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THE DESIGN AND IMPLEMENTATION OF A MULTIPLE INSTRUMENT FIELD EXPERIMENT TO RELATE THE PHYSICAL PROPERTIES OF CROPS AND SOILS TO THEIR MULTISPECTRAL REFLECTANCE

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Abstract

The design and implementation of an experiment covering three crop years for spring and winter wheat at three sites in the Great Plains region of the United States are described. The experiment involved the coordinated use of spectrometers mounted on mobile aerial towers, a helicopter-borne spectrometer, airborne multispectral scanners, and Landsat multispectral scanners.

Development and use of procedures for obtaining radiometrically calibrated spectral measurements has permitted valid comparisons to be made among data acquired at different dates and times, different sites, and by different sensors. The data sets acquired are comprehensive in terms of the number and kind of sensors, the number of sites and years included, the number of missions (8 to 12) for each year, and the amount of supporting agronomic and meteorological data acquired. The experimental design and the formulation of a coordinated data base provides opportunities for researchers to relate agronomic and meteorological data to the spectral data. A companion paper discusses the analysis and results of a portion of the data.

Introduction

Major advancements have been made in recent years in the capability to acquire, process, and interpret remotely sensed multispectral measurements of the energy reflected and emitted from crops, soils, and other earth surface features. As a result of experiments such as the Large Area Crop Inventory Experiment (LACIE) the technology is moving rapidly toward operational applications [1]. There is, however, a continuing need for quantitative studies of the multispectral characteristics of crops and soils if further advancements in the technology are to be made. In the past, many such studies were made in the laboratory because of a lack of instrumentation suitable for field studies. But, the applicability of such studies is generally limited. The development of sensor systems capable of collecting high quality spectral measurements under field conditions has made it possible to pursue investigations which would not have been possible a few years ago.

A major effort was initiated in the fall of 1974 by the National Aeronautics and Space Administration, Johnson Space Center (NASA/JSC) with the cooperation of the U.S. Dept. of Agriculture (USDA) to acquire fully annotated and calibrated multitemporal sets of spectral measurements and supporting agronomic and meteorological data [2]. The Purdue University, Laboratory for Applications of Remote Sensing (Purdue/LARS) was responsible for the technical design and coordination of the experiment.

Spectral, agronomic, and meteorological measurements were made at three LACIE test sites in Kansas, South Dakota, and North Dakota for three years. The remote sensing measurements include data acquired by truck-mounted spectrometers, a helicopter-borne spectrometer, airborne multispectral scanners, and the Landsat multispectral scanners. These data are supplemented by an extensive set of agronomic and meteorological data acquired during each mission.

The LACIE Field Measurements data form one of the most complete and best documented data sets acquired for agricultural remote sensing research [3]. Thus, they are well-suited to serve as a data base for research to (1) quantitatively determine the relationship of spectral to agronomic characteristics of crops, (2) define future sensor systems, and (3) develop advanced data analysis techniques. The data base is unique in its comprehensiveness of sensors and missions over the same sites throughout the growing season and the calibration of all multispectral data to a common standard.

Experimental Approach and Rationale

Spectral, agronomic, and meteorological measurements for the field measurements project were made at three LACIE test sites during the 1975, 1976 and 1977 crop years. The sites are in Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota (Figure 1). Finney and Williams Counties were chosen to represent winter and spring wheat growing areas, respectively. Both winter and spring wheat are grown in Hand County. Data were collected at the sites for three years to obtain a measure of the year to year variation in growing conditions and their influence on spectral response.

The primary sensors were truck-mounted spectrometers, a helicopter-borne spectrometer, an aircraft multispectral scanner, and Landsat-2 multispectral scanner. Each sensor system has unique capabilities for acquiring spectral data. The spectrometer systems produce the highest quality reflectance measurements, but provide only limited measurements of spatial variability. On the other hand, an aircraft scanner provides spatial sampling of the scene and can obtain data at multiple altitudes, but its spectral coverage is limited to a fixed set of wavelength bands. The helicopter and aircraft data acquisition systems have the advantage of flexible scheduling and, therefore, provide greater opportunity to obtain cloud-free data at critical crop growth stages than the Landsat system provides. Landsat provides wide area coverage, but is limited in spatial resolution and the placement and number of spectral bands.

Helicopter-spectrometer and aircraft scanner data were collected over commercial fields in a series of flightlines over the LACIE intensive test site in each county. Landsat data were acquired over the entire test site as well as surrounding areas. These data provide a measure of the natural variation in the temporal-spectral characteristics of wheat and surrounding cover types. The staging of data acquisition is summarized in Figure 2.

The truck-mounted spectrometers collected spectra of controlled experiemntal plots growing at agricultural research stations near the test sites at Garden City, Kansas, and Williston, North Dakota. These data, combined with the more detailed and quantitative measurements of crop and soil conditions which were made on the experiment stations, enable more complete understanding and interpretation of the spectra collected from commercial fields. Past experience has shown that there are generally too many interacting variables in commercial fields to determine exactly what is the cause of observed differences in spectral response. With data from plots where only two to four factors are varied under controlled conditions, it is possible to better determine and understand the energy-matter interactions occuring in crops.

The spectral measurements were supported by descriptions of the targets and their condition. These data include descriptive observations, counts, and measurements of the crop canopy including: maturity, plant height, biomass, leaf area index, percent soil cover, and grain yield. Also included are the measurement conditions such as sensor altitude and view angle, as well as measurements of the atmospheric and meteorological conditions. The data are supplemented by aerial photography and ground-level vertical and oblique photographs of the fields and test plots.

A data library of all spectral, agronomic, and meteorological data collected is maintained at Purdue/LARS where the data are processed in standard data formats and measurement units and are provided to NASA/JSC supported investigators and other interested researchers.

Test Site and Experiment Descriptions

The test sites were located in Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota. Each site consists of a LACIE intensive test site; and in Kansas and North Dakota, an agricultural research station. Three years of measurements were acquired at the Kansas and North Dakota sites and two years at the South Dakota site.

The test sites were chosen to include as wide a range of important wheat production areas as possible. In addition, the Finney and Williams County sites were selected because of their close proximity to agricultural research stations. Personnel from the USDA/Agriculture Stabilization and Conservation Service were available in each county to collect the required intensive test site ground truth data.

Intensive Test Sites

The intensive test sites are 5 x 6 miles in size. Three flight-lines, six-miles long are located across each site. The number of fields of major cover types for each site for 1975-76 are summarized in Table 1.

Finney County, Kansas

The test site is located in the High Plains Tableland physiographic area; 38° 10' N latitude and 100° 41' W longitude. The elevation of the site is 900 meters. It is overlaid by 3 to 10 meters of loess from the early Wisconsin age. The area has a distinct continental type of climate characterized by abundant sunshine and constant wind. Most of the precipitation falls during the early part of the year with a rapid decline in the probability of receiving adequate rainfall during July and August. Thus, the growth cycle of winter wheat is well-matched to the available moisture supply. Average annual precipitation for Finney County is 48.5 cm with 14.3 cm from March to May, 20.1 cm during June to August, 9.7 cm between September and November, and 4.4 cm from December to February.

The soils of the test site are in the Mollisol order, Ustoll sub-order, and Argiustolls great group. Mollisols are soils that have nearly black, friable, organic-rich surface horizons high in bases. Ustolls are formed in semi-arid regions and are dry for long periods, or have subsurface accumulations of carbonates. The major soil series in the area are Richfield and Ulysses which are deep, fertile, well-drained, nearly level to gently sloping, loamy soils of the upland that are well-suited to cultivation.

The major crops in Finney County are wheat and grain sorghum which account for about 60 and 20 percent, respectively, of the total cropland. The majority of wheat is produced following summer fallow practices, although an increasing amount is being irrigated. Winter wheat is seeded in September or early October, then is dormant from December to February. Green-up occurs in March, by mid-May the crop is fully headed, and harvest is typically completed during the first week of July.

Williams County, North Dakota

This test site is located at 48° 9' N latitude and 103° 25' W longitude. It is representative of the cool temperature semi-arid areas of the northern Great Plains where annual precipitation averages 33 to 38 cm. The site is located at an elevation of 650 meters and lies in the glaciated area with a drift mantle and an undulating to steep surface.

The soils in the site are of the Mollisol order, Boroll suborder with Williams and Williams-Zahl being the major associations present. Both occur on undulating to rolling landscapes and are well to excessively drained. Much of the surface drainage is to depressions. The soils were developed from calcareous, loam glacial till and are suitable for cropland and pasture. The soils of the Williams association are very productive.

The climate of the area is typically continental with long cold winters, short warm summers, large diurnal ranges in temperature, frequent strong winds, and limited, as well as uncertain and highly variable precipitation. Averages amounts of precipitatwon are 4.6, 15.5, 12.2, and 4.3 cm in the winter, spring, summer, and fall, respectively.

The major crop is wheat which occupies about 70 percent of the grain crop acreage. Both hard red and durum spring wheats are grown. Most of the wheat is grown on summer fallow land. The major cover types in the site are wheat, summer fallow, and pasture; limited acreages of rye, barley, alfalfa, and flax are also grown. The cropping calendar for the spring wheats begins in late April to early May with seedbed preparation. Planting is generally in mid-May, heading occurs in late June to mid-July, and harvest is in mid to late August.

Hand County, South Dakota

The test site is in the north-central Great Plains at latitude 44° 34' N and 99° 00'W. It is a transition area with the Corn Belt to the east, spring wheat producing areas to the north and the winter wheat producing areas to the south. The boundary between the subhumid lowland of eastern South Dakota and the more arid Great Plains area of central and western South Dakota passes through Hand County. The area is nearly level to gently undulating. The principal soils of the test site are Houdek and Bonila which are in the Mollisol order, Ustoll suborder. They are dark colored, permeable loams underlaid by slowly permeable glacial till.

Hand County has a continental climate. Winters are long and cold, and summers are warm. The average annual precipitation is 47 cm; typically 33-36 cm fall between April and September. The county is subject to frequent weather changes and air masses that pass through the area bring a wide variety of temperature and moisture conditions.

The principal crops of Hand County are winter and spring wheat, pasture and hay, corn, barley, and oats. Most wheat is grown following summer fallow.

Agriculture Experiment Stations

Agronomic experiments with wheat and other crops were available for study on the agriculture experiment stations at Garden City, Kansas, and Williston, North Dakota. The research farms are operated by Kansas State University and North Dakota State University, respectively. The advantages of using experimental plots on the stations were (1) considerable amounts of agronomic data could be readily obtained describing the treatments and their effects on the growth and development of the crop, and (2) sources of differences in spectral response could be more readily determined since only the factors of interest were varied, while other factors were held constant. The experiments were designed to provide a range of growing conditions which are typical of those found in the intensive test sites. Plots were 4 x 12 meters in size and were planted, grown, and harvested using conventional practices and equipment.

Each treatment had two replications to enable statistical analysis and interpretation of measurements. The treatments are described below and the experimental designs for the 1977 crop year for each location are shown in Figures 3 and 4.

Garden City, Kansas

The objective of the Small Grain Experiment was to determine if various small grains can be discriminated from each other based on their spectral reflectance. The experiment included four winter wheat varieties and one variety each of barley, rye, and triticale.

The principal objective of the Dryland/Irrigated Winter Wheat Experiments were to determine the relation of leaf area index and biomass to multispectral reflectance as a function of crop maturity stage and the effects of irrigation, nitrogen fertilization, and planting date on spectral response. The treatments were selected to give a range of leaf area indexes and biomass at any particular maturity stage or measurement time.

Williston, North Dakota

The objective of the Small Grain Experiment was the same as for the small grain experiment at Garden City. This trial included two varieties each of hard red spring wheat, durum wheat, oats, and barley.

The objective of the Spring Wheat Experiment was to quantify the effects on spectral response of the major variables affecting wheat growth, development, and yield. The factors and levels of each factor were (1) Soil Moisture: wheat and fallow in 1976, (2) Cultivar: standard height and semi-dwarf, (3) Planting Date: early and late, and (4) Nitrogen Fertilization: none and 34 kg/ha.

Sensor Descriptions

The characteristics of the primary sensors used to acquire spectral data over the intensive test sites and agriculture experiment stations are described in this section. The sensors used in the intensive test sites included: Landsat MSS, airborne multispectral scanner, helicopter-borne spectrometer, and tripod-mounted Landsat-band radiometers. The sensor systems acquiring spectral data on the agriculture experiment stations were the truck-mounted spectroradiometer and interferometer systems operated by Purdue/LARS and NASA/JSC, respectively. General descriptions of the sensor systems are discussed below and summarized in Tables 2 and 3.

Landsat Multispectral Scanner

Landsat-1 and -2 MSS data were acquired at 18 day intervals. The MSS data has four spectral bands from 0.5 to 1.1 μm. The sensor scans cross track swaths of 185 km. Computer compatible tape (CCT) data and imagery (both color and black and white) were requested for each cloud-free overpass of the intensive test sites.

Airborne Multispectral Scanner

During 1975 the 24-channel scanner operated by NASA/JSC was the primary scanner system; during 1976 and 1977 the 11-channel Modular Multiband Scanner (MMS) was used [4]. Nine-inch color and color infrared photography were obtained during the scanner flights to be used as reference data by analysts.

Helicopter-borne Field Spectrometer System (FSS)

The FSS is a filter wheel spectrometer instrument which is basically a duplicate of the S-191 sensor used in the Skylab EREP experiment [5]. It has been modified by NASA for mounting on a helicopter (Figure 5). The instrument produces data in 14-track digital format which are converted to CCTs for subsequent reformatting and analysis.

The spectral range of the spectrometer is 0.42-2.50 μm and 6.0-16.0 μm. The field of view is 22 degrees which gives a spot size of 24 meters from 60 meters altitude. The helicopter flies at 50-55 knots. The camera has a 76-mm focal length and 36 degree field of view, giving 40 meter square ground coverage.

Truck-mounted Spectrometer Systems

The Exotech Model 20C field spectrometer operated by Purdue/LARS acquires spectral data over the visible, reflective infrared and thermal infrared wavelength regions [6]. The instrument consists of two independently functioning units. The short wavelength unit senses radiation from 0.38 to 2.4 μm and the long wavelength unit senses radiation from 2.7 to 5.4 and 7.0 to 13.5 μm. The short wavelength unit is equipped with a transluscent diffusing plate which is used to monitor incident spectral irradiance. Each optical head has a reflective fore-optic system that permits remote selection of the field of view (3/4 or 15 degrees).

The instrument is mounted on a mobile aerial tower that operates with an instrumentation van containing the control electronics and data recorder for the system (Figure 6). The data produced by the instrument are recorded on an analog magnetic tape recorder and later converted into digital information by a laboratory analog-to-digital converter. Calibration sources designed for field use are used to calibrate the spectroradiometer on site. Calibrated spectral data and field observations are combined on digital magnetic tapes during the data reformatting process.

The Block wideband interferometer (Field Signature Acquisition System or FSAS) operated by NASA/JSC acquires spectral data over the visible and infrared portions of the spectrum [7]. The instrument scans the spectrum rapidly enough to account for environmental variables and is equipped with a self-contained computer system that yields spectral data from the interferograms produced by the instrument. The instrument control electronics and computer are mounted in an instrument van and the optical head of the instrument is mounted on a mobile aerial tower. The spectral data (wave number) produced by the instrument were processed by JSC to provide CCTs of spectral reflectance factor calibrated with respect to wavelength.

Landsat-Band Radiometers

Four-band radiometers with the same spectral bands as the Landsat MSS were used to acquire measurements in selected fields at the Finney County and Williams County test sites. These data are used to support canopy modeling studies.

Meteorological and Atmospheric Sensors

Standard meteorological instrumentation was used to obtain measurements of temperature, humidity, wind speed/direction, barometric pressure, and total irradiance. Solar radiometers were used to obtain measurements in six visible-infrared bands of optical depth during Landsat overpasses and during aircraft and helicopter missions.

Sensor Calibration and Correlation

A key objective of the LACIE Field Measurements Program was the acquisition of calibrated multispectral data. Calibrated data are required in order to: (1) facilitate comparisons of data from different sensors and (2) compare and relate spectral measurements made at one time and/or location to those made at other times and locations.

In order to have comparable data, scene reflectance was chosen as the measured property rather than scene radiance. Scene reflectance is a property of the scene, whereas scene radiance is also a property of the illumination. The fundamental property describing the directional reflectance distribution characteristics of a surface is the bidirectional reflectance distribution function; this property is difficult to measure, so more common use if made of the bidirectional reflectance factor.

Reflectance factor is defined as the ratio of the radiant flux reflected by a sample surface to that which would be reflected into the same reflected beam geometry by a perfectly diffuse (Lambertian) standard surface identically irradiated and viewed [8]. Since the principal component of the irradiance is direct solar irradiance and the measurement is made in a relatively small cone angle (15 to 20 degrees) the bidirectional reflectance factor is used to describe the measurement. One of the directions is specified by the solar zenith and azimuth angles; the other is specified by the zenith and azimuth viewing angles.

Since no perfectly reflecting diffuser is available, painted barium sulfate reference surfaces which are highly diffuse were used [10]. The spectral bidirectional reflectance factor of these surfaces was measured in the laboratory and field by processes which are traceable to the reflectance of pressed barium sulfate (Figure 7). A correction using the published reflectance of the pressed barium sulfate enables the computation of an approximation to the bidirectional reflectance factor.

Due to the presence of skylight, the measurement is not strictly bidirectional. The process of eliminating skylight by subtracting the spectral response of the shadowed scene and shadowed standard has merit in that it could remove the effects of the skylight. However, the additional measurements and calculations add uncertainty to each computed reflectance. This uncertainty is greater than the effect itself [9]. Furthermore, since the interest of the project was in producing data directly relatable to satellite data which includes the effects of the skylight, the single comparison method was used. Since the dominant effects are due to the directional nature of the irradiance, the term bidirectional reflectance factor has been chosen to describe the measurements.

Truck-mounted Spectrometer Systems

Temperature variations, vibration, dust, and other adverse factors associated with field measurements require that calibration be performed at the site. The procedures chosen reflect the availability of suitable standards and the principal that the calibration measurements are obtained under the same conditions as the target measurements.

The short wavelength unit was calibrated for spectral reflectance factor. A standard based on the highly reflecting properties of barium sulfate was used as a basis for the reflectance factor calibration. The standards were prepared according to procedures described by Shai and Schutt [10].

The painted barium sulfate field standard was used to fill the field of view of the instrument under nearly the same conditions as the measurement of plots. For the simplest calibration, the response to the standard, the response to the scene, the full dark response (automatically provided during each spectral scan), and the spectral reflectance properties of the standard are used to compute the bi-directional reflectance factor. Since it is inconvenient to make this direct comparison for each measurement, the solar port is frequently used to transfer the reflectance standard for the Purdue/LARS Exotech 20C system.

The calibration calculation consists of forming the ratio of the instrument response for the target to that for the reflectance standard and correcting for the known reflectance of the standard. This procedure produces a reflectance factor for the given sun angle and normal viewing of the target.

During the calibration observations the instrument was aimed straight down at the reflectance standard from a distance of 2.4 meters for the Exotech 20C system and one meter for the FSAS system. Care was taken to ensure that the standards were not shadowed and that the illumination conditions were as similar to the conditions of the observation of the subject as possible. Additionally, steps were taken to minimize the shadowing of skylight and reflective interactions between the instrument support and the reflectance standard. Calibration observations were performed at a frequency commensurate with the efficient operation of each instrument and the acquisition of meaningful data.

Wavelength calibration of the reflective wavelength unit was accomplished by irradiating the solar port with sources having known spectral lines [11]. The primary sources are the GE A100.H4T mercury vapor lamp and the helium Pluecker tube. A field wavelength calibrator based on the helium tube was chosen for use because it has at least one strong line in the range of each section of the circular variable filters.

Helicopter-borne Field Spectrometer System (FSS)

The helicopter-borne spectrometer was calibrated at the site using a 60 percent reflectance canvas panel and the measurements made by the truck-mounted spectrometer of the canvas panel. To calibrate data from the FSS the following data collection sequence was followed:

1. Measure the reflectance factor of the painted barium sulfate field standard with the laboratory spectroradiometer. This is accomplished by comparing the painted barium sulfate panel to pressed barium sulfate at the beginning of the season in the lab at LARS.

2. Measure the reflectance factor of the 20 x 40 foot canvas reflectance standard with the truck-mounted spectroradiometer. This is accomplished by comparing the canvas standard to the painted barium sulfate field standard at the helicopter calibration site three to five times during the season.

3. Measure the response of the helicopter/FSS to the canvas standard. The helicopter/FSS makes these measurements just prior to flying each flightline (Figure 5).

4. Collect data over the flightlines with FSS.

The data processing facility converts the FSS data to reflectance factor based on the measurements made of the barium sulfate standard and canvas panel. The calibration calculation consists of forming the ratio of the FSS response for the target to that of the canvas standard and correcting for the measured reflectance of the canvas standard. This procedure produces a reflectance factor for the given solar illumination angle and normal viewing of the subject.

The calibration procedure used in this project deals with limitations imposed by the size and location of the standard by calibrating the instrument at a low altitude (6 meters) and collecting data over the flightlines at 60 meters. This procedure assumes that atmospheric absorption and path radiance are negligible for a 60 meter path.

The absence of an onboard solar sensor integrated into the instrument makes it desirable that calibrations be performed as frequently as possible. Therefore, the reflectance panels were centrally located and procedures were followed which allowed calibration within 15 minutes of any data acquisition (beginning of each flightline of data collection).

Field calibration of the FSS with respect to emissive radiation was accomplished by recording spectral observations of a blackbody at a temperature below ambient and another blackbody at a temperature above ambient. The subsequent scans of subject scenes were converted to spectral radiance using linear interpolation.

Airborne Multispectral Scanner

The reflective airborne multispectral scanner data can be calibrated to reflectance using the five gray canvas panels located at the site and the spectral reflectance factor measurements collected by the truck-mounted spectrometers over the canvas panels. The nominal reflectances of the panels are 6, 12, 18, 30 and 60 percent.

The gray panel reflectance factor and multispectral scanner response data collected 500 meters above the panels can be related through linear regression. The regression equation can then be used to transform the low altitude airborne multispectral scanner data to absolute scene reflectance factor. The higher altitude multispectral scanner data can be calibrated to reflectance factor using agricultural fields which were common at both altitudes as calibration targets to define another regression equation. The error in the reflectance factor calibration increases, however, with each transfer.

The emissive multispectral scanner data was calibrated using two blackbodies kept at known temperatures. The calibration bodies are located within the scanner system and are viewed with each scan of the scene.

The three major sensor systems, the truck-mounted spectrometers, the helicopter-borne spectrometer, and the aircraft multispectral scanner were correlated using the spectral data collected by each system over common targets, i.e., five 20 x 40 foot gray canvas panels (Figure 8). The aircraft scanner collected data over the panels during each mission. The helicopter and truck spectrometer systems measured the reflectance of the four darker gray panels during correlation experiments performed during each crop year. The calibration measurements made of the brightest canvas calibration panel by the helicopter and truck spectrometer systems are also used in correlating the sensors.

All the spectrometers were brought together in 1977 for complete calibration and correlation. This included measurement of common targets and reflectance standards (Figure 9), comparison of data collection procedures, and evaluation of instrument performance.

Data Acquisition

The collection of multispectral remote sensing, agronomic, and meteorological data for the intensive test sites and agriculture experiment stations are described in this section.

Intensive Test Sites

This section discusses spectral data collection procedures and the measurements and observations of crop, soil, and meteorological parameters in the intensive test sites.

Spectral Data Collection

Airborne MSS, helicopter-borne FSS, and tripod-mounted radiometer data were collected within a four day mission "window" - Landsat day minus one to Landsat day plus two. Over-flights were repeated on a clear Landsat day even if good data were acquired the previous day.

(a) Helicopter Spectrometer

The data were obtained under stable atmospheric conditions with 10 percent or less cloud cover at solar elevation angles greater than 30 degrees. At the test site, six 6-mile long flightlines were flown by the helicopter in three sets of two lines. Flightlines were flown at an altitude of 60 meters, 50-55 knot ground speed, and in an east/west direction. Approximately 40-45 minutes of FSS data were obtained, requiring approximately one to two hours of helicopter flight time in the test site area. Reference panel calibration measurements were made from a six meter altitude immediately prior to flying each set of two flightlines. Correlation of spectra and fields was accomplished using simultaneously acquired 70 mm color photography.

A total incidence pyranometer was located at the helicopter calibration site to provide a strip chart record of the irradiance conditions on the day of data acquisition (usually beginning one hour before and ending one hour after the data acquisition period). These strip charts provide the data analyst with a visual record of the irradiance conditions at the site during helicopter and multispectral scanner data acquisition.

(b) Airborne Multispectral Scanner

The airborne scanner system acquired data over the intensive test sites, and agriculture experiment stations concurrently with the helicopter spectrometer. The intensive test sites were over-flown at 3,300 and 10,000 meter altitudes and the experiment stations and calibration panels at 500 meters. The two altitudes over the test site flightlines provide data with different spatial resolutions and different amounts of atmosphere between the scene and sensor. Cloud cover was required to be less than 30 percent and solar elevation greater than 30 degrees. Nine-inch color and color infrared photography were obtained simultaneously with the scanner data.

(c) Tripod-Mounted Radiometers

A Landsat band radiometer mounted on a two meter tripod was used to collect data from one to three fields in the Finney and Williams County test sites. The measurements were made at four times (sun angles) during the day. A painted barium sulfate field standard was measured between each measurement of the canopy. Spectral measurements included wheat reflectance, soil reflectance, ratio of diffuse to total irradiance, and leaf transmittance. Canopy description data included leaf area index, biomass, number of tillers and leaves, and photographs. The photographs included vertical and 45 degree view photos, plus plant profile photos. The data were acquired (when possible) at five maturity stages (seedling, tillering, jointing, flowering, and ripe) at several locations in typical fields.

Agronomic Data Collection

Agronomic measurements and observations were acquired describing the condition of each of the fields for which spectral data were collected. These data describe the condition of each field as fully as possible and are used to account for differences in the spectral measurements. The data were recorded on standard forms, keypunched, and transmitted to LARS for inclusion in the data bank.

Data describing the fields in the intensive test sites were collected by USDA/ASCS [12]. The following data were collected during a spring and fall inventory of all fields in the test sites: field number, acreage, crop species and variety, irrigation, fertilization, planting date, and other descriptive information.

Periodic observations coinciding with Landsat overpasses and aircraft/helicopter missions were made to describe the condition of fields. The following variables were observed: maturity stage, percent soil cover, plant height, surface moisture condition, evaluation of stand quality, quality relative to other fields in site, field operations, density of stand, weed infestation, growth/yield detractants, vertical 35-mm photographs, and additional descriptive comments. Grain yields of selected fields were measured at harvest time.

Meteorological Data Collection

The following atmospheric and meteorological measurements were made in conjunction with FSS and aircraft scanner data collection at the intensive test sites [13,14]; percent cloud cover and type, wet and dry bulb temperature, barometric pressure, total irradiance, wind speed and direction, optical depth at seven visible and near infrared wavelengths. Daily measurement records of temperature, precipitation, relative humidity, soil temperature, and wind were obtained from the nearest weather station [15].

Agriculture Experiment Stations

The collection of spectral, agronomic, and meteorological data at the agriculture experiment stations are described in this section.

Spectral Data Collection

The spectral data on the agriculture experiment stations were collected by NASA/JSC at Garden City and Purdue/LARS at Williston. The primary sensors were the Block wideband field interferometer and the Model 20C Exotech field spectroradiometer. These were augmented by Barnes PRT-5 precision radiation thermometers boresighted with the spectrometers. To obtain data which could be readily compared, the two instruments were operated following similar procedures. The instruments were operated from their aerial towers at six meters above the target which minimizes the shadowing of skylight and yet ensures that the field of view of the instrument is only filled with the subject scene. Care was taken to avoid scene shadowing and minimize the reflective interaction due to personnel or vehicles. The routine data-taking mode of the instruments is straight down. Two measurements of each plot were made by moving the sensor so that a new scene within the plot filled the field of view.

To minimize the effect of solar elevation changes on the spectral response, measurements were only made when the sun angle was greater than 45 degrees above the horizon in the late spring and summer and greater than 30 degrees in the late fall and early spring.

Data recorded at the time of each measurement included: date, time, reference illumination, air temperature, barometric pressure, relative humidity, wind speed and direction, percent cloud cover and type, field of view latitude, longitude, and zenith and azimuth view angles. Periodically during the day, spectral measurements of skylight were recorded by spectrometers with a solar port. A 35-mm color photograph of each observation was taken from the aerial tower. In addition, oblique ground-level photos of each plot were taken.

Agronomic Data Collection

Crop and soil information for the plots on the research stations were collected by NASA/JSC with assistance from the Agriculture Experiment Station personnel at Garden City and by Purdue/LARS at Williston. At the beginning of the season information describing the species and cultivar, irrigation practices, fertilization history, soil type, and planting date was obtained for each plot.

Observations made at the time of each mission for each plot included: maturity stage, plant height, percent soil cover, surface soil moisture and roughness, evaluation of stand quality, field operations such as cultivation or harvesting, stress factors (insect damage, disease, nutrient deficiencies, moisture stress, weeds, or lodging), leaf area index, number of stems, leaves and heads, fresh weight of plants, dry weights of stems, leaves, and heads, soil moisture profile, and vertical and oblique 35-mm color photographs. Grain yields were measured at harvest time.

Meteorological Data Collection

Percent cloud cover and type, wet and dry bulb temperature (or relative humidity), barometric pressure, total irradiance and wind speed and direction were measured in conjunction with the truck-mounted spectrometer data collection. Daily measurement records of air temperature, humidity, radiation, wind, precipitation, and soil temperature were also obtained from the nearest weather station [15].

Schedule of Data Acquisition

Table 4 summarizes the data acquisition for crop year 1976 at Finney County, Kansas, and Williams County, North Dakota, for the major sensors involved in the experiment. In each year, as in 1976, an effort was made to obtain data at each of the important growth stages of wheat at each level of the sampling scheme, from controlled experimental plot to Landsat scene. Whenever possible helicopter spectra and aircraft scanner data were gathered near the time of a Landsat overpass. A complete schedule of acquired data for each location is described in the data library catalogs discussed in the following section.

Data Processing, Library and Analysis Systems

An important aspect of the project was to prepare data for analysis according to uniform formats, including registration of the agronomic, meteorological, and measurement data with the spectral data. Following processing, data were cataloged in the data library and distributed to interested researchers. Software for interactive plotting and analysis of the data has also been developed.

Data Processing

Prior to computer processing, spectrometer data were evaluated manually using strip charts of raw data, photographs, records of system parameters, and strip charts of irradiance conditions. Computer processing of spectrometer data included calibration, data quality evaluation, reformatting, and storage. In order to compare data from the different spectrometers, the spectrometer data were processed in 0.01 μm bands from 0.4 to 2.4 μm and 0.05 μm bands from 2.5 to 14 μm as the basis for a standardized format. Spectrometer data were merged with ancillary data for storage on 9-track computer compatible tapes.

Aircraft scanner data were first converted to visicorder imagery (a 13 cm wide, medium contrast paper strip record of the data for individual channels) for manual evaluation of data quality. Aircraft scanner data were also subjected to a computerized examination to validate the performance of the sensors and the data recording system. In addition, a strip chart of total irradiance was used to verify the irradiance conditions during the overflight. The scanner data were then processed to 9-track computer compatible tapes in LARSYS format.

Landsat multispectral scanner data were previewed using black and white transparencies of the image for each band to establish data quality and cloud cover conditions within the intensive test sites and the complete Landsat frames. Following data quality evaluation, Landsat multispectral scanner data were processed to 9-track computer compatible tapes.

Data Library

The multispectral data library maintained at Purdue/LARS for the LACIE Field Measurements Project contains over 100,000 spectra (corresponding to measurements of over 800 plots and fields) and over 2,000 observations made with Landsat-band radiometers [16]. The library also includes several hundred scenes of aircraft and satellite-acquired scanner data. A data library catalog was prepared for each crop year containing summary and detailed schedules of data acquisition by location, sensor system, and mission. Digital data products available for analysis include Landsat and airborne scanner data, helicopter- and truck-spectrometer spectra and ancillary data, and tripod-radiometer spectra and ancillary data. Aerial photography concurrently with spectrometer and scanner data are also available.

Data Analysis Systems

LARSYS (Version 3.1) is a fully documented software system designed to provide the tools for analysis of multispectral scanner data [17]. The pattern recognition and interactive data handling techniques in LARSYS have been used world-wide for analysis of the aircraft and Landsat scanner data for many applications.

EXOSYS is a specialized software system developed at LARS for analysis of spectrometer data. It provides researchers with the capability to recall spectrometer data by sorting on combinations of measurement (e.g., solar elevation) and ancillary parameters (e.g., leaf area index). Analysis features of EXOSYS include the ability to compute functions of band-averaged reflectances and perform correlations with crop parameters, polynomial curves may be fitted to the data using the least squares technique. Initial results are reviewed and then sent to a line printer or a graphics plotter.

Summary

A comprehensive set of multitemporal spectral, agronomic, and meteorological data were acquired for three test sites in Kansas, South Dakota, and North Dakota for three years. Spectral measurements were made of controlled, experimental plots of wheat using truck-mounted spectrometers and of commercial fields of wheat and other crops by a helicopter-borne spectrometer, an airborne scanner, and Landsat MSS. The spectral data are calibrated to provide valid comparisons of data from different sites, sensors, and dates, and are supported by an

extensive set of agronomic and meteorological data. The data are being analyzed to determine the relationship of agronomic and spectral characteristics of crops, define future sensor system requirements, and develop advanced data analysis techniques.

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Table 1. Number of commercial fields of each crop or cover type in the field measurements test sites, 1976.

	Test Site		
Cover Type	Finney Co. Kansas	Hand Co. South Dakota	Williams Co. North Dakota
Winter Wheat	85	43	2
Spring Wheat		38	222
Barley		9	
Oats		15	4
Rye		1	1
Fallow	87	32	212
Corn	18	17	
Grain Sorghum	61	5	
Alfalfa	1	26	1
Other Hay Crops		23	1
Pasture	9	48	61
Other	14	8	29

Table 2. Characteristics of the Multispectral Scanners Systems.

Characteristic	Landsat 1 & 2	MMS	MSS
Spectral Range (μm)	0.5-1.1	0.38-1.06,8-14	0.34-13.00
Number of Bands	4	11	24
Total Field of View (degrees)	11.56	110	80
Normal Operational Altitude Above Ground (km)	944	0.5-6.1	0.5-6.1
Instantaneous Field of View (m)	79	1-15	1-12
Precision of Data (bits)	5-6	8	8

Table 3. Characteristics of the Spectrometer and Radiometer Systems.

Characteristic	NASA/JSC FSS	Purdue/LARS Exotech 20C	NASA/JSC FSAS	Purdue&TAMU Exotech 100
Spectral Range (μm)	0.4-2.5, 6.0-16.0	0.4-2.4 2.8-13.4	0.4-2.5, 3-14	0.5-1.1
Spectral Resolution @ 1.0 (μm)	.025	.025	.0064	.3
Scan Time (scan/sec)	1	.033-2.0	10	
Field of View (degrees)	22	15 and 3/4	11	15
Boom Length (m)		8,8	13,11	
Normal Operational Altitude Above Ground (m)	60	6	6	2
Data Storage Format	Digital Tape	Analog Tape	Digital Tape	Hard Copy
Camera Focal Length (mm)	76	55	50	
Field of View (degrees)	36	43	46	
Film Type	70 mm color	35 mm color	35 mm color	

Table 4. Summary of data acquisition by wheat growth stage and sensor system for Kansas and North Dakota test sites, 1976.

Test Site/ Mission Date	Wheat Growth Stage	Sensor System			
		Landsat MSS	Aircraft Scanner	Helicopter Spectrometer	Truck Spectrometer
Finney Co., Kansas					
Sept. 14-17, 1975	Pre-emergence	X	X	X	
Oct. 2-6	Emergence	X		X	X
Oct. 20-23	Seedling	X		X	X
Nov. 11-12	Tillering		X	X	X
March 13-19, 1976	Tillering	X	X	X	
March 30-April 2	Tillering	X		X	X
April 9-10	Jointing	X			
April 18-21	Jointing	X	X	X	X
April 27-28	Jointing	X			
May 4-7	Pre-boot	X	X	X	X
May 14-16	Boot	X			X
May 24-27	Heading	X			X
June 2-3	Milk	X			
June 11-13	Dough	X		X	X
June 20-21	Ripening	X			X
June 29-July 2	Mature	X	X	X	X
July 18-19	Post-harvest	X			
Williams Co., North Dakota					
May 25-28	Emergence	X	X		X
June 3-7	Seedling		X	X	X
June 12-15	Seedling	X	X		
June 21-24	Tillering	X	X	X	X
June 30-July 3	Jointing		X		X
July 9-12	Boot	X	X	X	X
July 18-21	Heading		X	X	X
July 27-30	Headed	X		X	X
Aug. 5-8	Milk-Dough		X	X	X
Aug. 14-17	Ripening	X	X	X	X
Aug. 23-26	Mature		X	X	X
Sept. 1-4	Post Harvest		X	X	X

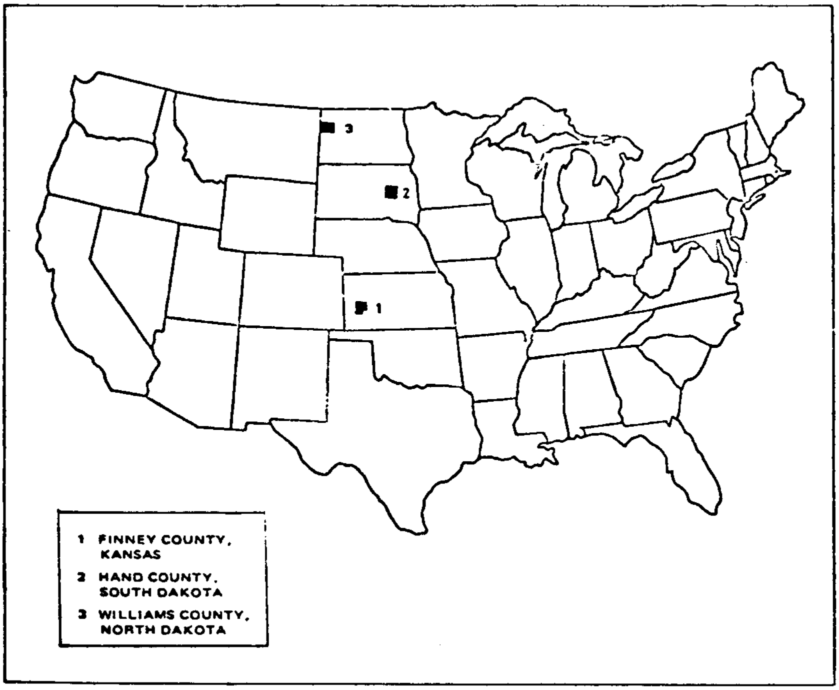

Figure 1. Location of LACIE Field Measurements test sites.

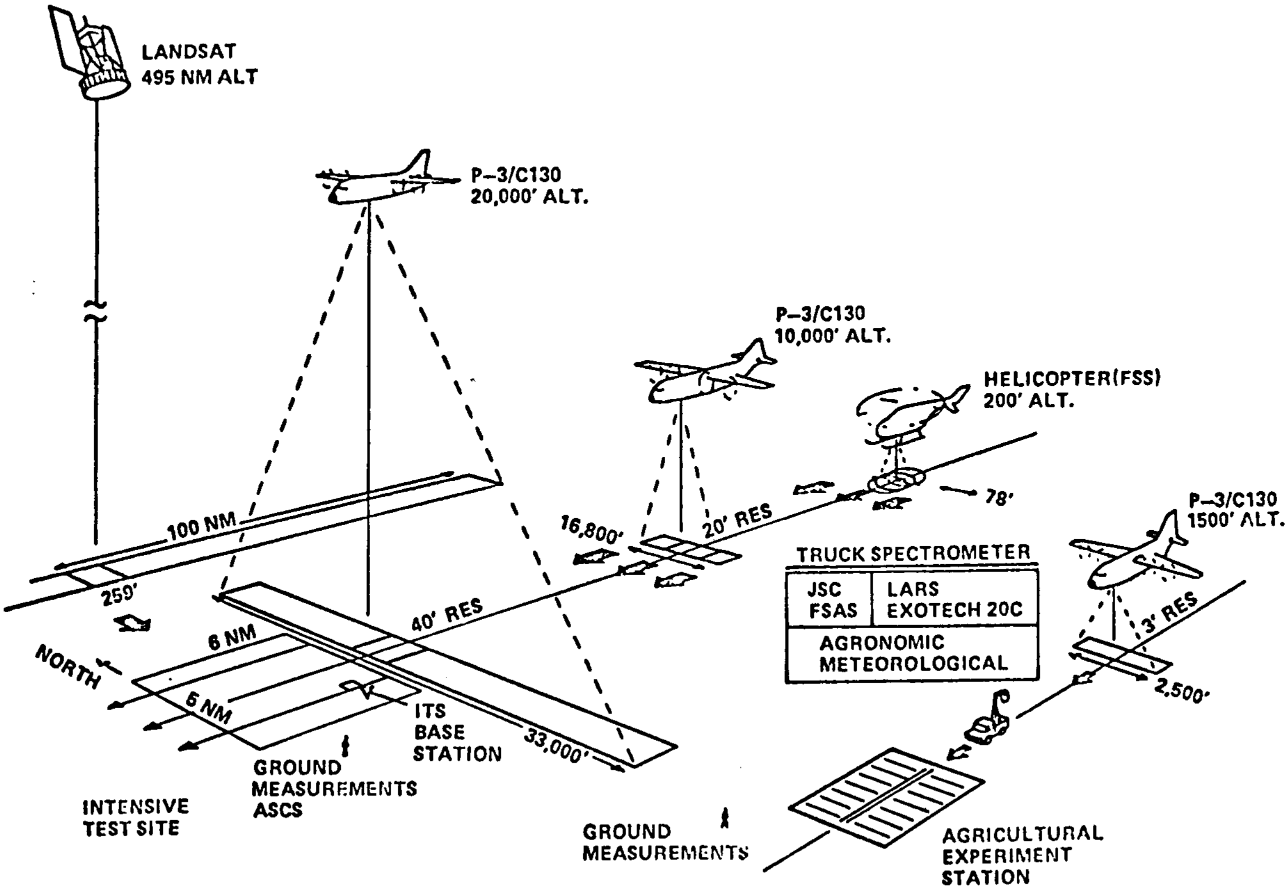

Figure 2. Schematic Illustration of LACIE Field Measurements Data Acquisition.

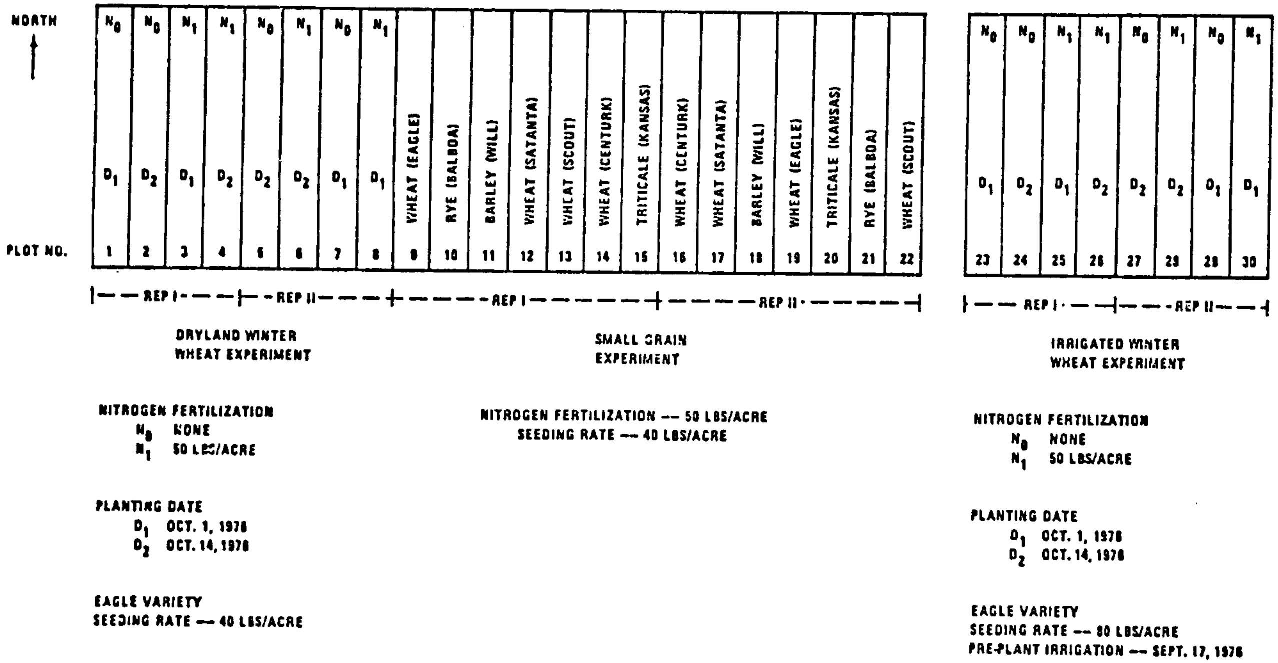

Figure 3. Remote sensing experiments at the Garden City, Kansas Agriculture Experiment Station.

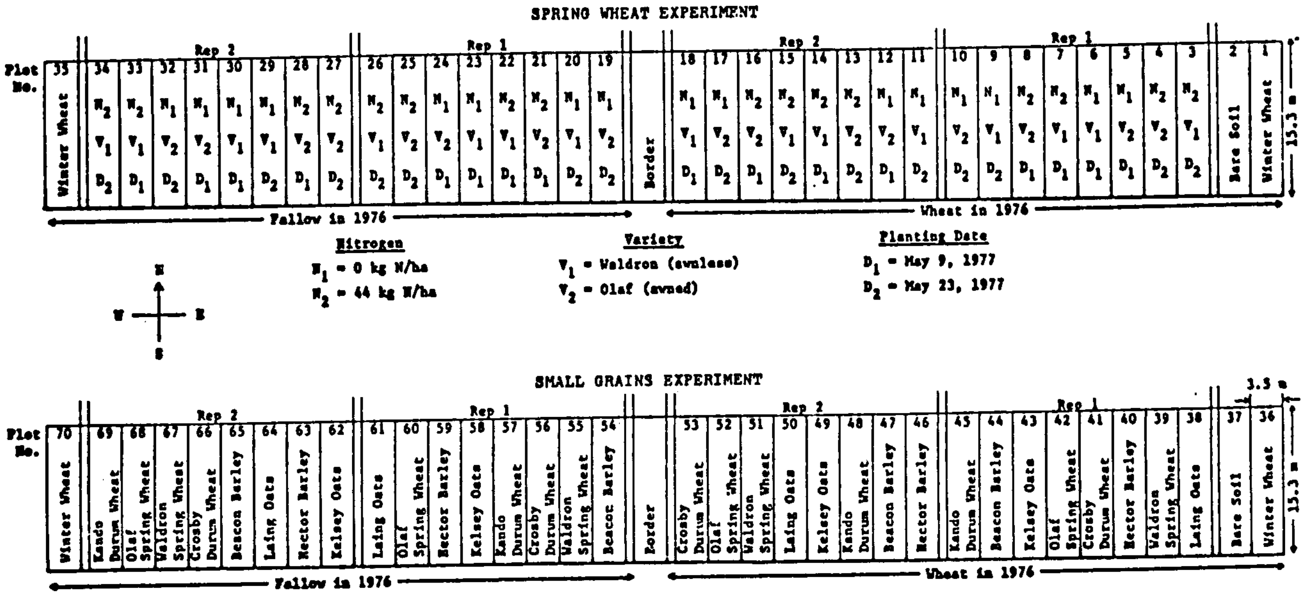

Figure 4. Remote sensing experiments at the Williston, North Dakota Agriculture Experiment Station.

Figure 5. Helicopter spectrometer system operated by NASA/Johnson Space Center hovering over calibration standard.

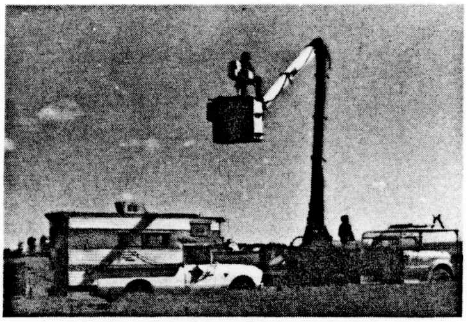

Figure 6. Field spectroradiometer system operated by Laboratory for Applications of Remote Sensing, Purdue University.

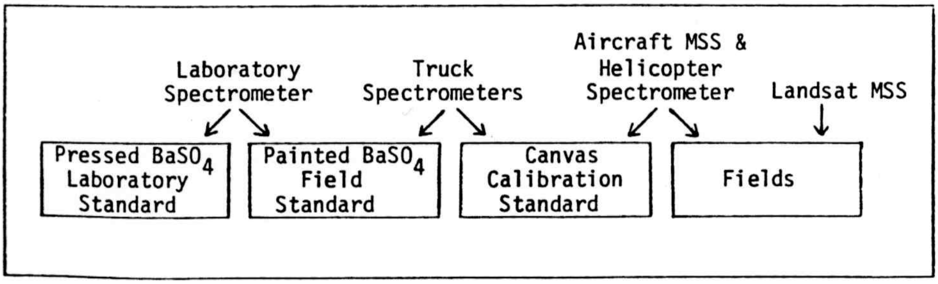

Figure 7. Schematic of the basic procedures used for reflectance calibration of LACIE field measurements data.

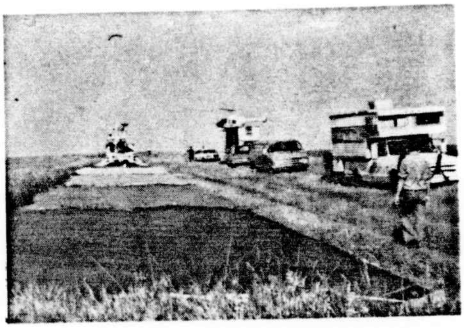

Figure 8. Canvas gray-level panels used for correlation of spectrometer systems and calibration of aircraft scanner data.

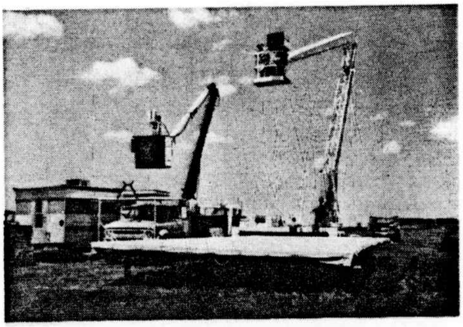

Figure 9. Truck-mounted spectrometer systems operated by Purdue/LARS and NASA/JSC preparing to measure the reflectance of canvas calibration panel in a sensor correlation experiment.