rapidly expanding population. These studies reveal great differences among the estimates of arable land within a finite total land area. The food production from the world's arable lands is highly variable and is greatly affected by the technology which is used and by the social, cultural and economic conditions which prevail. Moreover, land which is considered arable for cassava or sugarcane may not be suitable for wheat or soybeans. The lands of the world which have been classified as arable represent an exceptionally broad range in potential productivity of food.

Dudal (1978) compared the global increases over the past decades of arable land, population and fertilizer consumption (Table 1).

Table 1. 1957-1977 global increases in arable land, population and fertilizer consumption.

	Global Estimates		
	1957	1977	% increase
Arable Land	1.365 x 10^9 ha	1.5 x 10^9 ha	+ 9
Population	2.8 x 10^9	4.0 x 10^9	+ 40
Fertilizer Consumed*	24 x 10^6 MT	88.0 x 10^6 MT	+267

*Metric tons of N, P_2O_5, K_2O equivalent consumed annually

The area of arable land increased by 135 million hectares during the 1957-1977 period, an increase of approximately 9%. During the same period the world's population increased from 2.8 to 4 billion, an increase of 40%. In terms of increased production, the additional arable land at a low level of agricultural inputs would provide food for only an additional 400 million people. The food supplies for the 800 million additional people have been obtained from an intensification of agriculture on land already under cultivation. This intensification is reflected, in part, by a dramatic increase of annual fertilizer use, from 24 million tons of plant nutrients (N, P_2O_5, K_2O) in 1957 to 88 million tons in 1977, and a considerable expansion of irrigation. It is significant that 110 million hectares or 70% of the added arable land was added in developing countries while intensification of production occurred in industrialized nations which consumed 85% of the world's fertilizer produced in 1977.

The Value of Information

Information is a valuable commodity! For decades tens of thousands of scientist, concentrated principally in industrialized countries with temperate climates, have been engaged in providing decision-makers and policy-makers improved technical information about soils, conservation practices, crop varieties, tillage methods, plant nutrition, climate and water management. These scientists have been steadily adding to our understanding of soils, climate, crops and agricultural production.

It has been estimated that man's store of knowledge is doubling at least three times per century. However, the increase in knowledge about agricultural production is not equitably distributed over the arable and potentially arable lands of the world. Knowledge generation tends to be concentrated in those areas where both intensive and long range research is being conducted.

One way of characterizing the level of development of the agricultural resources of a nation is the degree to which accurate, useful and timely information is made available to agricultural producers, industrial decision-makers and government agencies. Nations with highly productive agriculture generally have an effective system for the acquisition, analysis and delivery of useful resource information. Those countries whose agricultural resources are poorly developed generally have little or no provision to deliver to the agricultural sector important information about their land, crop, rangeland and water resources.

Any discussion of the value of information would be incomplete if timeliness of information delivery is ignored. In agricultural production many kinds of information diminish in value with the passage of time. For example, a remote sensing monitoring system might be able to detect a disease or insect infestation and by repetitive observations provide data from which severity of infestation and rate of spread might be quantitatively assessed. If such information can be delivered to the farm managers concerned in near real time, decisions on treatments might be made which could save the crop. On the other hand, if the information delivery system delays the dissemination of information, it may be too late to apply treatment by the time the farm managers receive the information.

New Information Technologies

The past two decades which produced dramatic changes in the global food/population equation have brought equally dramatic changes in our capabilities to survey and monitor the Earth surface environment.

In 1948 the British astrophysicist Fred Hoyle wrote:

> "Once a photograph of the Earth, taken from the outside is available -- once the sheer isolation of the Earth becomes plain -- a new idea as powerful as any in history will be let loose."

Soon after being named by President Carter as administrator of the National Aeronautics and Space Administration (NASA), Dr. Robert Frosch (1977) made this observation:

> "We are the first generation to see the Earth as a whole. For centuries man has observed and tried to represent by drawings tiny areas of the Earth surface. He would piece these drawings together in an attempt to show what the Earth would look like if he could see it as a whole. A few decades ago he made a great leap forward by inventing the camera, then later placing the camera on aircraft. By these developments man extended his powers of observing the surface of the Earth. He could see much larger areas and less piecing together was necessary. But this is the first generation that has seen data that went the other way. Data which provide a broad synoptic view of the Earth can also be used to extract great details. So in a sense, we have

turned the whole enterprise around. Instead of starting with the details and trying to construct the big picture, we now have the capability to go the other way -- to look at the big picture and then figure out how to extract the details that explain it."

All participants in this ARI annual meeting were on hand at the birth of the "new idea as powerful as any in history" described by Hoyle. We are a part of that first generation suggested by Frosch to see the Earth as a whole. Although it is difficult if not impossible to foresee the long range implications of these new concepts, there is little doubt that significant changes lie ahead in acquiring, analyzing and delivering improved information related to land resources and food production. Three areas of recent technological development which promise to accelerate the flow of useful information will be described.

1. Data acquisition. Major advances have been made since 1960 in instruments, remote sensing devices, equipment and sampling strategies for observing, characterizing and monitoring a target or scene. New data acquisition methods in the laboratory, in the field and from air and space platforms provide new vistas of the universe, never available before, from the sub-atomic structure to thousands of square kilometers in a single view of the environment at the Earth surface.

For the purposes of this paper particular attention will be given to the Earth Resources Observation System (EROS) program. The launch of Landsat-1 by NASA in July 1972 ushered in a new era in Earth observations. Landsat-2 and -3 followed in January 1975 and March 1978, respectively. Landsat-D, which will become Landsat-4 after a successful launch, is scheduled to be placed in polar orbit during the fourth quarter of 1981. Landsats -1, -2 and -3 are in near polar, sun-synchronous orbit at an altitude of approximately 920 kilometers. The orbital and sensor designs are such that each satellite has the capability of observing the entire surface of the Earth every 18 days. After five years of successful data acquisition, Landsat-1 was retired from service in January 1978. Deterioration in performance of Landsat-2 sensors in late 1979 led to a shutdown of its data acquisition system after almost four years of service.

The satellites are equipped with return beam vidicon (RBV) cameras and multispectral scanners (MSS). Basic specifications for the sensors of Landsats -1, -2 and -3 are summarized in Table 2.

Table 2. Specifications of the return beam vidicon (RBV) and multispectral scanners (MSS) on Landsats -1, -2 and -3.

Landsat	Sensor	Spectral Bands(μm)	Description	Spatial Resolution(m)
1,2	RBV	0.475-0.575	visible blue, green	80
		0.580-0.680	visible orange, red	80
		0.690-0.830	near infrared	80
3		0.505-0.750		38
1,2,3	MSS	0.5-0.6	visible green	80
		0.6-0.7	visible red	80
		0.7-0.8	near infrared	80
		0.8-1.1	near infrared	80
3		10.4-12.6	thermal infrared	240

Landsat-D will have a nominal orbital altitude of 705 km and will maintain a 16-day cycle of repetitive coverage. The two on-board sensors (MSS and thematic mapper, TM) will provide ground coverage of about 185 x 170 km per scene. The MSS will obtain data in the same 4 reflective bands as those of previous Landsats and have the same instantaneous field of view (80 m). The TM, a line-scanning device also, will operate over 7 bands of the visible and infrared range of the electromagnetic spectrum and have an instantaneous field of view (IFOV) of 30 meters for all reflective bands (Table 3).

Table 3. Specifications of the Thematic Mapper of Landsat-D.

Spectral Bands(μm)	Description	Spatial Resolution (IFOV) (m)
0.45-0.52	visible blue	30
0.52-0.60	visible green	30
0.63-0.69	visible red	30
0.76-0.90	near infrared	30
1.55-1.75	middle infrared	30
2.08-2.35	middle infrared	30
10.40-12.50	thermal infrared	120

Data from Landsat sensors are transmitted to receiving stations in digital form. Receiving stations in operation as of October 1979 include the following:

U.S.A. (3 stations)
- Greenbelt, Maryland
- Goldstone, California
- Fairbanks, Alaska

Canada (2 stations)
- Prince Albert, Saskatchewan
- Shoe Cove, Newfoundland

Brazil - Cuiaba
Iran - Tehran
Italy - Fucino
Japan - Tokyo
Sweden - Kiruna

Receiving stations are under construction in Argentina, Australia and India. The common reception radius of ground receiving stations is 2780 km.

The products available from receiving stations include black and white single-band images, false color (multiband) images, and digital data on computer compatible tape (CCT). These images can be analyzed and interpreted by visual methods, or the digital data can be analyzed by computer-implemented pattern recognition techniques.

2. Data analysis. Traditionally the ability of the observer to acquire data has exceeded by far his pr her ability to analyze and interpret data. The computer revolution of the past 25 years has provided a giant leap forward in the human capability to cope with the masses of data which are accumulated. Ruth Davis (1977), writing on the evolution of computers and computing, states:

> "Computers are properly cited as the first as well as the most important invention ever that significantly extends man's intellectual capabilities. Until the age of computers, inventions had primarily extended our muscular powers as well as certain of our sensory powers."

Computers, or hardware, together with computer languages and analytical programs, or software, which have evolved during the past two decades, place at our disposal a "never before" capability to store, retrieve, overlay, analyze and interpret vast quantities of data. Computer technology is essential for handling the masses of data acquired by the sensors of Landsats-1,-2 and-3, each of which has the capability of transmitting more than one million quantitative reflectance measurements per second. In the analysis of Landsat data, computers may be used to produce high quality images for visual analysis by the human interpreter or to analyze the data by pattern recognition techniques for producing a computer-implemented classification of a specific area. Results of such analyses may be presented as a map and/or in tabular format indicating the area classified as wheat, corn, poorly drained soil, or other landscape features of interest.

In this presentation emphasis will be given to the application of pattern recognition techniques by digital analysis of multispectral data. The principle of computer-implemented pattern recognition techniques may be illustrated by examination of the spectral properties of different features in the landscape. Typical spectral curves have been plotted for green vegetation, bare soil and water (Figure 1). The horizontal axis represents wavelength in the visible (0.38 to 0.72 μm) and reflective infrared (0.72 to 2.50 μm) portions of the electromagnetic spectrum. The vertical axis represents the intensity of reflected energy as measured by a spectroradiometer. An examination of these curves reveals that there are certain wavelengths that are much better than others in separating green vegetation, soil and water.

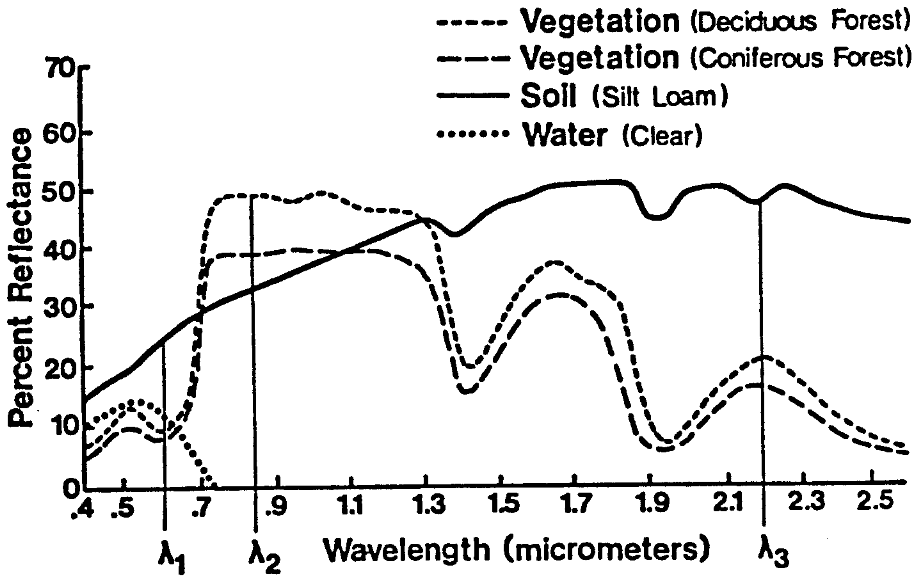

Figure 1. Reflectance curves for green vegetation, soil and water.

The same data used for plotting these spectral curves may be plotted in another fashion. For example, the reflectance values for each landscape feature (vegetation, soil, water) at three different wavelengths, represented by λ_1, λ_2 and λ_3, may be plotted in three dimensional space (Figure 2).

In the analysis of multispectral data by pattern recognition techniques, one of two general approaches is usually followed. One approach is termed "clustering" or "non-supervised" classification. With this approach an algorithm is used which directs the computer to examine the spectral data for the area of interest and to assign each picture element (pixel) to a cluster of pixels having similar spectral characteristics. The number of cluster classes to be spectrally separated is generally set arbitrarily by the analyst and may or may not be determined by the analyst's prior knowledge of the area being analyzed.

The other general approach is termed "supervised" classification. In this case the analyst provides the computer with a spectral definition of the classes to be spectrally identified and mapped. This spectral definition is provided in the form of a set of training samples of known identity from specific addresses within the multispectral data. The quality of the supervised classification results is dependent upon the spectral separability of the desired classes with existing spectral data and upon the quality of the training sets, i.e., the degree to which the training samples selected by the analyst are representative of the features to be classified by spectral analysis.

The identification and delineation of green vegetation, bare soil and

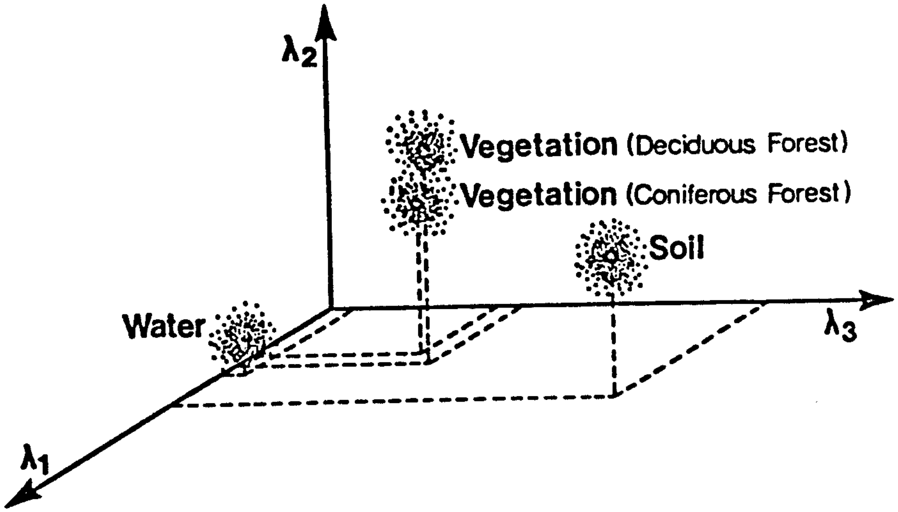

Figure 2. Locating green vegetation, soil and water in three dimensional space defined by specific wavelengths, λ_1, λ_2, and λ_3.

water by spectral analysis is quite simple and can be accomplished with a high level of accuracy with little or no knowledge of the ground scene by the analyst. However, the classification problem by spectral analysis becomes much more difficult when the objective is to classify the ground scene into many different subcategories of green vegetation, soil and water. Subcategories of interest might include many crop species, differences in plant vigor and biomass production, soils with varying contents of organic matter or different internal drainage characteristics, and water containing varying amounts of suspended matter. Complexity of classification at this level requires special interpretive skills by the analyst. Such skills can best be obtained through broad experience in spectral analysis and intimate knowledge of the area being classified.

Although human experience is limited to three-dimensional perception, the computer has no such constraints; it can operate in n-dimensional space. Thus, with appropriate algorithms the computer can examine the quantitative reflectance values for each of the four wavelength bands of the Landsat scanners and classify or assign each data point or picture element (pixel) to a specific spectral category. Many different algorithms have been developed for the computer-implemented analysis of multispectral data.

3. Information dissemination. The technology of communication is another of man's activities which has undergone revolutionary changes during the past two decades. It is now possible to transmit instantaneously voices, images and masses of quantitative data from any point to any other address on the surface of the Earth. This capability adds a new dimension to the delivery of useful, timely information to decision-makers and policy-makers.

New domestic and global communications systems have important implications for the future development and management of agricultural resources. This technology plays an essential role in several segments along the path of information flow from the moment of data acquisition by aerospace sensors to the delivery of useful information to the user.

Landsat-3 transmits through its communications channels a modest one million data points (quantitative reflectance measurements) per second to ground receiving stations. There will be a 10-fold increase in the amount of data transmitted from the sensors of Landsat-D. Communications technology will play an increasingly vital role in the development and management of agricultural resources.

New Possibilities for Inventorying and Monitoring Agricultural Resources

The integration of these new information technologies provide a new and fresh approach to inventory Earth resources and monitor changes in the landscape. Since the launch of Landsat-1 agricultural scientists in many nations have used satellite data to inventory and monitor Earth surface features related to agricultural production.

1. Crop inventory and monitoring. One of the most obvious agricultural applications is the identification and area measurement of cultivated crops (NASA, 1978). Equally important, but somewhat more complex is the use of this technology to improve crop yield predictions. An increasing research effort is being expended to use remotely sensed data to provide essential inputs into crop yield prediction equations.

For many years government agencies in some countries used aerial photography to identify crop species and measure the areas planted to crops. This is a rather expensive and time-consuming method to conduct inventories which may change from year to year.

The need to have more accurate and timely information about global grain supplies and food crop conditions has intensified during the past two decades. The Earth Observation Satellite program has opened new possibilities for inventorying the major food crops of the world and for monitoring crop conditions periodically through the growing season.

An example of the use of digital analysis of Landsat data to identify and measure the area of wheat is the work performed on data from Greeley County, Kansas. Spectral analysis was used to identify three features in the landscape of Greeley County. These features were fields of winter wheat, fields prepared for seeding summer crops and rangelands generally associated with the rough terrain along natural drainageways. In this county with a total land area of 202,803 hectares, the U.S. Department of Agriculture area estimate for winter wheat in 1973 was 73,000 hectares ± 5%. This estimate was derived from a standardized field sampling scheme which examines no more than two percent of the land area of the county. The 1973 wheat estimate for the county derived from data obtained by a Landsat-1 pass on 19 June 1973 was 77,000 hectares. In this instance with Landsat data every hectare of the county was examined and analyzed spectrally.

Early results such as these led to the planning and implementation

of the Large Area Crop Inventory Experiment (LACIE), a cooperative research program involving the U.S. Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA),and the National Oceanic and Atmospheric Administration (NOAA).

LACIE research was conducted during the period 1974 to 1978. Its primary objective was to improve the area, yield and production estimates of wheat in the winter and spring wheat area of the Central Great Plains of the United States. Results confirmed that remote sensing can make a significant contribution in identifying crops and making area estimates over large regions. Evidence was observed that remote sensing can be used effectively to monitor gross changes in crop conditions over large areas.

Although the LACIE program was terminated in 1978, new research programs are being continued and planned for the 1980's. These programs will expand crop inventory research to include other major food crops. Much emphasis will be given to the improvement of crop yield predictions.

2. Soil classification and survey. During the 1970's scientists in increasing numbers have been exploring methods of using satellite-derived images for delineating meaningful soil boundaries and characterizing soil conditions. One of the important uses of Landsat images is as a base from which preliminary soil legends can be described and general soil differences can be mapped. A single satellite image has a particular advantage over aerial photography because it provides a

synoptic view of a contiguous area covering 34,000 km^2. This synoptic view is valuable to the soil surveyor in correlating soils mapped in adjacent counties or political units by different surveyors at different times.

Visual interpretation of black and white and false color images produced from Landsat data were used by Westin and Frazee (1976) to produce general soil maps at scales of 1:250,000 or smaller with map units of 260 hectares or larger. Weismiller, et al. (1979) visually interpreted black and white and color composite images produced from Landsat data to determine soil parent material boundaries in Jasper County, Indiana at a scale of 1:125,000 (Figure 3). Confirming these boundaries by field observations, they then digitized these boundaries and overlaid them onto the four Landsat MSS bands which had been adjusted to a scale of 1:15,840. By computer-implemented pattern recognition techniques spectral maps delineating soils differences were then produced at this scale with map units as small as one hectare. These maps, delineating more than fifty different spectral classes in six different parent material areas are being used by soil surveyors as an additional valuable tool for a detailed soil survey of Jasper County, Indiana (Figure 4).

The digital format of Landsat MSS data permits rapid and easy merging and/or recombination of spectral classes to produce a wide array of smaller scale base maps for soil survey at different levels of generalization.

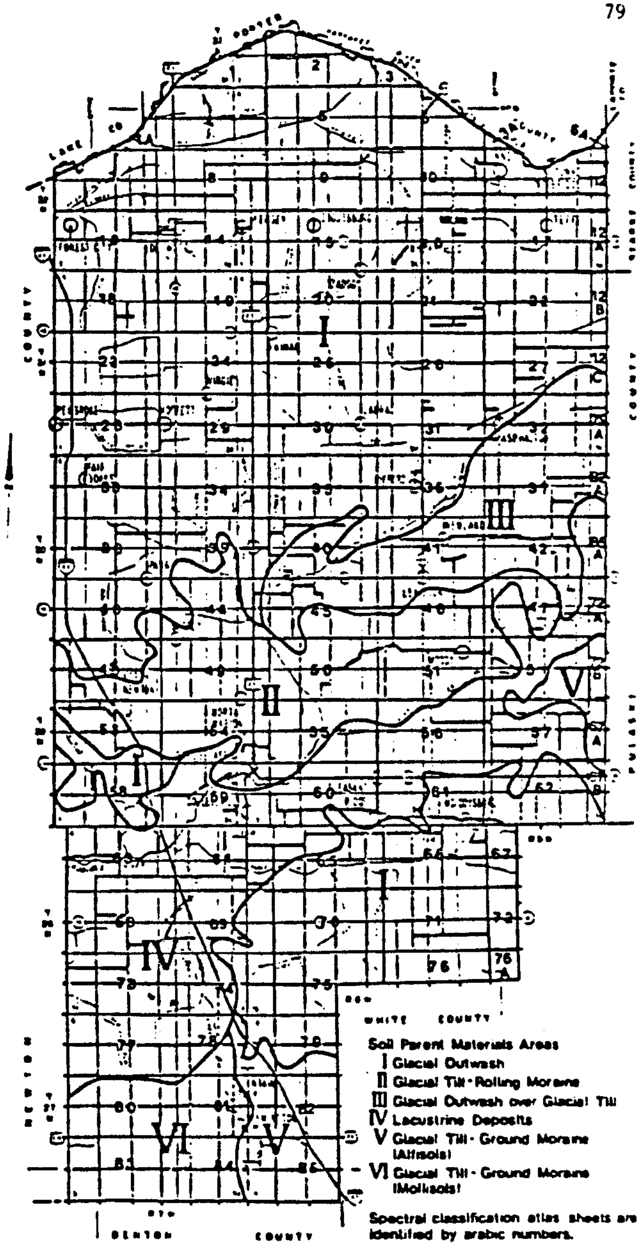

Figure 3. Parent material map of Jasper County, Indiana produced from visual interpretation of Landsat images. Original scale 1:125,000.

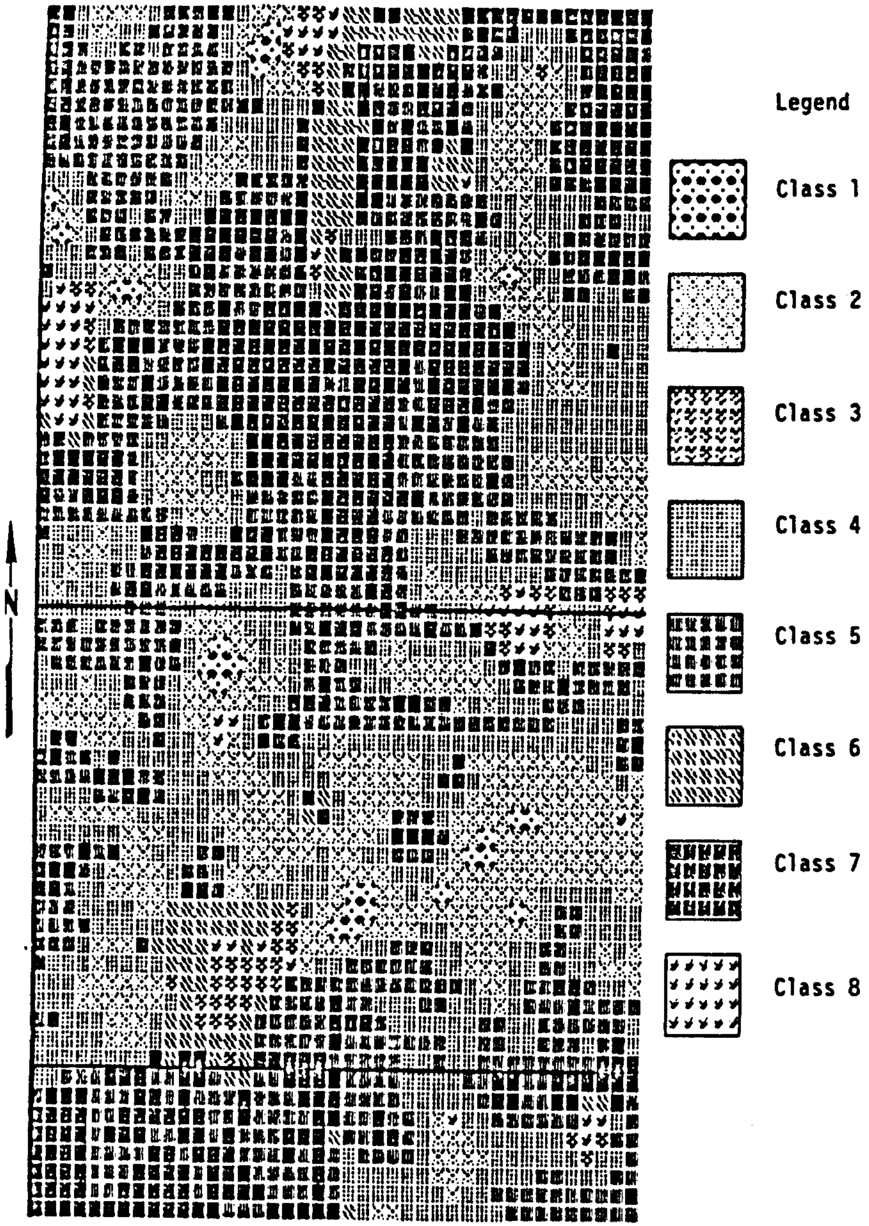

Figure 4. Spectral map derived from Landsat data delineating soil characteristics of a lacustrine area in Jasper County, Indiana. Scale 1:15,840. See Table 4 for class descriptions.

Table 4 Description of lacustrine soils within eight spectral classes derived from Landsat data obtained over Jasper County, Indiana (Figure 5)

Class	Description
1	Excessively to well drained soils with significant inclusions of moderately well drained soils.
2	Excessively to well drained soils with significant inclusions of moderately well drained soils. Minor inclusions of somewhat poorly drained and very poorly drained soils occur.
3	Excessively to well drained soils with a nearly equal amount of moderately well drained soils. Minor inclusions of somewhat poorly drained and very poorly drained soils occur.
4	Very poorly drained soils with significant inclusions of excessively to well drained, moderately drained, and somewhat poorly drained soils.
5	Very poorly drained soils with significant inclusions of somewhat poorly drained soils. Minor inclusions of excessively to well drained and moderately well drained soils occur.
6	Very poorly drained soils with significant inclusions of excessively to well drained and moderately well drained soils.
7	Very poorly drained soils. Minor inclusions of excessively to well drained, moderately well drained and somewhat poorly drained soils occur.
8 (Vegetation)	Predominately moderately well drained soils with significant inclusions of excessively to well drained and very poorly drained soils.

3. Land degradation mapping. There is increasing evidence that Landsat data can be useful for mapping and monitoring land degradation caused by wind erosion, water erosion, salinization, and flooding. Severe erosion caused by rainfall in the humid temperate region of central and northern Indiana has been detected and mapped by digital analysis of multispectral data. In these cultivated soils the exposure of subsoil resulting from severe erosion gives reflectance values measured by the satellite sensors which are considerably different from those of the less eroded surrounding soils.

A striking example of denudation and sand dune encroachment caused by wind action may be seen in an area along the Wadi Abu Habl in Western Sudan (Figure 5). The same data from which this detailed view (scale 1:25,000) of the southern extension of a sand dune was also used to examine the synoptic scene of many dunes at a scale of 1:250,000. The three spectral classes of the cultivated sands seemed to correlate well with the areas of millet, peanuts, and fallow.

Research Priorities for the 1980's

Should ARI be concerned with the quality and quantity of information available to the decision-makers and policy-makers in agriculture? Should ARI be leading, or should we be following someone else in the tasks which are required to improve information flow?

If the agricultural community is to gain optimum benefit from current and future remote sensing technology, attention must be given immediately to the formulation of research priorities and to the funding

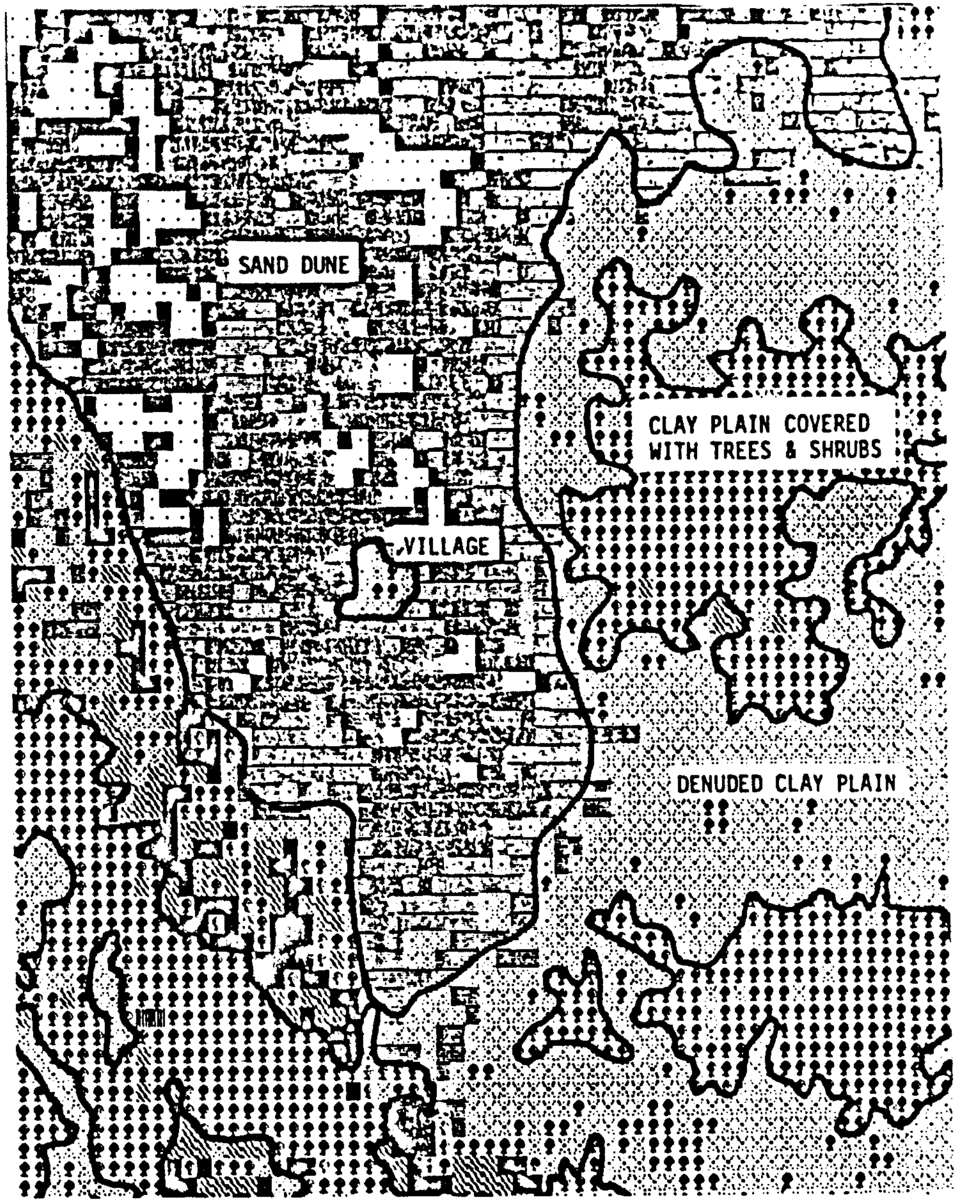

Figure 5. Computer-implemented classification of southern extension of a sand dune south of Wadi Abu Habl in Western Sudan; derived from Landsat MSS data. Scale 1:25,000

and implementation of appropriate research. Perhaps ARI can contribute to the defining of research priorities and to the support of essential research. Four general areas of needed research are presented for your consideration.

1. Understanding the agricultural scene. Our past and current understanding of the agricultural scene is colored largely by past and current methods of acquiring data. With repetitive Earth observation systems what new insights can we gain about the dynamics of agriculture? How can we best use remotely sensed data to supplement and improve our understanding of soils, crops and water resources?

2. Representing variations in the agricultural scene by quantitative measurements. Do current sensors obtain the quantitative measurements required in agriculture about crop conditions, soils, and water? What new instruments are needed? What spectral bands obtain the most useful data for specific applications? What are the optimum spatial and spectral resolutions of sensors used to obtain agricultural data?

3. Storage, retrieval, and analysis of agricultural scene data. How can we store, retrieve and overlay a wide variety of kinds of data about a specific land area? What kinds of data bases will be most useful to agriculture? Who should have the responsibility for the development and operation of data bases for land, crop, range and water resources?

4. Extraction and delivery of useful information about the agricultural scene. Who are the users of information about the agricultural scene? What kind of information do they want? When do they want it? How do they want it delivered? What format do they prefer? How do they use the information? What will be the cost of a desirable information delivery system of the future?

We can draw some valid conclusions about information from our experiences in the seventies. Accurate, timely, useful information about our land, crop, range, forest and water resources is becoming even more critical and valuable to the agricultural decision-maker. I contend that we will receive a good return on a well planned, long range investment in research designed to use the best in data acquisition, data analysis and communications technology to improve the efficiency of the flow of essential information to decision-makers throughout the agricultural sector.

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