NASA TECHNICAL MEMORANDUM

NASA TM X -64803

REMOTE SENSING IN AGRICULTURE

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February 12, 1974

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

(NASA-TM-X-64803) REMOTE SENSING IN AGRICULTURE (NASA) 30 p HC $4.50 CSCL 08F

N74-18040

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G3/13 31692

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REMOTE SENSING IN AGRICULTURE

INTRODUCTION

Remote sensing is a term applied to the process of gathering information about an object from a distance and with no physical contact with the object. Man has used remote sensing since ancient times when he walked to the top of a hill or climbed a tree to obtain, or sense, information about his surroundings. A large step forward occurred about 100 years ago with the inventions of photography and balloons. Man could then obtain and record information about the features of the terrain from a vertical position by the use of photography. With the development of the airplane, aerial photography became more practical. Most of the early uses were by the military, but soon after World War I many civilian applications began. The use of aerial photography has continued to spread into newer areas, and its uses are now widespread. Cameras carried into space by satellites provided photographic coverage of the earth. The Earth Resources Technology Satellite (ERTS) provides photo-like images on a regularly recurring schedule.

Remote sensing includes not only photography but also radar, infrared scanners, television, passive microwave receivers, and other sensors. Aerial photography remains a very important remote sensing method, and this report will be confined primarily to aerial and satellite photography and photo-like images from the scanner on ERTS-1. ERTS-1 imagery is available for a nomial cost, and a considerable amount of aerial photography is available. Additional aerial photography can be obtained more easily than data from other types of remote sensors. Photographic images can be evaluated by human interpreters with a limited amount of equipment such as magnifiers, stereoscopes, and light tables. The images can be evaluated by automatic data-processing techniques, which are used in some of the references in this report.

Much valuable information can be obtained from photographs and images obtained in the visible and near infrared part of the electromagnetic spectrum (0.38- to 0.78-μm wavelengths). Images obtained may be black-and-white panchromatic, black-and-white infrared, normal color, or color-infrared. One of the most useful types of photography for vegetation studies is color-infrared photography. In color-infrared photography, the film used is a three-emulsion layer film sensitive to the visible and near infrared portion of the electromagnetic spectrum. The layers of the film are sensitized so that the reflection in the green part of the spectrum forms the blue record, the reflectance in the red part of the spectrum forms the green record, and the reflectance in the near infrared part of the spectrum forms the red record. Healthy vegetation reflects highly in the near infrared and will appear red on color-infrared photography. In this report, the term "agriculture" is applied to cultivated crops, irrigated and improved pastures, livestock operations, forestry, and range management. Some of the earliest uses of remote sensing were in agriculture, and the uses of remote sensing in agriculture continue to expand as new sensors and methods are developed.

It is not the intent of this report to show all the uses of remote sensing but instead to illustrate what can be done and is being done in a few selected areas. Table 1 is a matrix which shows some of the uses of remote sensing in agriculture and the references which give additional information on the application of remote sensing in these areas. There are many excellent articles in the literature, and all of them could not be included here. No attempt has been made to provide an extensive bibliography. An extensive bibliography has been compiled by Krumpe [1]. Murtha [2] has compiled a bibliography on forest stand damage.

A number of books have been written on remote sensing, photogrammetry, and photo interpretation. Among these are References 3 through 6. A book has been published by the National Academy of Sciences [7] which describes the various sensors used in remote sensing in agriculture and in identifying many uses and potential uses of remote sensing. Many practical applications are included.

A number of symposia and conferences on remote sensing are held. Many of the papers presented are related to agriculture, forestry, and range and provide information on the state of the art in remote sensing. The proceedings are usually published and are available at a nominal cost. Some of these continuing meetings are the International Symposium on Remote Sensing of Environment, Willow Run Laboratories, Environmental Research Institute of Michigan, Ann Arbor, Michigan; the Annual Earth Resources Program Review, Johnson Space Center, NASA, Houston, Texas; and the Symposium on Significant Results Obtained from the Earth Resources Technology Satellite, Goddard Space Flight Center, NASA, Greenbelt, Maryland.

TABLE 1. MATRIX OF USES OF REMOTE SENSING

	ALDRICH (1971)	ALDRICH & GREENTREE (1972)	ALLEN (1972)	A. S. P. MANUAL OF PHOTOGRAMMETRY (1966)	A.S.P. MANUAL OF COLOR AERIAL PHOTO (1968)	AVERY (1968)	AVERY (1969)	BLILIE (1972)	CARNEGGIE & DeGLORIA (1973)	CIESLA ET AL (1967)	CIESLA ET AL (1971)	CLIFTON (1972)
AGRICULTURE												
CROP ACREAGE DETERMINATION				X	X	X						
CROP TYPE DETERMINATION				X	X	X						
ESTIMATION OF CROP YIELD												
PLANT STRESS			X		X	X		X				X
FORESTRY												
FOREST TYPE DETERMINATION	X	X		X	X	X	X					
FOREST AREA DETERMINATION	X	X		X	X	X	X					
TIMBER VOLUME ESTIMATION	X					X	X					
INSECT AND DISEASE DETECTION					X	X				X	X	
FOREST FIRES									X			
RANGE												
RANGE CONDITIONS & INVENTORY					X				X			
LIVESTOCK INVENTORY					X							

	COLWELL (1962)	COLWELL (1970)	COLWELL (1973)	DETHIER ET AL (1973)	DRAEGER & BENSON (1972)	DRISCOLL (1970)	GATES (1970)	HALL (1973)	HELLER & BEGA (1973)	JOHANNSEN ET AL (1972)	JOHNSON & COLEMAN (1973)	JOHNSON (1966)
AGRICULTURE												
CROP ACREAGE DETERMINATION	X	X			X							
CROP TYPE DETERMINATION	X	X			X		X				X	
ESTIMATION OF CROP YIELD	X	X										
PLANT STRESS	X	X					X			X		
FORESTRY												
FOREST TYPE DETERMINATION		X		X		X	X					X
FOREST AREA DETERMINATION		X										X
TIMBER VOLUME ESTIMATION		X										X
INSECT AND DISEASE DETECTION		X					X	X	X			
FOREST FIRES		X	X									
RANGE												
RANGE CONDITIONS & INVENTORY		X				X						
LIVESTOCK INVENTORY		X										

	KLIEN (1973)	MAC DONALD ET AL (1972)	NALEPKA ET AL (1972)	NATIONAL ACADEMY OF SCIENCES (1970)	PEARSON & MILLER (1972)	PHILLIPS ET AL (1972)	SEEVERS & DREW (1973)	SPURR (1960)	TUELLER & LORAIN (1973)	WEAR (1972)	WILLIAMS ET AL (1973)	VOGT & WENDEROTH (1971)
AGRICULTURE												
CROP ACREAGE DETERMINATION				X				X				
CROP TYPE DETERMINATION				X				X			X	X
ESTIMATION OF CROP YIELD				X								
PLANT STRESS		X	X	X		X						
FORESTRY												
FOREST TYPE DETERMINATION				X				X				X
FOREST AREA DETERMINATION				X				X				
TIMBER VOLUME ESTIMATION				X				X				
INSECT AND DISEASE DETECTION	X			X				X		X		
FOREST FIRES				X			X	X	X			
RANGE												
RANGE CONDITIONS & INVENTORY				X	X		X	X	X			X
LIVESTOCK INVENTORY				X								

AGRICULTURE

Remote sensing is presently used in many different ways in agriculture. The potential uses are far greater than the current uses. Present and future uses include crop identification, crop acreage determination, crop yield prediction, and plant stress detection. A number of books and publications are devoted to remote sensing in the field of agriculture. Reference 7 is a book largely concerning cultivated agriculture. Chapter 10 in Reference 6 is primarily on the agricultural uses of aerial photographs.

In this section, the term agriculture is used to refer to cultivated crops and improved pasture as distinguished from forestry and range, which are covered in later sections.

Crop Acreage Estimation

One of the earliest uses of remote sensing, and still an important one, is the estimation of acreage planted to various crops. A vertical aerial photograph on flat terrain can be used as a map. Even though photographs are seldom truly vertical and the terrain is seldom flat, the photographs can still be used to accurately determine the acreage of agricultural fields (methods for determining areas are explained in the section on forestry). The Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture has made black-and-white panchromatic aerial photographs of most of the agricultural areas of the United States. Figure 1 is a typical ASCS aerial photograph of farmland in the southeastern United States. These photographs are used to determine the acreage planted to certain crops. They are available at a nominal cost and are useful for a number of other purposes.

For larger areas, space photographs and imagery can be used to determine the areas in cultivated agriculture and those planted in certain crops.

Crop Type Determination

The identification of crop types is closely related to the determination of acreage. It is necessary to be able to delineate the crop type in order to determine the area in each crop. To accurately identify a crop implies that all the fields of a particular crop must be identified; therefore, it must be accurately delineated for identification. To identify crop types, the imagery must be obtained when the crop is in an optimum phenological stage. In the early stages of growth, many field crops have a similar appearance on photographs, and during or after harvest many crops appear the same. The optimum conditions usually occur during the peak of the growing season.

A system for identifying crop types that has proved helpful to the interpreter has been developed. A brief summary of the system follows. For more details and examples, the reader is referred to Reference 8.

The agricultural crops grown in the area are classified into categories. The following categories are useful in most agricultural areas: (1) orchards, (2) vine and bush crops, (3) row crops, (4) continuous cover crops, (5) irrigated pasture crops, and (6) fallow ground. A list of all crops grown in the area is compiled. A key is prepared from a preliminary study of aerial photographs that show representative samples of each crop type.

A method of crop identification using ERTS-1 imagery in conjunction with a crop calendar is being developed by Johnson and Coleman [9]. The sequential images obtained from ERTS-1 are used to follow crop rotation in the Imperial Valley of California. Four distinctive colors were noted on the imagery — red, purple, lavender or brown, and white. The red indicates growing crops, and the white indicates bare, dry fields. The other colors indicate a transition from fallow fields to growing crops. The detection of these four colors provides a method to follow the crop cycle from fallow, to plowed, to irrigated seed, to growing crops, to harvest. The crop calendar provides the information as to what stages of growth the various crops of the area are in. By comparing the two, the type crops and the areas in each crop can be determined. When a new crop is introduced, its presence is detected since it does not fit the pattern. An Apollo image of the Imperial Valley is shown in Figure 2.

Another example of the use of ERTS-1 imagery for crop identification is for the identification of winter wheat in Kansas [10]. Knowledge of local environmental conditions and the crop cycle was used in conjunction with the ERTS-1 imagery to identify fields of winter wheat.

An investigation regarding the potential usefulness of ERTS-1 imagery for agricultural resource evaluation in San Joaquin County, California, is being conducted by Draeger and Benson [11]. The imagery has been successfully used to identify and delineate safflower fields. Preliminary results of this investigation indicate a great potential for use of these data on a local field-by-field inventory, as well as regional land classification.

Estimation of Crop Yield

An estimate of crop yields can be determined photogrammetrically by the use of the yield-per-unit area and the total area. In some cases the yield can be determined with little or no ground checking, while in other cases ground checking is required. Ordinarily, ground checking is required, but an example of where the yield can be determined without ground checking is the determining of the yield of vineyards in the San Joaquin Valley of California. In this case aerial photographs of the vineya ds are obtained. In vineyards which are devoted to raisin production, the grapes are harvested and placed on trays to dry. Usually 9 to 11 kg (20 to 25 lb) of grapes are placed on each tray. The number of trays can be counted on the aerial photograph and the production of the vineyard determined. The description of the method and the specifications for the photography required are given by Colwell [12].

When the crop yield is uniform throughout the field, the yield can be determined by multiplying the yield-per-unit area by the total area. When the yield is not uniform, the computations become more complicated. In this case, it is necessary to delineate each significant vigor class and determine the yield of each class. The summation of each vigor class will give the total estimate of the yield.

Methods for obtaining yield estimates when the crop is not accessible, or when estimates must be made before the crop matures, are explained by Colwell [8].

Plant Stress

Healthy green vegetation reflects highly in the near infrared portion of the electromagnetic spectrum. This property can be used to determine the vigor of plants. When the plant begins to lose vigor, the reflectance in the near infrared decreases. Figure 3 is a color-infrared photograph illustrating loss of vigor in plants. This often allows plant stress to be detected by infrared photography before it is visible to the human eye or on normal color photography. A detailed explanation is given by Gates [13]. A number of examples illustrating this use in detecting plant disease are given by Colwell [8]. These include diseased wheat, oats, potatoes, and stone fruit trees.

One of the most extensive and important uses of remote sensing for plant disease detection was during the recent corn blight. Remote sensing was used to detect the development and spread of the corn blight across the corn-growing region, to assess the extent and severity of the blight, and to assess the impact of the blight on yield. Remote sensing was successfully used to monitor these conditions.

This experiment, known as The 1971 Corn Blight Watch Experiment, is described in a series of seven papers presented at the Fourth Annual Earth

Resources Program Review held at the Johnson Space Center, Houston, Texas [14–20]. The results are described by MacDonald et al. [21].

Multispectral photography is useful for determining stress in agricultural crops. Images are obtained simultaneously in two or more parts of the electromagnetic spectrum. A common method for obtaining multispectral photography is to use a camera having four lenses to simultaneously obtain images in the blue, green, red, and near infrared bands of the spectrum. The four images can be projected simultaneously onto a viewing screen. A variety of images can be created by inserting appropriate filters in the individual light paths. Images can be obtained similar to black-and-white panchromatic, black-and-white infrared, normal color, and color infrared. In addition, false color images can be created that often enhance detail and provide information not otherwise available. Multispectral photography has been used by Yost and Wenderoth [22] to study agricultural crops and forestry.

An active program is in progress at the Marshall Space Flight Center using multispectral photography for studying plant stress in cotton, peanuts, and tomatoes. A useful false color image for studying stress in tomatoes and other truck crops was created by using the red and near infrared bands. The red band is projected through a red filter, and the infrared band is projected through a green filter. This is illustrated in Figure 4, which shows fields infected with nematodes and/or improper soil pH. The results are explained in Table 2.

FORESTRY

Some of the earliest uses of remote sensing were in the field of forestry. Forest photo-interpretation was first used by an unknown German forester in 1887 who attempted to obtain a forest-type map by photographing the forest from a balloon.

From this beginning, the use of remote sensing (primarily aerial photography) has been refined to the point that much useful information is now available to the forester to assist him in making management decisions. Among the uses of remotely sensed data are the determination of areas, types, timber volume, disease and insect damage assessment, and forest fire detection and damage assessment.

A number of books are devoted to the use of remote sensing in forestry. Among these are References 5 and 6 and Chapter 4 in Reference 8.

TABLE 2. EXPLANATION OF EFFECTS SHOWN IN FIGURE 4.

Field No.	Crop	Treatment
1 and 2	Tomatoes	Broadcast-treated for nematodes
3	Tomatoes	Nemagon granules in fertilizer
4A	Tomatoes	No nematode treatment
4B	Tomatoes	Broadcast-treated for nematodes
5	Tomatoes	Nemagon granules in fertilizer
6	Tomatoes	Broadcast-treated for nematodes
7	Okra	Broadcast-treated for nematodes except upper left corner
8	Pole lima beans	Broadcast-treated for nematodes
9	Early pole beans overgrown with weeds	Broadcast-treated for nematodes

Forest Type Determination

Remote sensing has been used for forest type determination since the beginning of aerial photography. An example of early attempts to map types was previously given. In some cases, where the forest types are simple and clearly defined, the forest type can be delineated easily on the photographs. Where the forests are more complex, more sophisticated methods must be used.

The infrared part of the electromagnetic spectrum provides much useful information in separating the different forest types. During the seasons when the hardwoods are in full foliage, infrared photography provides a means of separating the hardwoods from the conifers. The hardwoods reflect more radiation in the infrared part of the spectrum than do the conifers. Thus, the hardwoods will appear lighter on black-and-white prints. References 5, 6, and 23 explain this method in detail and include a number of examples.

Most of the type classification in forestry has been done using photo scales of 1:15 800 to 1:30 000. Photography and imagery of smaller scales can be used successfully. Hardwood and coniferous forests can be separated on ERTS imagery. The sequential imagery from ERTS is useful for this purpose. Images obtained during the summer when hardwoods are in full foliage can be compared with images obtained during the winter. The difference in forested areas can be readily seen (Fig. 5). Dethier et al. [24] use this method, called phenology or the brown wave green wave, to study vegetation using ERTS-1 imagery. Aldrich and Greentree [25] used photography with a scale of 1:420 000 to separate forest from nonforest lands using color-infrared photography. Broad forest types can be classified on small-scale photography and forest lands.

Identification of individual tree species is usually possible only on large-scale photography. Driscoll [26] successfully identified shrub-type vegetation on large-scale photography, and the same methods would apply to the identification of forest trees.

Multispectral photography is useful for identifying various types of forest. (See the section on plant stress for a description of multispectral photography.) It has been used by Yost and Wenderoth [22] to study agricultural crops and forests. Different species of trees were identified using photography having a scale of 1:38 000.

Multispectral photography obtained at 3660-m (12 000-ft) and 18 300-m (60 000-ft) altitude, high-altitude color-infrared photography obtained at 18 300 m, and ERTS-1 imagery are being used at the Marshall Space Flight Center to study the forests of the Tennessee Valley. Human interpreters and also automatic processing methods are used to identify forest cover types.

Forest Area Determination

Aerial photographs are useful for determining areas. After the forest types have been delineated on a photograph or map, the areas these types occupy can then be determined. If the photographs are very nearly vertical and the terrain is level or slightly rolling, the areas can be determined directly from the photographs. For more accurate measurements, maps may be constructed from the photographs [5].

Areas may be obtained by using a planimeter, dot grids, or by carefully cutting around the area with a sharp instrument and weighing the piece removed. This weight is then compared with the weight of a known area of the same material. These methods are explained by Spurr [5] and Avery [6].

Timber Volume Estimation

The primary uses of aerial photography in timber volume estimation are for type classification and area determination, although timber volumes can be estimated from photographs. In most timber cruises, the area can be determined more accurately by using aerial photographs (or maps made from aerial photographs) and the volume determined more accurately from ground cruises. Since the volume of timber in a tract is determined by multiplying the volume per area as determined by sample plots by the total area, it is important that both the area and volume be accurately determined. The volume of the sample plots is usually more accurately determined by a ground cruise, while the area is more accurately determined by aerial photography. This is referred to as a photo-controlled ground cruise. Spurr [5] and Avery [6] describe methods of estimating the volume of timber from aerial photographs. Tree height, crown diameter, and crown closure are used to estimate the volume. This is referred to as a pure photo cruise. Although it is not as accurate, the results of a pure photo cruise are often satisfactory if only the total gross volume is required. Johnson [27] describes the various methods of timber volume estimates using aerial photographs.

For estimating timber volumes over large areas, photography obtained from space is useful. Aldrich [28] uses color-infrared photographs from the Apollo 9 flight and multistage sampling to obtain timber inventories in the Mississippi Valley and Georgia. The photograph of the Mississippi Valley is shown in Figure 6. Results of this study were conflicting with a reduction in sampling error of 58 percent in the Mississippi Valley but with no such reduction in Georgia. The study did demonstrate that space photography can promote survey efficiency.

Insect and Disease Detection

Insects and diseases are the most destructive forces in the nation's forests. Annually they destroy far more timber than is destroyed by forest fires. Remote sensing can be used to detect and locate stress in trees caused by insects and diseases. Normal color and color-infrared photographs are useful in studying stress in forest trees. Often a disease in a plant can be detected on color-infrared photographs before it is visible on normal color photographs or to the human eye. This is because healthy vegetation reflects more strongly in the infrared part of the spectrum than dead or dying vegetation. While this is useful in detecting plant disease in agriculture, it has had limited success in forestry.

Aerial photography has been used to detect a number of diseases in trees. Heller and Bega [29] summarize the methods used and the results of a number of diseases including air-pollution injury, ash dieback, Dutch elm disease, oak wilt, dwarf mistletoe, Fomes annosus, and others. Aerial photography has been used by Wear [30] to determine signatures of Poria weirii in Douglas-fir and hemlock stands in Oregon. There is a good possibility that the method could be used to detect characteristic signatures of root rot diseases throughout the United States.

Insect-infested forest stands can be detected by aerial photography and, if the infested areas are sufficiently large, by ERTS imagery.

Aerial photography has been used by Ciesla, Bell and Curlin [31] to estimate the level of infestation of the Southern pine beetle in Eastern Tennessee.

Color aerial photographs obtained with a 35-mm camera were used to detect beetle-killed lodgepole pine in the Intermountain West [32]. This study shows that inexpensive methods can produce effective results in the detection of insect damage in forests.

In the Sierra Nevada mountains of California, an investigation is being conducted to determine if ERTS-1 imagery can be used to detect damage by the mountain pine beetle in lodgepole pine [33]. Preliminary results indicate that the insect infestations can be successfully detected using ERTS-1 imagery and U-2 underflights; however, there is still much work to be accomplished before it can be definitely determined that insect damage can be detected from orbit.

Aerial photographs were used to monitor the effectiveness of sprays on the forest tent caterpillar in southern Alabama hardwoods. The photographs provided an effective method of determining the amount of foliage saved by comparing the treated plots with untreated plots [34].

Multispectral photography has been used at the Marshall Space Flight Center to determine infestations of the southern pine beetle [35]. Medium-altitude [3660-m (12 000-ft)] aerial photography was used to locate pine stands that were infested. The study is being expanded to include high-altitude [18 300-m (60 000-ft)] color-infrared photography and ERTS imagery.

Forest Fires

The use of aerial photographs to supplement aerial observers in forest fire protection and actual supression activities is in general use [5]. For example, aerial photographs of a fire can be taken, developed in the plane, and dropped to the fire-fighting crews on the ground. This method provides more information on the location of the fire lines than can be obtained by ground reconnaissance. Forest fires can be detected from orbit. Several photographs from the Gemini and Apollo programs clearly show smoke plumes from forest fires throughout the world. Forest fires are also detectable on ERTS-1 imagery. An area in Alabama being burned during site preparation for replanting shows clearly in ERTS-1 imagery, as illustrated in Figure 7. These photographs and images have limited usefulness in actual fire suppression because of the time lag in getting the information from the sensors in orbit to the users in the field.

High-altitude and satellite imagery is very useful for accurately determining the burned area and assessing the damage caused by the fire. High-altitude photography has been used by Seevers and Drew [36] to assess the damage caused by a range fire in Nebraska. The same methods could be used to assess forest fire damage. Determining the actual area burned has always been a problem, particularly in mountainous areas. Often the fire will jump an area and leave an unburned stand completely encircled by a burned area. Those stands are often missed by ground observers, causing an error in assessing the damage, but they are apparent in aerial and satellite photographs and images.

An important use of remote sensing is in determining fire hazard buildup, in forests and on the range. Colwell [37] used high-altitude photographs and ERTS-1 imagery to assess fire hazards in California. The potential flash-fire hazard caused by an abundant growth of wild Spanish oats in the rangelands was assessed, as was the fire hazard caused by frost-killed eucalyptus trees. Both the grasses and eucalyptus trees are scattered widely throughout the state. ERTS imagery was useful in determining where a closer survey should be made using aircraft photography. Colwell concluded that the use of ERTS-type imagery, when used with limited amounts of aerial photography and direct on-site observations, can greatly facilitate the making of fire hazard appraisals of this type.

RANGE

Nearly one-half of the land area of the United States is devoted to rangeland. West of the 100-degree line of latitude, much of the land is not suitable for cultivated crop production but is used for rangeland. These rangelands provide forage for domestic and wild grazing animals. Precipitation is usually the limiting factor in forage production, and since the precipitation is highly variable, in quantity and timing, the forage production also varies. If accurate inventories of the quantity and quality of forage are available, the carrying capacity of the range can be increased by more intensive management. Because of the extensive and varied nature of the rangelands, remote sensing appears to be the most effective method for obtaining information on range conditions.

A common method of predicting range conditions is to clip a portion of the herbage at a number of sample plots on the range and analyze it for quantity and quality. The information is used to predict the range conditions and determine carrying capacity. Many of these rangelands are large and relatively inaccessible, which prevents a thorough inventory and also limits the frequency of the surveys. For efficient management of the rangelands, frequent evaluations of the resources available are needed. Conventional aerial photographs and images and photographs obtained through the use of satellites can provide valuable information needed to determine the range conditions and to predict the carrying capacity. The uses of color-infrared photography and infrared scanning are two of the most promising methods for sensing rangeland conditions. Small-scale photographs and images from high-altitude aircraft or satellites are useful for determining conditions of large areas, while large-scale photographs obtained at low altitudes are usually better for species identification and livestock inventories.

Range Conditions and Inventory

Data obtained from ERTS images have been used by Carneggie and DeGloria [38] to monitor the forage resources in California. The ERTS imagery provides information from which gross vegetation maps showing forest land, rangeland, and meadowland can be obtained. The resolution does not permit the detailed mapping needed for evaluating management problems or making management decisions, but vegetation-soil maps derived from high-altitude aircraft data generally are detailed enough to be useful to local or district range managers. The most important use of the ERTS images is for monitoring changes in the range conditions. Recently germinated annual grasslands could be distinguished from areas where germination had not occurred, and the spread of germination could be determined from images obtained on subsequent passes. It should be possible to predict the time when grazing could begin and when it should be terminated. Analysis of ERTS imagery should reveal the location and extent of ranges affected by favorable or unfavorable climatic conditions. The imagery can provide information to determine the location and extent of potential fire hazards caused by early drying of the forage or the presence of abundant forage. In general, the ERTS data do not provide sufficient resolution to determine the condition of perennial rangelands in California. Carneggie and DeGloria summarize the results of the study as follows:

> In summary, the data provided by ERTS and high altitude aircraft enables range managers to monitor the development of range lands throughout California. By providing timely and accurate data regarding the availability, distribution and condition of forage, the ERTS satellite can contribute greatly to more effective utilization and management of California's rangelands. To the extent that predictions of forage production can be made from ERTS data (in conjunction with ground and climatic data), range managers, feedlot operators, and suppliers of feed supplements can more efficiently predict the time, direction and numbers of animals moving to and from rangelands, and determine the need for feed supplements which will sustain the animals until they are converted to consumable meat products.

Small-scale (1:120 000) color and color infrared photography obtained by high-altitude aircraft has been used by Draeger [39] to monitor the annual grasslands of California. Information regarding expected yields can be used to provide more efficient utilization of the range. Predictions can be made as to whether the grasslands are overutilized because of below-average growth or underutilized because of insufficient grazing animals to fully utilize the forage.

Tueller and Lorain [40] have used ERTS imagery to inventory annual grassland (cheatgrass) in Nevada and plan to expand the program to include irrigated fields, pastures, meadows, wildfire scars, water bodies, playas, land forms, and other resource features. They feel that these total inventories are not economically feasible by any other known method.

ERTS imagery has been used by Seevers and Drew [36] for managing range resources in the Sand Hills region of Nebraska. The imagery has been used to estimate forage density and forage utilization, soil mapping, and detection of areas burned by range fires. High-altitude color-infrared imagery was used to detect the fire pattern. Improved range management can be directly related to the economy of the Sand Hills region, and it is the opinion of Seevers and Drew that ERTS-1 imagery will be significant in increasing the productivity of range operations.

Range managers need information on the species types composing rangelands and the quantities of forage available. The scale of ERTS imagery is too small to fulfill most of these requirements. However, large-scale aerial photography obtained at low altitude is useful for species identification. Driscoll [26] used large-scale (1:600 to 1:1500) color and color-infrared photographs to identify individual species in shrub-type vegetation, resulting in a considerable cost savings.

A study to estimate the biomass of the Shortgrass Prairie is being conducted by Pearson and Miller [41] using multispectral data. A definite relationship has been demonstrated between the amount of green vegetation present on a plot and the spectroradiance of the plot. This method requires the use of multispectral scanner data which are not as readily available as aerial photography, but it is a powerful method of obtaining quantitive data on the vegetation present and could be used to determine forage available on the range.

Livestock Inventory

The use of aircraft photography for livestock inventory is still in the research stage. The results are encouraging but have not resulted in significant changes in the methods of inventory. A study was conducted by Vidya Division of the Itek Corporation in California and is described by Colwell [8]. Interpretation of the panoramic photography indicated that both cattle and sheep could be detected at scales as small as 1:20 000. However, age and sex could not be determined, and the report stated that some cattle had probably been overlooked.

In studies conducted at the University of California's Davis Campus, Colwell reports that livestock inventories are feasible using photos with a scale of 1:6000. Spring is the best time for livestock inventories using photographs because at this time the animals are not as likely to seek shade, the animals contrast better with the grass, and trees are not in full leaf and are less likely to obscure the animals.

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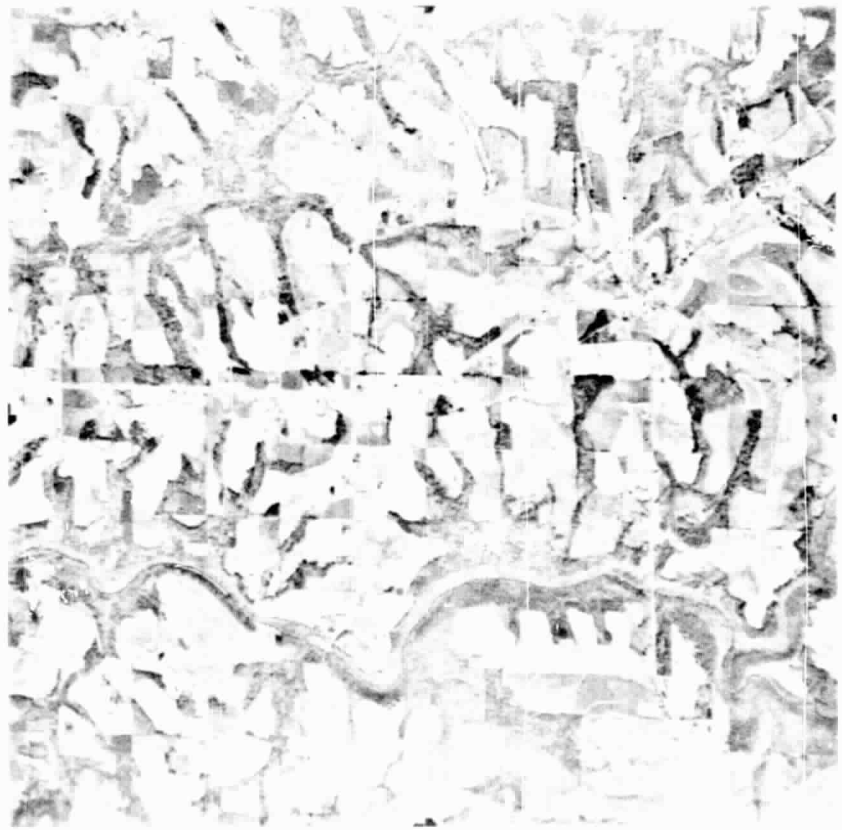

Figure 1. An ASCS panchromatic aerial photograph used for crop acreage determination in the southeastern United States

Figure 2. An Apollo 9 image of the Imperial Valley in California. Vigorously growing vegetation shows as bright red.

Figure 3. A color infrared photograph showing loss of vigor in plants.

Figure 4. False color image of agricultural crops showing effects of nematodes and low soil pH.

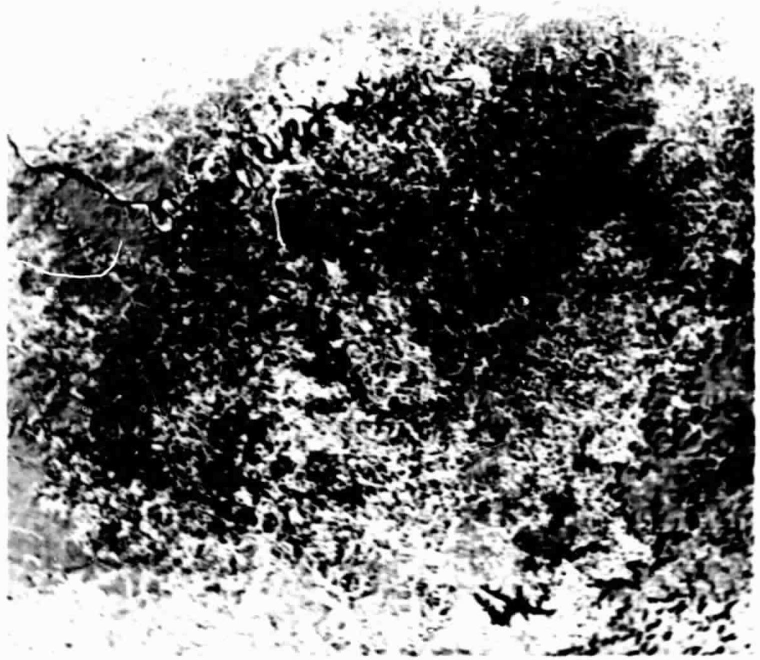

Figure 5. An ERTS-1 image of middle Tennessee in winter. The evergreen trees appear red.

Figure 6. An Apollo 9 photograph of the Mississippi Valley.

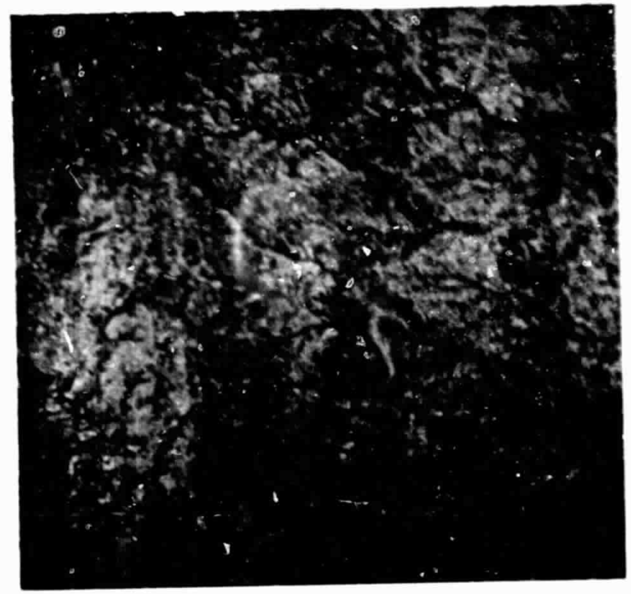

Figure 7. An ERTS-1 image of Alabama showing smoke plume from a forest fire.

APPROVAL

REMOTE SENSING IN AGRICULTURE

By Sanford W. Downs, Jr.

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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