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CONTRIBUTIONS OF AUTOMATIC CROP SURVEYS TO AGRICULTURAL DEVELOPMENT

by

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-- NOTES --

CONTRIBUTIONS OF AUTOMATIC CROP SURVEYS TO AGRICULTURAL DEVELOPMENT*

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Abstract

Remote sensing and automatic data processing techniques applied to problems in agriculture have given encouraging results at the Laboratory for Agricultural Remote Sensing at Purdue University. The development of a capability to collect almost unlimited quantities of agricultural data over a large geographical area in a very short time span and to analyze this data automatically has many important implications in agriculture, both in the United States and abroad. Recent results of research in automatic crop survey techniques are discussed. Potential applications in conjunction with three stages of development of this research are suggested. The latter half of the paper discusses contributions of the potential applications to agricultural development. Since agricultural technology is applied on a very different plane in the United States from that of most countries in Latin America, Africa, and Asia, the contributions of automatic crop surveys to agricultural development are discussed under two different conditions: 1) a highly mechanized and productive agriculture, and 2) agriculture in the less developed countries.

I. Introduction

Agricultural development in a hungry world looms as a top priority item in the minds of political leaders, engineers, and agricultural scientists around the world. The Food and Agriculture Organization of the United Nations has estimated that to provide a decent level of nutrition for the world's peoples the production of food will have to be doubled by 1980 and tripled by 2000. In May 1967 the President's Science Advisory Committee pub-lished Volumes I and II of "Report of the Panel on the World Food Supply." One of the basic conclusions of the Panel seems apropos to the message of this paper.

> "The scale, severity, and duration of the world food problem are so great that a massive, long-range, innovative effort unprecedented in human history will be required to master it."(4)

Today as never before during man's sojourn on this planet we are faced with the growing crisis of resource development and management. The rate of development and efficiency of management must be improved considerably if man is to satisfy his hunger, indeed, if man is to survive. For thousands of years man has been engaged in one way or another in managing the resources around him. Throughout history the primary driving force for resource management was the need for food, clothing, and shelter.

Modern man has seen the rise of nations with a large affluent middle class citizenry. In these countries a major effort has gone into resource management the purpose of which has been to provide recreation, pleasure, and leisure activities for man. The management of natural resources on a vast scale to serve man's recreational needs is a modern phenomenon, and only a small fraction of the world's population has had the privilege of this luxury.

However, the preoccupation of the majority of humanity remains that of satisfying man's hunger. Today the impending crises of bulging human populations, water shortages, and limitations of arable land present a new problem unique in man's history. Man is challenged to devise new techniques for development and management of the earth's resources.

Another significant observation recorded by the Panel on the World Food Supply seems appropriate here.

> "The scarcest and most needed resource in the developing countries is the scientific, technical, and managerial skill needed for systematic, orderly decision-making and implementation." (4)

An attempt is made in this paper to show how remote sensing techniques and automatic data processing methods can be put to use in both the developmental planning and management stages of the resources at man's disposal.

II. Laboratory for Agricultural Remote Sensing

The Laboratory for Agricultural Remote Sensing (LARS) at Purdue University was established in 1965 as a result of the intense interest of the National Aeronautics and Space Administration and the U. S. Department of Agriculture in the development of remote sensing techniques for characterizing agricultural situations.

Remote multispectral sensing research has been carried on at Purdue University for about a year and a half. This research is directed at establishing methods to determine by remote means,

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species identification, state of crop maturity, disease conditions, soil types, soil moisture conditions, soil types, soil moisture conditions, and many other crop and soil parameters.

Engineering and life scientists are cooperating to develop techniques to sense remotely (observe and record from above ground level) agricultural situations and to assess automatically (review and determine by computer) their important characteristics.

LARS Program Objectives. Overall objectives of the research may be defined as follows:

- To determine the degree to which selected major crops of the Corn Belt region, such as corn and soybeans, can be differentiated on the basis of their multispectral response at various times during the growing season.
- To determine the amount of variation and to identify the major sources of variation in the multispectral response of selected agricultural features such as soil conditions and major crop species of the Corn Belt region at various times during the growing season.
- To determine and prescribe methods for gathering information from the ground that will allow prediction of multispectral response characteristics obtained by remote multispectral sensing techniques.

To achieve these objectives, the research at Purdue University involves three interrelated study areas:

1. Biophysical studies in the laboratory and field, designed to:

- Learn more about natural variations in plant and soil reflectance spectra and the factors which influence variations.
- Determine optimum portions of spectrum for remote sensing.
- Determine optimum time during the growing season to obtain remote multispectral data with airborne systems.

2. Remote multispectral sensing studies, using aircraft flights over selected agricultural areas near Lafayette, Indiana. Such aircraft systems can obtain simultaneous data on reflectance and emission characteristics of areas flown over in many spectral bands between 0.32 and 15 microns wavelength. Such data are currently recorded electronically on analog tapes and later converted to digital form. Data from this phase of the program are being used to determine the feasibility of optical-mechanical scanner system surveys to supplement U.S. Department of Agriculture, Statistical Reporting Service crop reporting survey system.

3. The third major study area is data handling and pattern recognition techniques. To study the remote sensing survey systems, enormous amounts of data must be processed and analyzed by extremely specialized techniques. Therefore, data handling and pattern recognition problems become a crucial part of a thorough investigation to determine the feasibility and practical applications of the system.

III. Automatic Crop Surveys

Remote Sensing. Various remote sensing methods have been applied to agricultural problems for many years. Aerial photography has been used for several decades by the soil surveyor as an important tool in soil mapping and classification. The U. S. Department of Agriculture has made extensive use of black and white aerial photographs to record and measure crop areas of those species under strict acreage allotment. In both instances photographs are analyzed by visual observation, requiring on a national scale an expenditure of millions of man hours and dollars.

Today new remote sensing techniques which supplement classical photographic methods are being developed. One of the systems which seems to hold great promise for agriculture consists of spectral data collection with a multi-channel optical-mechanical scanner mounted in air-or spacecraft. Figure 1 shows such a scanner as it might be mounted in an aircraft. Landgrebe and Phillips (3) describe the operation of this scanner as follows:

> "The energy radiated by a specific ground resolution element at a given instant of time passes through the scanner optics and is divided according to its spectral wavelength and directed to an appropriate detector. The output of all such detectors are simultaneously recorded on a multiband instrumentation recorder. The transverse motion provided by the rotating mirror and the forward motion of the aircraft cause a continuous raster to be formed for each spectral band of the scanner output. An important feature of a system such as this is that by simultaneously sampling the output of all bands, one obtains a vector which contains all spectral information available about a given resolution element on the ground."

Through the use of such remote sensor systems, providing they have been properly calibrated, one can integrate the energy in a given wavelength band which is received from a relatively small portion of the earth's surface. The size of the area covered is dependent upon the optical characteristics of the system being used, as well as the altitude from which one is obtaining such data. By sensing the reflected or emitted energy from a given area in each of many discrete wavelength bands, a "multispectral response pattern", similar to that shown in Figure 2 was derived by Hoffer, et al. (2) This pattern represents a combination of signals received from a given target (an object, land area, other) on a given date. It is hoped that by studying many such patterns for each crop and soil condition of interest, one may establish a characteristic, consistent, and predictable pattern, capable of quantitative expression and of known statistical reliability. Such a pattern would be called a "multispectral response signature". A multispectral response signature can thus be defined as a particular set of reflectance and emittance properties of a target (an object or area of interest) which makes possible the detection and identification of a target from a remote location, with an acceptable degree of statistical reliability.

Two of the primary advantages of this system over photographic sensors is that the data can be analyzed 1) very rapidly and 2) in large quantities with the use of computers. One other

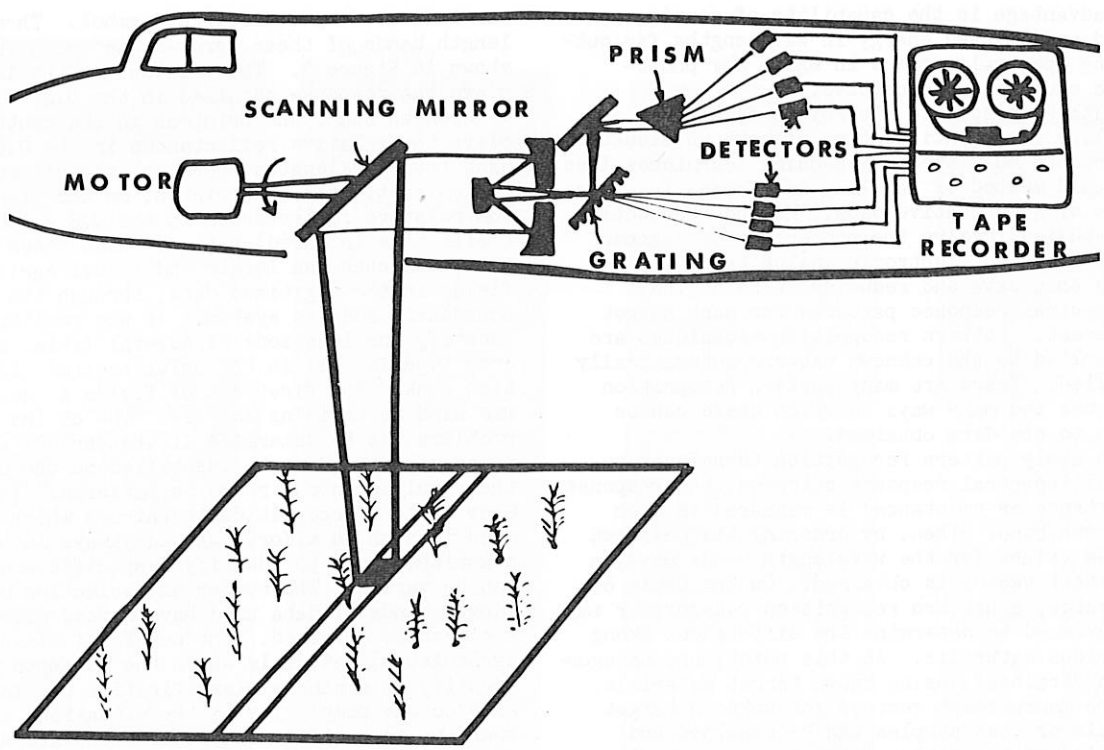

Figure 1. A Multi-channel Optical-mechanical Scanner.

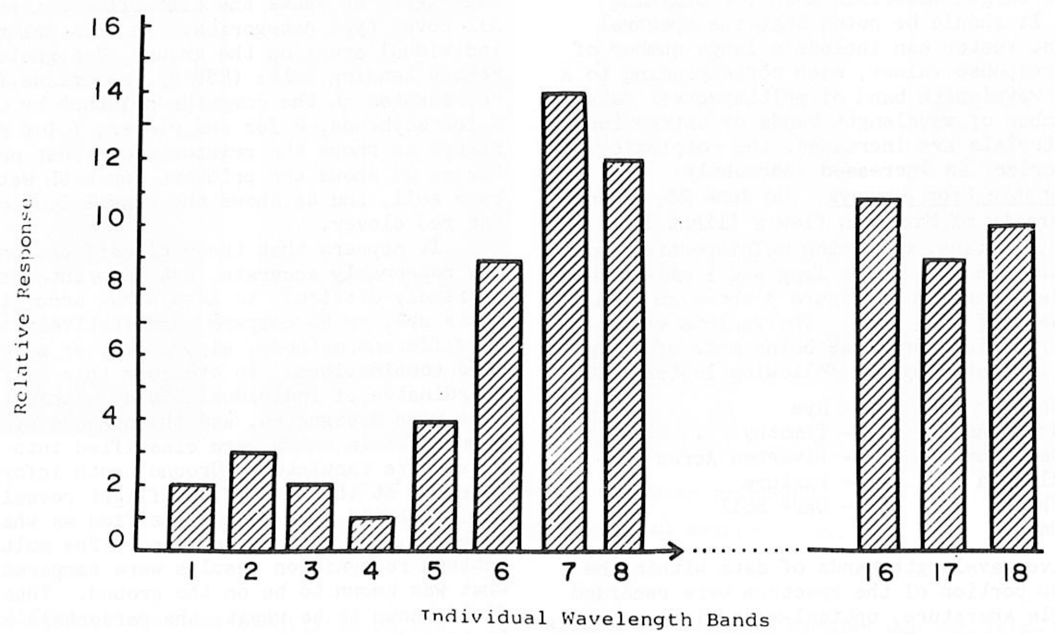

Figure 2. Multispectral response signature obtained through use of 18 wavelength bands.

major advantage is the capability of sensing reflected and emitted energy in wavelengths far outside the spectral regions in which any photographic emulsion is sensitive.

Data Processing. The key to developing a capability for identification of unknown situations using remote multispectral sensing techniques lies in a rapid method of handling and processing large amounts of quantitative data. Methods currently being studied involve the processing of scanner data obtained on electronic analog tapes, calibrating this data and reducing it to digital multispectral response patterns for each target of interest. Pattern recognition techniques are then applied to the unknown pattern automatically classified. There are many pattern recognition techniques and many ways in which these can be applied to the data obtained.

To apply pattern recognition techniques to such multispectral response patterns, the response (reflectance or emittance) is measured in each wavelength band. Then, by ordering the measured response values for the wavelength bands used, a measurement vector is obtained. On the basis of this vector, a pattern recognition categorizer may be programmed to determine the differences among the various materials. At this point, the categorizer is "trained", using known target materials. Then the measurement vectors for unknown target materials or test samples can be examined and classified on the basis of the known spectral response measurement vectors. Thus, the categorization phase of spectral pattern recognition techniques involves decisions as to which category of target materials the unknown data fits. If the unknown target material does not achieve specified limits to fit one of the known training sample categories of target materials, it can be classified as "other", or as not belonging to any of the classes of target materials used for training samples. It should be noted that the spectral measurement vector can include a large number of measured response values, each corresponding to a different wavelength band of multispectral data. As the number of wavelength bands or categories of target materials are increased, the complexity of the categorizer is increased enormously.

Automatic Crop Surveys. On June 28, 1966, the University of Michigan flew a flight line near Lafayette, Indiana, obtaining multispectral data over an area about 4 miles long and 1 mile wide. The far left portion of Figure 3 shows an aerial photo mosaic of this area. The various crop species or agricultural use being made of each field is indicated by the following letter symbols:

C -- Corn	R -- Rye
S -- Soybeans	T -- Timothy
RC -- Red Clover	DA -- Diverted Acres
A -- Alfalfa	P -- Pasture
W -- Wheat	BS -- Bare Soil
O -- Oats	

Twelve wavelength bands of data within the 0.4 - 1.0u portion of the spectrum were recorded by a single aperature, optical-mechanical scanner, which allowed the reflected energy from a single small area on the ground to be recorded simultaneously in all wavelength bands.

Each of the twelve wavelength bands of data to be used were digitized, and computer printouts were obtained which show the amplitude of the reflected energy received in each wavelength band, displayed in a series of 16 steps each of which was indicated by a different symbol. Three wavelength bands of these "grey-scale" printouts are shown in Figure 3. The printout on the left displays the response obtained in the 0.40 - 0.44u wavelength band; the printout in the center displays the relative reflectances in the 0.62 - 0.66u band (red wavelengths where chlorophyll absorption is dominant); and the printout on the right displays the relative reflectances in the 0.8 - 1.0u (reflective infrared) region. With these printouts the researcher can locate individual agricultural fields in the digitized data, through the use of a coordinate address system. It was possible to identify the locations of several fields of each crop type for use in the multispectral classification task. The first set of fields so designated was used as training samples. One of the first problems was to determine if the various crop types could in fact be identified on the basis of their multispectral response patterns. There are many pattern recognition techniques which could be used in such an effort, and many ways in which the algorithms used to identify a specific crop type can be varied. The number and selection of wavelength bands of data used have marked effects on the results obtained. The number of classes of agricultural materials which one attempts to identify in a single classification problem also adds to the complexity of the situation, i.e., it would be more difficult to differentiate and identify wheat, oats, corn, and soybeans than to identify only the wheat.

In one analysis effort with this data, a maximum likelihood technique was used in an attempt to identify the following cover types: wheat, oats, rye, corn, soybeans, red clover, alfalfa, bare soil, water, and "other", such as roads. The results of this classification are shown in Figure 4. The left side (a) shows the photo of this area, and Figure 4b shows the classification results for all cover type categories. In this printout, individual areas on the ground, designated as Remote Sensing Units (RSU's), are classified and represented on the computer printout by C for corn, S for soybeans, R for red clover, Y for rye, etc. Figure 4c shows the printout for wheat only, and Figure 4d shows the printout for both water and bare soil, and 4e shows the classification results for red clover.

It appears that these classification results are reasonably accurate, but in printouts, it is extremely difficult to assess how accurate the results are, or to compare quantitatively the results of different methods, algorithms, or wavelength band combinations. To overcome this difficulty, the coordinates of individual fields within the flight line were designated, and the numbers of RSU's within each field which were classified into each crop class were tabulated. Ground truth information obtained at the time of the flight revealed which fields should have been classified as wheat, corn, soybeans, and other categories. The multispectral pattern recognition results were compared with what was known to be on the ground. Thus, in a field known to be wheat, the percentage of the RSU's in that field which were actually classified as wheat could be calculated. The number of RSU's classified into each class of agricultural cover type is summarized in Table 1 for all fields used as training samples. The number of fields used and the percent correct classification is also shown. These results tend to indicate that even similar crop species such as red clover and alfalfa can be

Figure 3. Annoted photograph and computer printouts of three wavelength bands of multispectral scanner data.

accurately differentiated and identified on the basis of this type of remote multispectral imagery. However, this table presents the tabular results for fields used as training samples, which were carefully selected "typical" crop fields. When the results are tabulated for the remaining large fields of each crop type found within this flight line, the classification results are not as spectacular, as seen in Table 2. The primary reason for the change in accuracy is that the number of training samples was not large enough to represent all variations of multispectral response patterns of the different crop species. It must also be pointed out that these are rather preliminary research results, and are shown to indicate the potential of spectral pattern recognition rather than what could be done using an operational system.

An examination of the classification results for individual fields indicates that most errors

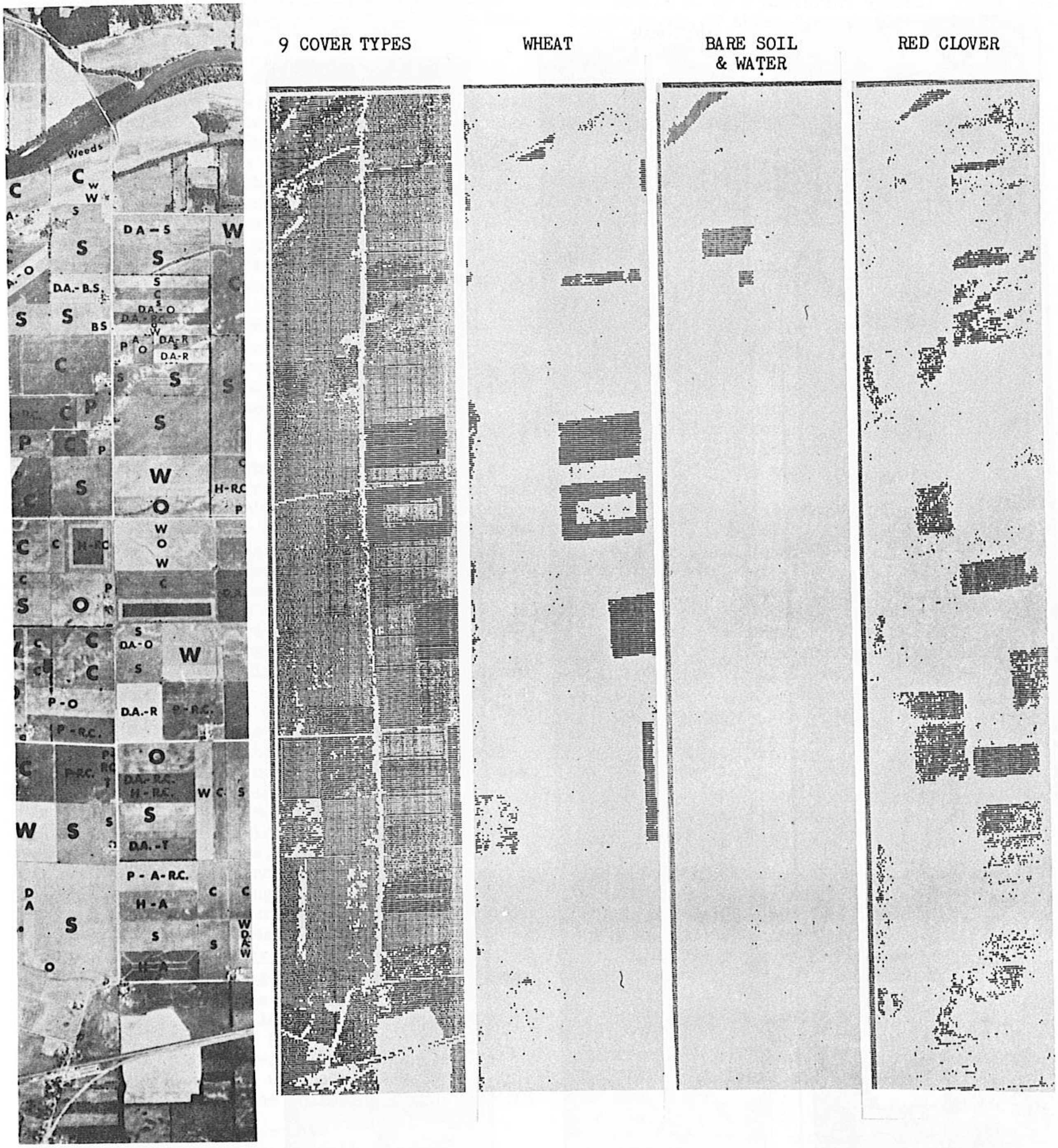

Figure 4. Annotated photograph and automatic printouts of specific agricultural cover types.

were among similar crop species. This led to an analysis of the results using crop type groupings rather than individual crop species. Figure 5 shows the comparison between test sample classification results using individual crop species and the crop type groupings. By combining wheat, oats, and rye into a cereal grain group, the percentage correct classification rose to 83%; red clover and alfalfa combined into a forage group had 77% correct classification. Whereas corn and soybeans as individual crop species had 65% and 77% correct classification respectively, combining them into a row crop grouping gave a correct classification of 92%. These data indicate a very good potential for identifying crop type groupings. Of the 33 individual fields used in the test sample group, only 3 fields did not have better than 70% of

TABLE I. SUMMARY OF CLASSIFICATION RESULTS FOR TRAINING SAMPLES
(Flight Line C-1, data obtained on 28 June 1966 at 12"30 p.m.; 12 wavelength bands used)

Class or Cover Type	No. of Fields	Percent Correct Classification	Total No. of RSU's	Number of RSU's Classified Into: Water I	Bare Soil X	Wheat W	Oats O	Rye Y	Red Clover R	Alfalfa A	Corn C	Soybeans S	Other
Water (I)	4	100.0	95	95	0	0	0	0	0	0	0	0	0
Bare Soil (X)	1	100.0	170	0	170	0	0	0	0	0	0	0	0
Wheat (W)	4	95.5	595	0	0	568	24	1	0	0	0	2	0
Oats (O)	4	93.6	936	0	0	26	876	1	21	0	11	1	0
Rye (Y)	1	100.0	494	0	0	0	0	494	0	0	0	0	0
Red Clover (R)	3	97.8	771	0	0	0	6	0	754	7	4	0	0
Alfalfa (A)	2	96.8	315	0	0	0	1	0	6	305	0	1	2
Corn (C)	4	94.6	1344	0	0	0	6	0	17	1	1272	43	5
Soybeans (S)	5	99.2	1819	0	0	0	0	1	0	1	13	1804	0

TABLE II. SUMMARY OF CLASSIFICATION RESULTS FOR TEST SAMPLES
(Flight Line C-1, data obtained on 28 June 1966 at 12:30 p.m.; 12 wavelength bands used)

Class or Cover Type	No. of Fields	Percent Correct Classification	Total No. of RSU's	Number of RSU's Classified Into: Bare Soil X	Wheat W	Oats O	Rye Y	Red Clover R	Alfalfa A	Corn C	Soybeans S	Other
Bare Soil (X)	1	100.0	56	56	0	0	0	0	0	0	0	0
Wheat (W)	6	78.0	1810	0	1412	51	186	0	0	0	0	161
Oats (O)	1	73.9	460	0	2	340	0	32	0	51	34	1
Rye (Y)	1	73.0	126	0	2	2	92	0	0	1	8	21
Red Clover (R)	5	69.6	1986	0	4	270	1	1379	152	115	3	58
Alfalfa (A)	1	52.4	418	0	0	21	0	100	219	10	6	62
Corn (C)	7	65.5	2020	0	0	0	4	3	0	1324	677	12
Soybeans (S)	11	76.7	4972	16	3	3	11	325	35	581	3815	183

the RSU's correctly classified on a crop type grouping basis. Research conducted to date by the Purdue/LARS staff indicates that agricultural applications of remote sensing and automatic data processing may be categorized as follows:

Category A - These tasks appear to be feasible with present equipment and techniques.

1. Map of bodies of water (lakes, rivers, streams)
2. Winter wheat acreage map
3. Green vegetation map
4. Map of roadways
5. Measurement of relative surface temperatures
6. Bare soil map (light colored, dark colored soils)
7. Detection of plant stress

Category B- These tasks are more difficult but it seems reasonable that they can be accomplished.

1. Map of wet soil areas
2. Map and measurement of crop species
3. Topographic maps
4. Map and measurement of forest species
5. Gross characterization of soil permeability
6. Map and measurement of crops severely damaged by wind and hail

Category C - These tasks are difficult but perhaps possible.

1. Measurement of crop cover density
2. Measurement of available soil moisture
3. Detection and measurement of crop disease areas
4. Detection and measurement of areas of insect infestation
5. Prediction of crop yields
6. Detection of plant nutrient deficiencies
7. Weed surveys
8. Detection and location of certain water pollutants

IV. Automatic Crop Surveys and Agricultural Development

Agricultural Development. "Agricultural development" is a very broad and general term. As it is used in this paper, it may be defined as those processes of resource planning and management which result in increased productivity of food and fiber products per labor unit expended. Perhaps it can be assumed that agricultural development is occurring in most countries of the world. The rate at which it is occurring varies tremendously from one country to another. In fact, it may be possible to pinpoint certain instances where a

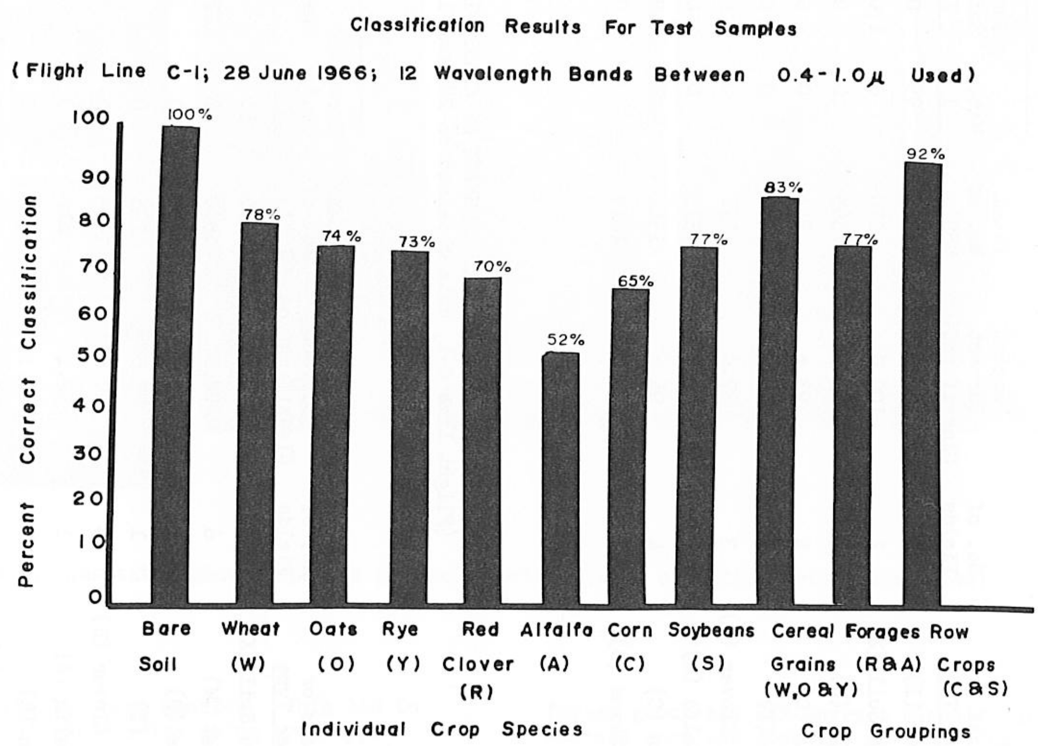

Figure 5. Comparison between test sample classification results using individual crop species and crop type groupings

regressive situation exists in a nation's agricultural sector. The point here, however, is that agricultural development is not something which is underway only in the "have-not" countries. Science and technology are now providing more developmental advancement and change in United States agriculture than at any other period of its history.

How then can remote sensing and automatic data processing serve agriculture and increase efficiency of production within the two broad categories of nations, namely; (1) those with highly mechanized and productive agriculture and (2) those with less efficient agriculture of low productivity?

Nations with Highly Productive Agriculture. The United States, Canada, Japan, and several countries of Western Europe have rather effective systems of collecting and analyzing agricultural data and of making the results available to the public. However, even in these countries the lagtime between the date of data collection and information dissemination may be months, or even years in some instances. In the United States each year many millions of dollars are expended in the collection, analysis, and dissemination of agricultural statistics.

The key to the contributions which remote sensing and automatic data processing techniques can make to agriculture in these countries is the timeliness with which vital information can be made available to the decision-makers, the planners, the producers. Rather than replace the present data collection systems remote sensing techniques should be used to supplement them and to increase their efficiency and accuracy if possible.

Nations of Low Agricultural Productivity. In this group of nations a primary gap in the development process is a lack of knowledge of the available resources. One of the first tasks of the Food and Agriculture Organization, the Ford and Rockefeller Foundations, the U.S. Agency for International Development, or any other agency which undertakes an agricultural development project in one of these countries is to prepare an inventory of the disposable resources. Very often many man years may be expended in assembling essential information and preparing such an inventory. In many countries agricultural statistics are nonexistent.

Remote sensing and automatic data processing techniques could be applied very usefully in obtaining important resource information which could be used initially in development planning and later in resource management. For example, one of the critical agricultural problems in the humid Pampa Region of Argentina is poor soil drainage. Large areas throughout the Pampa are relegated to very low productivity because the soils are waterlogged during a major part of the growing season. The total area covered by these depressional soils and the drainage properties of the Pampa soils have never been characterized and mapped. A significant contribution could be made with remote sensing and automatic mapping of all standing water in the Pampa immediately following a general rain. These techniques could be used in preparing maps of the same area three days and ten days after the general rain. Analysis and comparison of the three maps should indicate rather vividly where the most serious drainage problems are. Further, the information would serve as a first good approximation in defining the drainage properties of the Pampa soils. Such information is basic to any rational scheme of providing artificial drainage facilities.

Potential Users of Automatic Surveys. In the agricultural sector of many nations automatic crop and soil surveys can serve as useful tools at many different levels. The following users could benefit greatly from their application:

1. The Agricultural Producer. Today's experienced and highly skilled agricultural producer uses a great quantity of information in arriving at resource management decisions. If information from automatic crop surveys were available to him in real time, there are many benefits he could derive from this service. Early detection and warning of crops under stress caused by drought, insects, weeds, and diseases could become an invaluable aid in management. Early information about world crop conditions could have an important bearing on planned cropping patterns. Characterization of forage cover on rangelands by remote sensing could bring a new dimension into range management methods.

2. Government Agencies. Any new system which can add efficiency and economy to an important function of a government agency should be seriously considered. The Soil Conservation Service, the Economic Research Service, and the Statistical Reporting Service, to mention only three, are agencies which collect, analyze, and classify large quantities of agricultural information. Automatic agricultural surveys offer these agencies the possibility of more timely and potentially more accurate survey information.

3. Industry. The stockpiling and movement of agricultural chemicals to key distribution points at the appropriate time means success or failure to industry. Automatic surveys of crop conditions could alert industry to the specific needs for agricultural chemicals in a region. Early reporting of regional crop conditions and yield estimates could help to assure adequate harvesting, storage, and transportation facilities at the time and place of greatest need.

4. International Agricultural Development Agencies. There are many private organizations and foundations, as well as government agencies, involved in international agricultural development programs. Some of these operate only in a very limited area. Others have rather sizeable operations and are involved in resource development planning at regional and national levels. The latter group could benefit greatly from automatic surveys of the soils and vegetation of a region. Basic to any scheme of agricultural development is an inventory of disposable resources. Remote sensing and automatic data processing may save much time and energy in characterizing the natural resources of an area hitherto unexplored or undeveloped.

5. The Research Scientist. The agricultural economist, the economic geographer, the soil scientist, and the land use planner may all come to depend upon remote sensing and automatic data processing methods to collect certain types of agricultural information for research purposes. These techniques should be adapted readily to following the changing land use patterns with time. Information about changing cropping patterns, marketing trends, dates of various farming operations is of interest to the farm management specialist.

Research results to date indicate that much new information and understanding of soils properties and plant growth characteristics are to be gained through the use of remote sensors.

Summary and Conclusions

The future appears to hold great promise for remote sensing and automatic data processing. If the capabilities of characterizing soil and crop conditions by automatic means and of getting such information to the user in real time can be developed, we will enter a new era in resource utilization and management. Researchers at the Laboratory for Agricultural Remote Sensing at Purdue University are working to accomplish these capabilities. The task is not an easy one. Difficult problems still to be solved and techniques to be improved fall into three categories.

1. Agricultural research. Better and more efficient means of collecting ground truth are essential. Variations in spectral patterns caused by stage of crop maturity, varietal differences, moisture conditions, cloud cover, sun angle, soil temperature, and other parameters must be more thoroughly investigated.

2. Measurements. The need for more adequate and flexible spectrometers designed for field use and for air and space platforms is critical. In addition to instrument development, much work is needed on problems of instrument calibration and studies of radiation phenomena.

3. Data processing. If automatic agricultural surveys are to have any success, data processing techniques must be able to handle vast quantities of information and to solve complex pattern recognition problems.

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