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Agricultural Applications of Remote Sensing

by

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ABSTRACT

The responsibility of agriculture to feed and clothe the rapidly expanding population of the world calls for a more adequate agricultural information system. It is suggested that remote sensing and computer-implemented data processing techniques may play a significant role in providing such a system. A wide array of potential applications of remote sensing to the development and management of agricultural resources is discussed.

Introduction

I wish to quote from Chapter III of The State of Food and Agriculture 1970, published by FAO (2). This chapter is entitled "Agriculture at the Threshold of the Second Development Decade."

> The problems of agricultural development have been studied more closely than ever before during the past 25 years. To a greater or lesser degree agricultural development is now 'planned' in almost all of the developing countries, as a part of an overall planning of the national economy.

FAO has played a very significant role in this planning. Other national and international agencies have been deeply involved in world agricultural development programs. The past 25 years have brought many specialists in agricultural development to a painful awareness of the critical need for a more accurate and efficient information system for world agriculture.

In most countries of the world there is a dearth of current and accurate information about land use, soil productivity, areas of cropland and pastureland, arable land subject to flooding, cultivated lands subject to wind and water erosion, crop yields, potential arable land, and other data of importance to the development and management of agricultural resources.

I wish to address myself to the question of how aerospace technology may contribute to a better information flow for world agriculture. Previous speakers at this Technical Consultation have described various data acquisition systems and methods of processing and analyzing large quantities of remote sensing data.

My presentation will be a discussion of several specific potential applications of remote sensing to the management of agricultural resources. Although the areas are closely related, I am separating the agricultural applications of remote sensing into two groups:

1. Remote sensing and food production
2. Managing the agricultural environment

Major emphasis will be placed on the use of multispectral data obtained with an airborne optical-mechanical scanner.

For many years aerial photography has played an important role in agriculture. Today panchromatic photographs are used in many countries as a base on which soil mapping is done. The United States Department of Agriculture uses aerial photography widely to identify, map, and measure the areas of specific crops in its program to limit production.

This paper is not designed to treat those types of remote sensing which are operational and have been applied to agricultural problems for many years. Rather this discussion is about the potential applications of recently developed techniques to several specific tasks in agriculture. More specifically, this presentation will be confined to the applications of multispectral scanner data and computer-implemented analysis to the management of agricultural resources.

Ground Observations

Much gross information about earth surface features may be obtained from multispectral scanner data without the aid of simultaneous ground observations; however, many of the most useful applications of remote sensing to agriculture require ground observations as training sets for computer-implemented analysis of the data. It is essential that any potential user of these techniques recognize the importance of obtaining accurate and sufficient ground data at the appropriate time.

Much thought and effort have been expended in determining the best techniques for relating ground observations to multispectral scanner data which is recorded on magnetic tape. It is necessary that one be able to relate certain measured parameters of a given address on the ground with the address of the radiation data recorded on tape.

In our multispectral study of agricultural soils and crops at Purdue University a technique was developed through which ground data and scanner data could be related with a high degree of accuracy. That is, the address on the ground where soil and plant measurements or observations were made could be related to the radiation data obtained from the address.

Spectral studies of crops and soils have been conducted in several test areas in the state of Indiana. In each test area selected for detailed study, the field is carefully measured and gridded. Soil and plant samples are obtained at the grid points. Since each grid point is related to a bench mark which is easily identifiable on the scanner data, it is a relatively simple exercise to relate each grid point to the appropriate address on the magnetic tape.

Before proceeding to a discussion of specific applications, it should be emphasized that the successful implementation and use of these techniques are greatly dependent upon three factors:

1. the capability to obtain good-quality multispectral data from the area of interest at the appropriate time;
2. the capability to obtain the essential ground observations and measurements at the appropriate time; and
3. the facility and capability to handle, process, and interpret the data.

Remote Sensing and Food Production

Remote sensing and computer-implemented data processing can be used to produce very rapidly different kinds of inventories of earth surface features. Scientists at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, have been experimenting with techniques which will provide a variety of maps and inventory-type information of significance to agricultural production.

1. Mapping crop species

Perhaps no information is more basic for agricultural planning, export-import negotiations of agricultural commodities, and yield predictions than data on crops being grown in a region or a country. Early work at LARS showed the easy separability of multispectral data into the broad surface-feature categories of green vegetation, bare soil, and water (Figure 1). The identification and mapping of specific crop species requires the acquisition of sufficient and accurate ground observations as training sets for computer-implemented analysis.

An important consideration in the task of species identification is the stage of growth of the crop. For example, late June is not the ideal time to obtain multispectral data in Central Indiana, U.S.A., for separating and mapping fields of maize and soybeans. At that time much of the radiation received by the scanner is from the soil and the reflectance from maize and soybeans is similar. A more appropriate time to separate and map these species is in early August when there is a maximum amount of vegetative cover and the maize is fully tasseled.

2. Area Measurements

After the techniques for identifying crop species with multispectral scanner data have been refined, the next logical step is that of developing the techniques of obtaining accurate measurements of the areas of each crop which were planted and harvested. This kind of information is basic to an understanding of yields, trends, and changes in the agricultural sector of every country. Such information is also an integral part of any yield prediction equation.

Some estimates of crop areas have been made from multispectral scanner data, but much more research is required before computer programs can be written which will calculate areas of specific surface features with the desired precision.

3. Yield Predictions

Can the potential yield of a crop be related to the intensity and quality of energy which is reflected and emitted from that crop? Preliminary studies at Purdue University indicate that there is a relationship between the yields of maize and soybeans and multispectral measurements obtained by scanner flights during the month prior to harvest. This is another area which requires much more research. It is of particular importance that observations be obtained under a wide range of geographical, climatic and soil conditions.

An initial study in Central Indiana showed a fair correlation between multispectral measurements and three yield levels of soybeans. This study was conducted on deep silt loam soils formed under tall prairie grass conditions.

4. Percent Ground Cover

A variable which is important in yield prediction is the proportion of the soil which is covered by crop canopy. This is generally expressed as percent ground cover. A related measurement is leaf area index.

It is well known that the relative reflectance of soils in the visible region of the electromagnetic spectrum is much higher than it is in the reflective infrared region. On the other hand, the relative reflectance of green vegetation in the visible region is much lower than it is in the reflective infrared region of the spectrum. These relationships may make it possible to use multispectral scanner data to estimate percent ground cover and related parameters.

Dr. S. Kristof, using uncalibrated multispectral scanner data obtained over a period of three years and under many different conditions, found that the ratio between the visible and infrared reflectance values would give a rapid survey of broad earth surface features in an area where ground observations may not be available.

The ratio value is determined by the equation,

$$A = \frac{V}{I},$$

where A is a ratio between the relative reflectance values of visible and infrared radiation

V is the relative intensity of visible reflectance, and

I is the relative intensity of infrared reflectance.

In quantifying V, Dr. Kristof used the sum of the relative reflectance intensity from each of the wavelength channels or bands in the visible region (0.40-0.72 μm). The value of I was found by summing the relative reflectance values of all the channels in the reflective infrared region of the spectrum (0.72-0.60 μm). His further work has shown that the ratio values are more convenient and meaningful if the relative reflectance values from a single channel (0.58-0.62 μm) in the visible and a single channel (0.8-1.0 μm) in the infrared region of the spectrum are used.

When relative reflectance values from these channels are used to calculate R, it is found that for 100% soil R = 1.4-1.6. For 100% green vegetation, R = 0.55-0.75. Presently research is being conducted to determine the shape of the curve which connects the two extremes between reflectance from 100% soil and 100%

green vegetation. However, before these relationships can be determined with precision, it is necessary to have multispectral data which can be calibrated.

If it can be established that reflectance values obtained from multispectral scanner data correlate significantly with percent vegetative ground cover, an important new technique will be available for use in evaluation of crop vigor, crop yield prediction, pasture management, conservation planning, and other land use management problems.

5. Nutrient Status of Soils and Plants

In the realm of international agricultural development, few subjects have been given more attention during the past two decades than soil fertility and productivity. Soil testing programs have been established in country after country. Fertilizer manufacturing facilities have been built throughout the world. Yet the need may never have been greater than it is today for a rapid method of identifying, locating, and mapping nutrient deficiency areas in the croplands and pasturelands of the world. Remote sensing techniques may be able to assist with this task.

Let me emphasize that the results presented here have been confined to a relatively limited geographical region, but the techniques are basic and should be applicable universally, wherever quality multispectral data and essential ground observations and measurements can be obtained.

Studies have been conducted in Indiana to examine the relationship between multispectral data and the nutrient status of plants and soils. These studies included maize and soybeans at three different locations. Initially an attempt was made to identify those nutrients--primary, secondary, and trace--which may show some correlation with energy measurements. Results under these limited conditions indicated a reasonably good correlation between spectral response and plant content of nitrogen, phosphorus, and potassium. It is anticipated that further refinement of these techniques may make it possible to detect nutrient stress and evaluate the extent of this stress.

6. Disease and Insect Infestation

Any condition which causes a significant change in the radiating leaf area or which causes a deterioration in chlorophyll will affect the quantity and quality of energy radiating from that scene. Senescence of the maize or soybean plants is one of the many conditions which cause significant changes in chlorophyll and in the radiation characteristics of plants.

Infestation by insects and infection by disease may cause reduced growth, change in percent ground cover, lodging, deterioration of chlorophyll and other spectrally detectable symptoms. If the change from normal growth characteristics affects the radiation properties of the affected plants, multispectral analysis may be useful in detecting, locating, evaluating, and mapping the affected areas.

During the 1971 growing season a cooperative program between the U. S. Department of Agriculture, the National Aeronautics and Space Administration, the University of Michigan, and Purdue University has been conducted in the 7 major maize-producing states in the Midwestern United States. Multispectral analysis and photo-interpretation of color infrared photography are techniques which have been used to identify and evaluate the extent of corn leaf blight (Helminthosporium maydis) infection. Although the southern corn leaf blight has not proved to be very serious in 1971, it has been possible to identify and map different levels of infection with multispectral analysis (Figure 2).

7. Mechanical Destruction of Plants

Many of the important food-producing regions of the world are located in climatic zones where destructive wind, hail, and rainstorms occur with relatively high frequency. A study is in progress in which multispectral data are being used to estimate the percent of the leaf surface which has been removed by mechanical means. If multispectral data can be correlated well with the amount of radiating leaf surface which has been damaged, these techniques will be very useful in making rapid and objective assessments of the destruction of crops by storms or other mechanical means.

8. Moisture Stress

Moisture stress in plants causes a variety of physiological changes. Some of these changes can be related to spectral response. When a maize plant is fully turgid, all leaves are extended at angles which provide a near optimum surface for photosynthetic activity and a maximum percentage of ground cover. This condition also yields maximum reflectance in the reflective infrared spectral region. When moisture stress occurs, these conditions may change drastically. The surface area of the leaf exposed for optimum photosynthetic response is reduced. The leaves curl and droop. The percent ground cover may be reduced dramatically.

Studies are being conducted to determine the possibility of detecting moisture stress with multispectral measurements before the stress has caused permanent injury or reduction of yield. Such techniques would be of great benefit in regions of irrigation agriculture. These methods would also be of use in assessing the extent of drought and the predicted reduction in yield.

9. Tillage Operations

Remote sensing techniques can be used in recording the kind, amount and time of tillage or other farming operations which have been completed in a region. In the fall it is of great interest to the fertilizer industry in the Midwestern United States to know the day-by-day and week-by-week status of the maize and soybean harvest. They also wish to know how much fall plowing is being done. Such information assists them in planning the shipment and stock-piling of fertilizer materials.

The spectral response of maize which has been harvested is quite separable from that of unharvested maize. The plowed area of a field of soybeans or maize is easily distinguished by spectral analysis from the harvested but unplowed areas.

The time and rate of seedbed preparation in spring is an indication of the earliness or lateness of the growing season. This information has a bearing on crop yield predictions (Figure 3).

It should be possible to identify, measure, and map the rate and extent of many spectrally distinguishable tillage and harvest operations.

Managing the Agricultural Environment

In long range planning for the development and management of agricultural resources, food production alone is not the only consideration. The use and management of all land resources must be taken into account. Man's future and the quality of his environment is being decided today to a large extent by the decisions which are being made with reference to land use.

From The State of Food and Agriculture 1970 (2):

> It is the use and abuse of modern technology, combined with the population explosion, that have mainly given rise to the worsening pollution and degradation of the human environment.

The Food and Agriculture Organization and agricultural scientists in all countries bear a large part of the burden to assure that world agriculture will utilize development and management techniques which will minimize pollution and environmental degradation. One of the objectives in all agricultural development and management should be the elimination of pollution and the conservation of a friendly and aesthetic environment. Remote sensing and automatic data processing techniques can surely be utilized to accomplish this objective.

Remote sensing techniques may be applied effectively in the areas of inventorying various kinds and conditions of earth resources and monitoring those parameters of soils, plants, water, and air important in maintaining a quality environment.

1. Inventory of Soil Parameters

A thorough knowledge and understanding of soils is basic in developing and managing agricultural resources. As recently as 100 years ago man began to separate and classify soils in an attempt to explain why soils are different. Today the body of knowledge about soils is substantial; however, the mapping and definition of the properties of specific soils is still tedious and very slow. In 1971 there are detailed soils maps for a relatively small proportion of the land area of the world. There is urgent need for new and more rapid methods of delineating differences between soils, of characterizing physical and chemical parameters of soils, and of mapping these many differences.

It has been found that multispectral measurements of soils can be related to some of the physical and chemical properties which significantly affect soil management. It is quite a simple procedure to select training sets for computer-implemented analyses of spectral data from soils. Maps can be produced by computer which delineate differences between soil mapping units based on the spectral properties of the surface soils (Figure 4).

Kristof (3) and Zachary et al. (4) reported a multispectral study of soils in Morgan County, Indiana. The study area had been covered by the early stage of the Wisconsin Glacier and is referred to as the Tipton Till Plain. The soils are Alfisols (gray brown podzolic) developed primarily under dense forest. Surface colors vary but are generally light and the soils low in organic matter. A comparison of the computer printout of seven spectral categories with the mapping units prepared by conventional soil survey methods shows that there is a striking similarity in the soil identification.

Matthews et al. (4) used multispectral data obtained at an altitude of 1600 m along a 70-km flightline in southeastern Pennsylvania, U.S.A. Their study had two primary objectives. The first was to determine if multispectral data could be used to delineate and map boundaries between different geologic features or parent materials. Analysis of the spectral data gave them a computer-implemented map whose parent material boundaries compared very favorably with the boundaries identifiable on aerial photography.

Their second objective was to delineate and map on the basis of spectral properties, soils differences in an area of homogeneous parent material and several soil types. The parent material of the soils selected for this study was Ordovician limestone. With carefully selected training sets, a spectral map was produced with close similarity to the soil map which was made by conventional soil survey methods.

Soil scientists for many decades have known that the quantity and quality of organic matter greatly affects the spectral properties of mineral soils. Kristof (3) and Baumgardner et al. (1) have used multispectral data and computer-implemented analysis to delineate and map five different ranges of organic-matter content for mineral soils containing from 0.5 to 7% organic matter (Figure 5). Prairie soils, forest soils and transitional soils have been included in this study.

Since the organic matter content affects the color, heat capacity, water holding capacity, cation exchange, structure, and erosivity of soils, a rapid and easy assessment of this parameter may be of great utility to the soil surveyor and to the land-use planner.

Studies at LARS have also shown a relationship between multispectral response and clay content of surface soils. Initial research results indicate that multispectral analysis and pattern recognition techniques may be used to delineate and map gross textural differences in surface soil.

2. Inventory on Conservation Needs

In recent years agricultural resource conservation has come to have a very broad meaning. It implies the use of land and water resources for the production of man's food and fiber needs while at the same time preserving and improving those conditions which will maintain high yields into the indefinite future. Today a second very important implication demands that land and water resources be so managed that a quality environment be reinstated and maintained.

Soil in runoff water is agriculture's greatest contribution to the pollution of lakes, rivers and streams throughout the world. The color of the water loaded with sediment reflects the spectral properties of the soils from which the sediment was eroded (Figure 6). It may be possible to develop spectral analysis techniques to determine the source of sediment and to estimate the sediment load of a stream or river. Spectral analysis has clearly shown that certain tributaries or streams in a river system in Indiana have strikingly different spectral properties than others, indicating that the degree and kind of soil erosion is different from one small watershed to another.

The rapid identification and mapping of bodies of surface water by spectral analysis and pattern recognition techniques is a routine task by remote sensing. During times of excess rainfall and flooding, these methods can be used for real-time assessment of flood damage and inundated areas.

When surface soil is removed by erosion and subsoil is exposed, significant changes occur in the spectral properties of the radiating surface. Spectral studies of soils of undulating topography in Pennsylvania and Indiana have shown that moderate to severe erosion can be detected and mapped by remote sensing procedures. Research is proceeding on this problem in an attempt to estimate by spectral analysis the degree of erosion which has occurred.

Drainage of superfluous or excess water is a serious limitation to food production in many agricultural regions of the world. In some of these regions there is a need for more information about the drainage properties of the soils and about the natural drainage system of the land. Remote sensing techniques could provide an inventory of drainage problems. Analysis of multispectral data obtained sequentially over a watershed immediately after a heavy rainfall and at 24-hour intervals thereafter would help to pinpoint the soils with very poor internal drainage properties and those with good internal drainage.

3. Survey of Current Land Use

The uniqueness of the methods described in this paper lies in the speed with which large quantities of data can be handled and processed. This feature lends itself well to the task of providing current information about land use, shifting patterns, urban sprawl, and the changing interface between agricultural and nonagricultural exploitation of the land. The degree to which regional planners, developers of earth resources, and government administrators in different countries use such information varies from none to substantial. It should certainly be an objective of FAO that this kind of information enter into the development planning and management of all countries.

It has been demonstrated in many instances that remote sensing and pattern recognition techniques can provide a quick landscape survey which can delineate and map cropland, forests, grassland, bodies of water, bare soil, roads, and urban areas. With sequential scanning and computer overlay capabilities, many more categories or surface features may be identified and mapped.

Several research projects involving geographers, geologists, land-use specialists and soil scientists, are currently being conducted with multispectral data in a study of land use. A major objective is to develop methods of identifying and mapping different categories of nonagricultural land use such as industrial areas, commercial marketing, high income housing, middle income housing, and blighted residential districts.

Conclusion

The task of agriculture is to feed and clothe people of the world. The rapidly expanding population requires rapid development of agricultural resources. To accomplish this task agriculture needs a better information system which will provide broad dissemination of data very rapidly. Remote sensing and computer-implemented analysis can help to fill this need.

It is my hope that this presentation has stretched your imagination and helped you to visualize some of the applications of remote sensing which may soon become commonplace. Not all the potential applications which have been presented will prove to be feasible or practical; however, you and your agricultural-data-using colleagues around the world may think of many other useful applications for these techniques.

I am convinced that there is a bright future for remote sensing in agriculture.

Literature Cited

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Figure 1. Panchromatic aerial photograph and computer printout delineating water, roads, bare soils, and green vegetation.

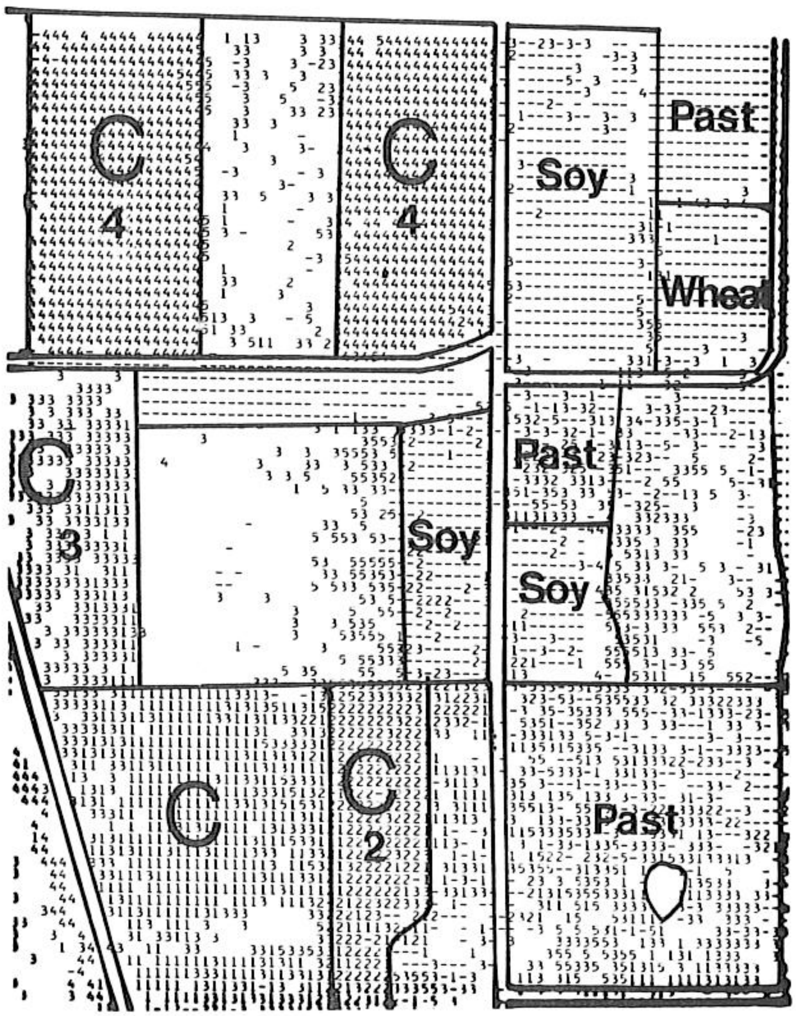


Figure 2. Multispectral delineation of degrees of corn leaf blight infection (C represents normal corn, C_2 slight, C_3 moderate, C_4 severe infection).

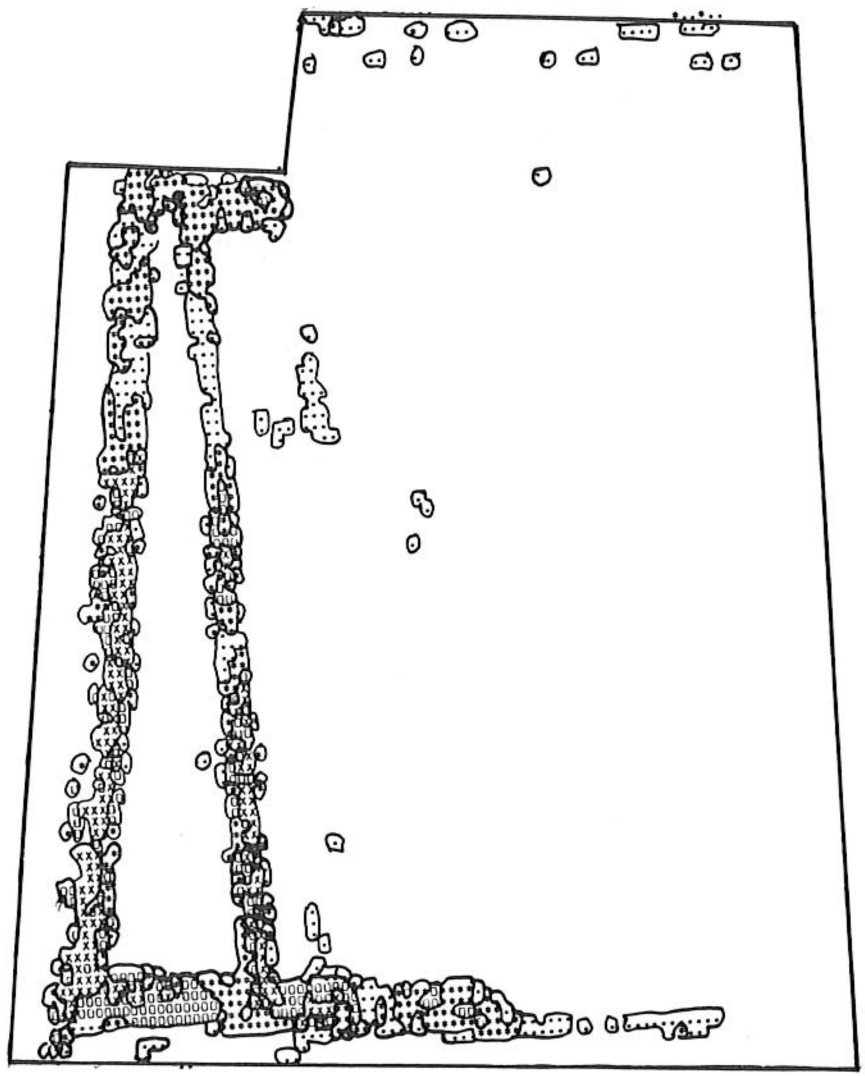


Figure 3. Computer printout showing freshly plowed strips across field.

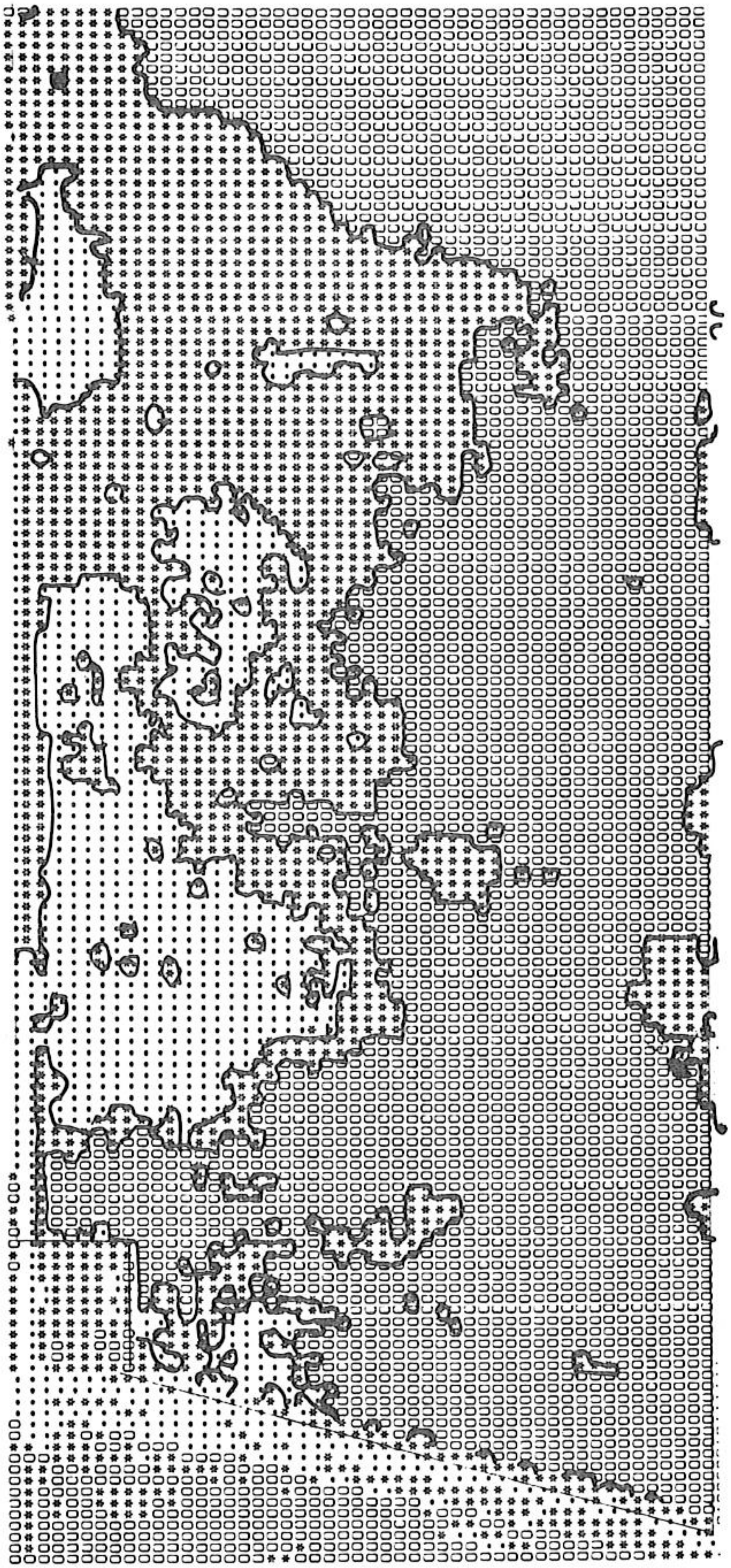
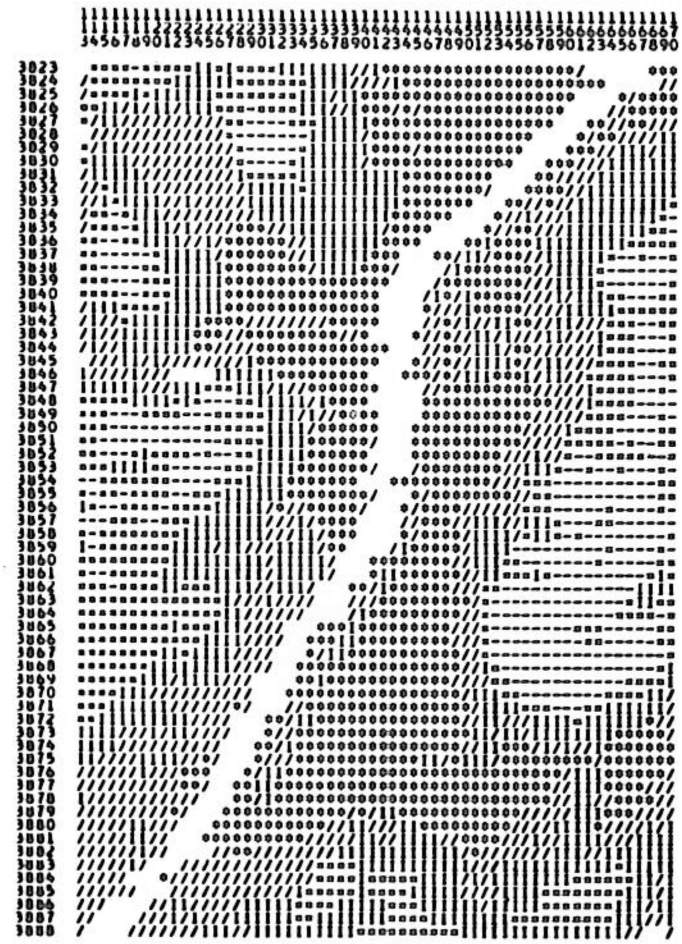


Figure 4. Three spectral classes of soils in 55-hectare field mapped by computer analysis.



TOTAL NUMBER OF SAMPLED POINTS = 3028

Figure 5. Five levels of soil organic matter in 20-hectare field mapped by computer analysis of multispectral data.

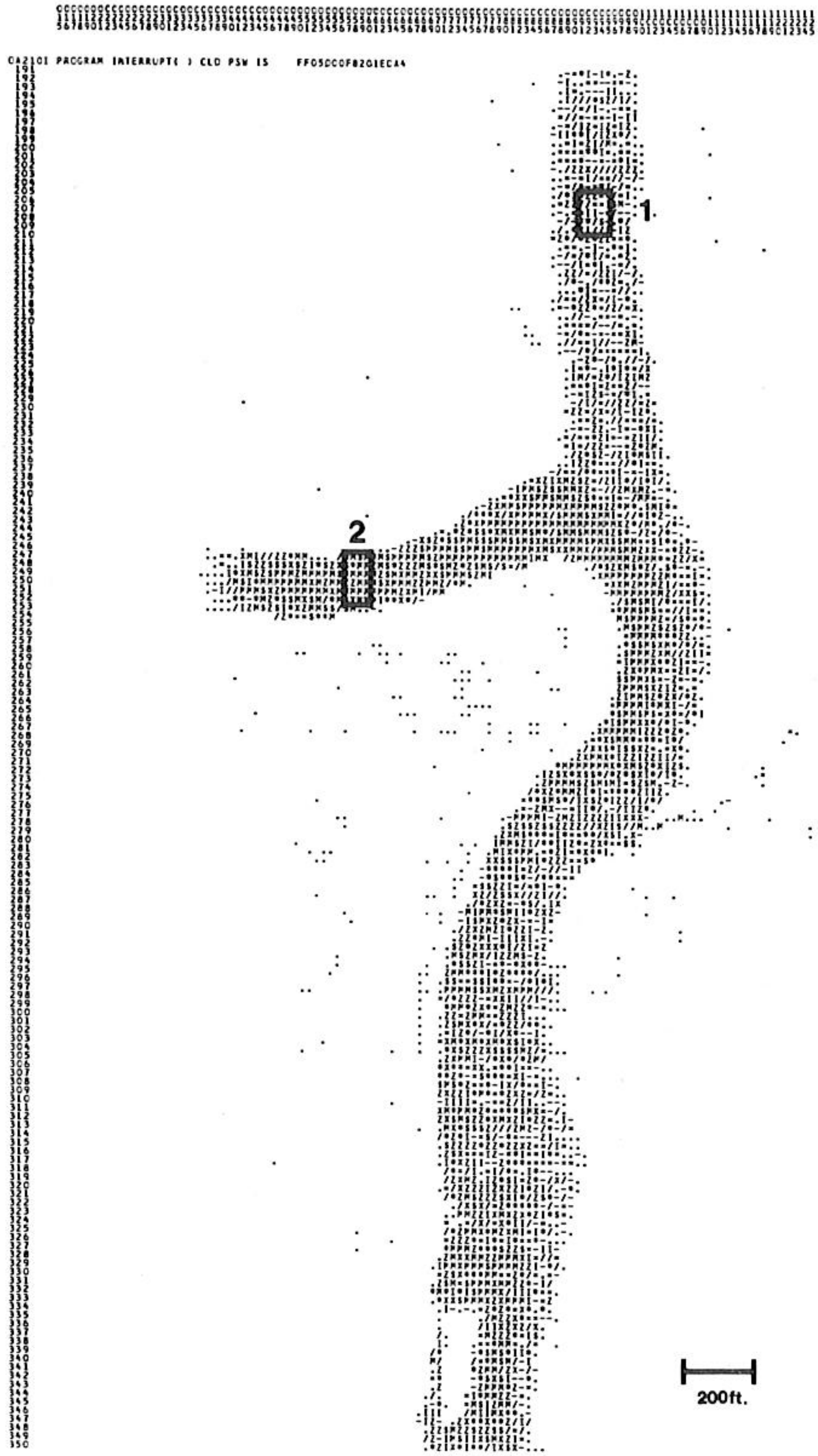


Figure 6. Spectral analysis reveals differences in two streams (water in area 1 is heavily polluted with sediment; water in area 2 is clear).